Ministry of
Environment & Renewable Energy

Sri Lanka
Sustainable Energy Authority

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விதுள்கா
Vidulka
ENERGY EXHIBITION

National Energy Symposium 2013

for a Future Driven by Energy Sustainability...

National Energy Symposium 2013

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Organized by

Sri Lanka Sustainable Energy Authority
Ministry of Environment & Renewable Energy

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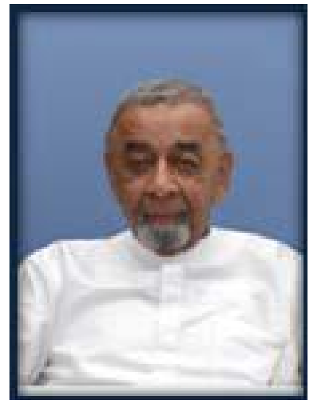
Message from the Minister of Environment & Renewable Energy

Energy is of prime importance in the journey of national development. In the global level, nations are focusing attention to energy with the identification of the limitations in the conventional energy sources in terms of quantity and quality. It has lead the energy and environmental crisis. We can be proud as a nation, has stepped in the right direction in putting more and more emphasis to sustainable energy. The national policy document, "Mahinda Chinthana" focuses on this important area and it has set sustainable energy targets as 20% of renewable energy to the grid electricity generation and saving 8.7% electrical energy by 2020. The achievements so far are satisfactory and a level of 7% renewable energy in the national grid has been surpassed. Similar progress has been realized in the area of energy conservation and management.

In context of long-term sustainable energy development, **"Vidulka"** will provide a very valuable opportunity for a dialogue on energy among different strata of the society. I highly commend the great work done by the researchers by way of involving in R&D as well as project implementation in the area of sustainable energy. I sincerely hope that "Vidulka" will support the nation in relieving the energy burden in the long run. I wish success of the programme.

Hon. A.D. Susil Premajayantha
Minister of Environment and Renewable Energy



Message from the Deputy Minister of Environment & Renewable Energy

The world is facing numerous challenges in achieving economic development owing to the scarcity of natural resources and energy is one of them. The three dimensions of sustainable development viz. social, environmental and economic could be well supported by adopting the concepts of sustainable energy in the country's development plan. In this respect, there are many interventions around the world where different modalities are being introduced which ultimately leads to the establishment of the sustainable societies.

In context of creating a sustainable society, knowledge, skills and attitudes on renewable energy and energy conservation of the entire community are vital elements. Above all, thorough awareness on the global sustainable energy initiatives will be very important, and I understand that SLSEA has taken tremendous efforts to realize this. I trust Vidulka 2013 will be an appropriate forum for a sound dialogue on sustainable energy.

I wish success of the programme with valuable inputs to the society.

Hon. A. R. M. Abdul Cader
Deputy Minister of Environment and Renewable Energy

Message from the Secretary of Environment and Renewable Energy

Sri Lanka Sustainable Energy Authority focuses on the thrust areas of renewable energy development and energy efficiency improvement, conservation and management. Integration of renewable energy in the energy mix of Sri Lanka will endow the nation with many benefits in terms of economy, society and environment. Firstly, it will cleave the cycle of draining of foreign exchange on fossil fuel imports and retain the wealth among the public, while creating diverse job opportunities. Secondly, the living standards will be uplifted, especially with the provision of rural energy services through renewable energy. Further, practising energy conservation and management concepts in all the sector will support towards economic benefits to the country. These sustainable energy interventions will contribute to mitigate the local environmental issues as well as cushion the climate change related global issues in broader sense.

The promotion of sustainable energy requires a proper dialog across the whole society. Thus it is timely that a forum has been established by Vidulka with the participation of professionals, academia, researchers, governmental institutions, industrial & commercial sectors, private practitioners and the general public.

I wish that all the engagements of Vidulka 2013 – Energy Symposium, Exhibition and the Award Ceremony will forge productive outputs in the context of sustainable energy.

B.M.U.D. Basnayake
Secretary
Ministry of Environment and Renewable Energy

Message from the Chairman of Sri Lanka Sustainable Energy Authority

Sri Lanka Sustainable Energy Authority, with the support and guidance of the Ministry of Environment & Renewable Energy has planned to contribute to the economic development of the nation through the promotion of sustainable energy. This is envisaged through two main interventions: by increasing the renewable energy share in the national energy mix and improving energy utilization efficiencies in all the energy consuming sectors – industries, commercial establishments, households and even in the transport sector.

It is to be reiterated that energy goes into a wide spectrum and there are many opportunities for all the sections of the society to contribute to the national sustainable energy development. Scenario changes that are required to maximize the benefits in the application of sustainable energy technologies could be achieved if the required knowhow is properly disseminated. Nevertheless integration should be done with due professionalism, and proper dialogue among all parties concerned. I'm sure Vidulka 2013 will provide ample opportunity for this.

I express my sincere gratitude to all those who have immensely contributed to make this important national event a success.

Prasad Galhena
Chairman
Sri Lanka Sustainable Energy Authority

Production of Biodiesel and Bioethanol from Algae

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Abstract

The focus of this study was to develop and examine methods of converting algae into different types of biofuel and select the best to recommend for large-scale applications as a sustainable energy solution. The algae were grown in a simulated activated sludge process (ASP) in a pond system and 5 experiments were conducted. Direct combustion of algae as a semi-solid fuel was tried. It needed the development of nozzles for injecting fluidized slurry of mixed fuel while IC engine tests were done for bioethanol and biodiesel. The algae were fermented with *aspergillus niger* and ethanol was double distilled. CO_2 produced in the fermentation was sent through the pond to maximize the algal production. The slurry consisted of pressurized bioethanol and biodiesel without any non-external pressure systems. Plate flame tests were done for all fuels. The mixed fuel did combust efficiently in plate test and blowlamp. Blowlamp gave flame lengths and widths of 18 -19 cm and 1.6 -1.8 cm for bioethanol and 24 -25 cm and 2.8 - 3 cm for biodiesel, respectively. Mass balance showed that 0.498 ml of bioethanol/g of algae and the remaining slurry and CO_2 emissions. In biodiesel, 0.607 ml/g of algae was obtained.

Keywords: Algae, Semi- solid fuel, Biodiesel, Bioethanol, IC Engine

Introduction

Energy insufficiency is one of the key issues that world faces at present which prevents reaching sustainable development goals. In overcoming these issues, development of projects on generating energy using renewable, alternative, sustainable and biological sources and these by products are appropriate options. Bio energy is one of the alternative renewable energy sources, which can be directly converted into liquid fuels, termed biofuels. A variety of biomass from different sources, including agriculture field, fresh and marine aquatic sources, artificially growing systems have been investigated as the feedstock for the production of different biofuels including biodiesel, bioethanol, biogas and bio-hydrogen [1]. They are biodegradable, non-toxic and cleaner-burning alternative fuels. With the use of biofuels in place of petroleum, significant reduction in toxic air pollutant emissions can be achieved.

Energy Consumption and Crisis in Sri Lanka

The energy demand of Sri Lanka is met with combination of indigenous sources together with imported primary and secondary energy sources. The main indigenous primary energy sources in Sri Lanka are biomass and hydro resources [2]. These two sources of energy constituted more than 52% of the primary energy supply in 2011. Imported primary energy sources are crude oil and small quantities of coal. Refined petroleum products are the imported secondary energy sources. Economically extractable fossil fuel reserves have not been identified so far; however the Government of Sri Lanka is committed to go ahead with the identification the resource with the help of foreign experts. It is believed that a substantial resource of crude oil is available in the seas in the territorial waters of Sri Lanka. Large quantities of diesel are imported to cater to the increasing energy demand which cannot be supplied by the local refinery [3].

The next promising energy sources would be modern biofuel and wind energy. The respective biofuel potential has been identified in a preliminary study, but the exact amount which can be absorbed technically and economically is not yet established in Sri Lanka. So, this research was focused to develop and introduce a sustainable algal based semi solid fuel as a renewable and alternate source of energy to combat the national energy crisis.

Material and Methods

The algae were grown in a simulated activated sludge process (ASP) and a pond system. Five experiments were conducted at the Department of Agricultural Engineering and Faculty of Agriculture, University of Peradeniya. Direct combustion of algae as a semi-solid fuel was tried. It needed the development of nozzles for injecting fluidized slurry of mixed fuel while IC Engine tests were done for bioethanol and biodiesel. The algae were fermented with ***aspergillus niger*** and ethanol was double distilled. CO_2 produced in the fermentation was sent through the pond to maximize the algal production. The slurry consisted of bio ethanol and bio-diesel. Both pressurized and non-external pressure systems were tested. They consisted of blowlamp, plate test and measurement of flame length. A mass balance was done in analysing the system. The algae harvesting was carried out by centrifuging at the Agricultural Biotechnology Centre, University of Peradeniya. Laboratory analysis was conducted at the Soil and Water Engineering Laboratory, Department of Agricultural Engineering, University of Peradeniya.

Algae Production Bioreactor

Transparent plastic bins of 50 l volume were used as the reactors as open algae growing ponds. Then 10 l of leachate was used to fill these reactors and another 10 l of fresh water was mixed into each bin. Leachate was the nutrient source. Ten litre of algae sample was added into an open pond, which was collected from a lake and a concrete pond at the University of Peradeniya premises. The aeration supply was done through a diffused aerator and aeration of the reactors was carried out intermittently. Urea and triple super phosphate were added in 3 trials at different rates as given in Table 1. Algae growing reactors were maintained for 15 days. After that, algae were harvested using centrifugation methods. Flow diagram of the study was given in Figure 1.

Analytical Procedure

The quality of leachate that was used for growing of microalgae as well as microalgae medium before harvesting and after harvesting was analyzed for pH, Conductivity, Salinity, Total Solid, Total Suspended Solids, Volatile Solids, Total Dissolved Solids and Volatile Suspended Solids.

Table 1: Amounts of nutrients added

Trial No.	Amount of fertilizer added per litre	
	Urea (g)	Triple super phosphate (g)
1	0.00	0.00
2	0.00	0.00
3	0.05	0.2
4	0.05	0.3
5	0.05	0.4

Density of Fuels

A density meter (Thermo Scientific, model Orion 44) was used to measure density of the fuel samples.

Calorific Value of Algae and Fuel Samples

Adiabatic calorie meter was used to measure the calorific values of dry algae, bioethanol and biodiesel.

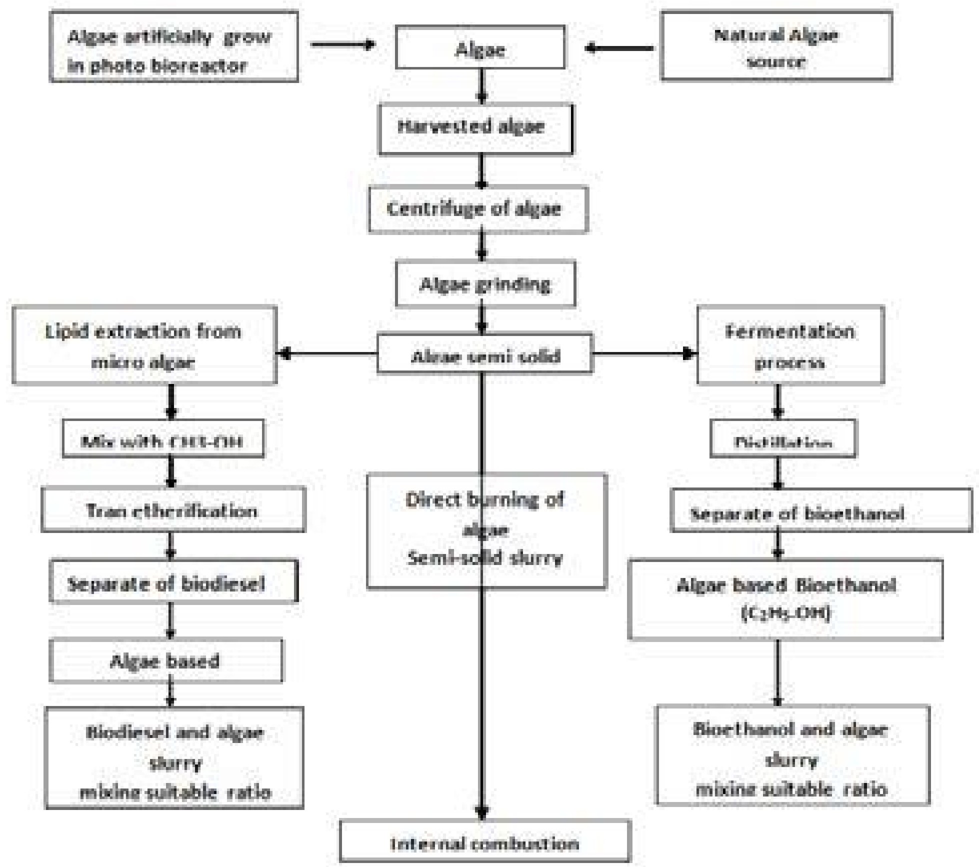

Figure 1: Process flow diagram

Results and Discussion

In this study, initially leachate without any additives was used as the growing media for the algae. The quality of used leachate is given in Table 2. As reported by many authors [4], phosphate is the limiting factor in landfill leachate. Therefore, without any additives, the growth rate of the algae is low in the trial 1 and the trial 2 as in Table 3. Hence, 0.2 g, 0.3 g and 0.4 g of triple super phosphate per litre of algae growing medium were added to trials 3, 4 and 5, respectively as a phosphate source. And 0.05 g of urea per litre of algae growing medium was added. The yield of the algae drastically increased from 0.48 g/l to 0.99 g/l after adding TSP (Table 3). Therefore, lack of phosphate in leachate was one of the controlling factors of algae growth. It was also observed that, the quality of the leachate/algae growing media became poor with the growth of algae. For instance, the TDS concentration of the leachate/algae growing media significantly reduced as given in Table 2. This concluded that, growing of micro algae could effectively treat the leachate with a phosphate source. Instead of triple super phosphate, low cost naturally available phosphate sources such as straw, cow dung, etc. can be used. Further, domestic sewage is an excellent phosphate source. The leachate could be mixed with domestic sewage to use as an algae growing medium. Centrifuge process was tried to optimize the harvesting of algae. It is a high energy consuming process. In the case of centrifugation, initially the samples were centrifuged at 7,800 rpm for 15 minutes. Thereafter, all the samples were centrifuged at 7,000 rpm for 3 minutes.

Bioethanol Production

Saccharomyces cerevisiae and ***aspergillus niger*** is the recommended catalysts in ethanol fermentation processes for micro algae. Fermentation medium is very important to enhance the hydrolysis of lignocelluloses materials of micro algae strains. The highest ethanol production of ***A. niger*** was 54.3% ethanol (w/w) with lignocelluloses biomass in 48 hours. The highest ethanol production of ***S. cerevisiae*** was 47.8 % ethanol (w/w) [5]. The volume of bioethanol yield was increased with ***aspergillus niger*** media than sachcharomises substrate. Ethanol production was double distilled for enhancing the bioethanol concentration. After that, the density was 0.89 gcm^{-3}, which is similar to the reported value [6]. In this study, conversion percentage of algae biomass to ethanol with ***saccharomyces cerevisiae*** was 43.92% ± 5 wet basis whereas, the conversion percentage was 47.1% ±6 wet basis with ***aspergillus niger.***

Biodiesel production

Biodiesel production was based on transesterification reaction. Biodiesel is a mixture of fatty acid alkyl esters obtained by transesterification of fatty acid. These algae lipid feedstock are composed of 90-98% (weight) of triglycerides and small amounts of mono and diglycerides. Transesterification is catalyzed by acids, alkalis and lipase enzymes alkali catalyzed transesterification is about 4,000 times faster than the acids catalyzed reaction [6]. Consequently, alkalis such as sodium and potassium hydroxides were commonly used as commercial catalysts at concentrations of about 1% by weight of oil. In this study, Sodium hydroxide was used as the catalyst.

Large excess of methanol ensures that the reaction is driven of methyl ester towards biodiesel. The yield of biodiesel exceeds 98% on a weight basis [7]. In this research, the average biodiesel yield was 59.65 % ±1 on weight basis. Wet algae biomass was recovered to 54.03 % ±6 on weight basis. Normally, micro algae recorded methyl ester/ biodiesel of 60%-63% on a weight basis [8]. Density of the biodiesel produced was 0.88 gcm^{-3} and it was similar to the recorded value. Since the moisture content of the harvested algae is 80%, about 3,624 g of lipid can be recovered from 1 kg of dry algae while 2,428 ml of biodiesel can be produced from 1 kg of dry algae.

Table 2: Quality of leachate, algae growing medium and effluent after harvesting of algae

Trial No.		1	2	3	4	5
pH	1	7.76	7.76	7.61	7.59	7.8
	2	7.56	7.9	7.64	7.53	7.21
	3	7.43	7.36	7.95	7.98	7.15
Salinity (%)	1	9.80	10.60	9.20	9.80	10.30
	2	7.20	6.70	6.50	6.30	5.95
	3	6.20	5.90	6.20	5.30	3.93
Conductivity (ms)	1	16.99	18.19	15.76	16.73	17.62
	2	15.36	16.89	14.67	14.98	12.90
	3	15.20	15.12	12.98	11.97	10.25
TDS (mg/l)	1	10,700	10,100	10,800	11,200	10,500
	2	3,300	2,850	2,660	1,920	1,740
	3	2,560	2,340	2,190	1,450	1,270
TS (mg/l)	1	7.366	9.445	9.564	8.332	8.967
	2	7.126	8.943	8.544	-	-
	3	5.895	7.367	6.947	-	-
TSS (mg/l)	1	1	0.82	0.652	-	-
	2	0.75	0.74	0.592	-	-
	3	0.6	0.67	0.51	-	-

Note: 1- leachate, 2- Algae growing medium just before harvesting, 3 – after harvesting of algae

Table 3: Algae yield from different trials

Trial No.	1	2	3	4	5
Yield – wet basis (g/l)	3.195	3.450	3.825	4.450	4.980
Yield – dry basis (g/l)	0.488	0.593	0.742	0.835	0.992

Combustion Characteristics of the fuel produced

Combustion is a process and fire is the actual outcome. It is burning, a self-propagating oxidative chemical reaction producing light, heat, smoke and gases in a flame front. In this study, some combustion characteristics were studied and applied for developing semi-solid fuel, bioethanol and biodiesel such as flame colour, flame length and calorific value.

For semi solid slurry however, plate flame tests were done. It had a characteristic blue flame. The mixed fuel did combust efficiently in plate test and blowlamp. Blowlamp gave flame lengths and widths of 18 -19 cm and 1.6 -1.8 cm for bio ethanol and 24 -25 cm and 2.8- 3 cm for biodiesel, respectively. The highest concentration of 3.99 g/l was obtained by increasing the addition of phosphate to the pond simulation. Mass balance showed 0.498 ml of bioethanol/g of algae and the remaining was slurry and CO_2 emissions. In biodiesel, 0.607 ml/g of algae was obtained. Hence, at least 18-20 litres of biodiesel/day can be produced while treating the leachate. The future research should be focused on increasing the production of algae with bubbling of CO_2 emitted from the power plant, which will be established in the near future.

Conclusion

The premise that micro algae are small particles that can be fluidized in a slurry or dried form does not hold true. They seem to agglomerate together forming bonds, most likely hydrogen bonds. In the absence of any measure to characterize the combustion of the slurry, plate test was used and positive results were obtained. It was compared with mixed slurries with algae based bioethanol and algae based biodiesel and with the known fuel petro diesel the mixed fuel, gave flames when composted in a blowlamp. The performances were acceptable with well defined flame characteristics of lengths and widths.

The traditional methods of converting algae into bioethanol and biodiesel gave comparative yields and they are the best solutions. Out of them, biodiesel is very promising and could reduce the cost of treating landfill leachate. Nevertheless, improved methods of harvesting the algae should be developed because centrifuging and filtration are high energy consuming techniques.

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Modelling, Simulation and Optimization of a Heat Exchanger Network for Maximum Energy Efficiency and Minimum Cost

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Abstract

Heat Exchangers are one of the major items of equipment applied in combination with almost all the unit operations in the process industry. Therefore, optimizing heat exchangers would be an ideal solution for the problem of increasing energy costs in the industry. Pinch analysis can be used to identify minimum energy cost and energy efficient heat exchanger networks through the recognition of pinch point as referred to the temperature profile of the process at which the minimum level of allowable temperature difference is achieved. The pinch analysis first predicts the minimum requirement of external energy, heat exchanger network area and the number of units for the typical process at the pinch point. Then, the heat exchanger network design that satisfies the minimum energy target is synthesized. Finally, it is optimized by comparing the energy cost and the capital cost. Pinch analysis to reduce external utility loads can be performed in special computer software packages for even rigorous heat exchanger networks. The prime objective of this research is to utilize a computer aided modelling and simulation approach to provide a generalized methodology for the optimization of a heat exchanger network through pinch analysis for a typical distillation column.

Keywords : Exchanger Networks, Pinch Analysis, Minimum Energy Target, Computer Aided Modelling and Simulation, Generalized Methodology

Introduction

Industrial process technology involves separation, purification and recovery techniques of the output products, by-products and untreated raw materials. Among such unit operations, distillation has become obviously the leading separation process, affecting for more applications than all the other separation methods such as extraction, adsorption, crystallization, membrane-based technologies and so forth. Therefore, distillation has turned into the most energy-intensive separation process expansively used in many industries. In fact, distillation columns expend more than 95% of the total energy used in separations in chemical process industries all over the world [1]. If this extremely energy consuming entity is analyzed for opportunities for energy saving, a substantial amount of industrial energy consumption can be dropped down [2]. Whenever, any distillation column is considered, there is a heating duty and a cooling duty for the particular application. Generally, the separation of liquid mixtures by means of continuous distillation depends on differences in volatility between the components. There may be two or more components in the feed for such a distillation column whereas, greater the relative volatilities, the easier the separation. During the distillation action, vapour flows up the column and liquid counter-currently flows down the column. Meanwhile, the vapour and liquid are brought into contact on plates, or packing. Part of the condensate from the condenser is returned to the top of the column to provide liquid flow above the feed point which is called reflux, and part of the liquid from the bottom of the column is vaporized in the re-boiler and returned to the bottom. The basic equipment required for continuous distillation process is shown in Figure 1.

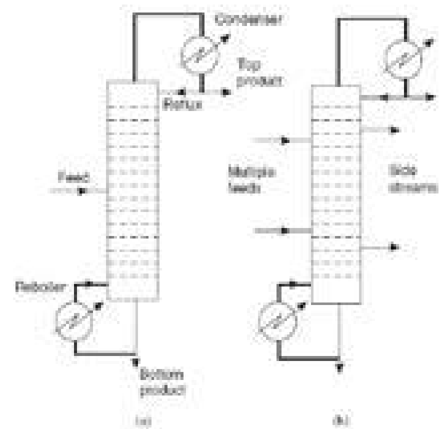


Figure 1: Distillation column (a) Basic column (b) Multiple feeds and side streams (Source-Reference [3])

Since, the condenser and the re-boiler are two heat exchangers, even a basic distillation column will be simplified to a heat exchanger network comprised of at least two heat exchangers, where a significant potential of energy recovery and maximization of energy efficiency is possible through process integration by way of pinch technology, in comparison to the conventional methods. Therefore, it is constructive to study a basic continuous distillation column application amalgamated with process integration using computer aided modelling and simulation, which is able to be easily derived into a paradigm of heat exchanger network optimization for the scholarly ground, in another way which is the principal objective of this research study. Therefore, this study will be based on a basic distillation column that has been simulated for process integration via pinch analysis using computer simulation tools.

The term 'Pinch Technology' has been introduced by Linnholf and Vredeveld with the purpose of representing a set of thermodynamic methods that can be utilized in designing heat exchanger networks for minimum energy levels. In fact, it is a kind of systematic analysis of processes and affiliated utility systems by means of first and second laws of thermodynamics. The enthalpy changes in the streams those are passing through a heat exchanger can be calculated using the first law of thermodynamics meanwhile, the direction of heat flow is determined by the second law of thermodynamics. In consequence, a hot stream is not be able to cool down below the cold stream supply temperature and the cold stream is impossible to be heated above the hot stream supply temperature. In another way, this can be denoted as 'no temperature crossovers' in the hot and cold stream profiles in a heat exchanger. Practically, the hot stream can be cooled down only to a certain temperature value defined by the temperature approach of a heat exchanger which is the minimum allowable temperature difference (DT_{min}) in the stream temperature profiles of a heat exchanger unit. However, the temperature level where this minimum allowable temperature difference can be observed in a process is called the 'Pinch point' or 'Pinch condition'. [4].

When a typical process involves single hot and cold streams, it is easy to design a heat exchanger network for the optimum heat recovery by heuristic methods. Once the number of streams is higher, the traditional design approach has been found to be limiting the design of a good network [5]. Anyhow, with the use of pinch technology, not only optimal network design is made possible, but also considerable process improvements can be discovered. A comparison of the traditional and pinch approaches are depicted in Figure 2.

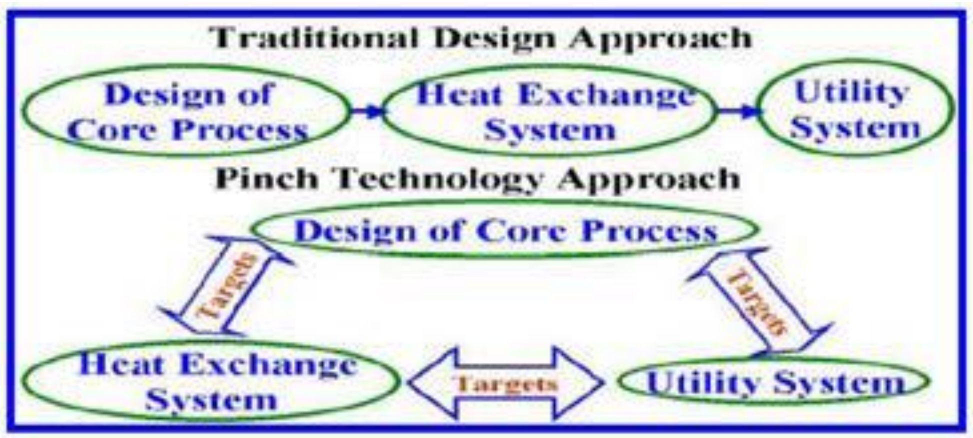


Figure 2: Graphical Representation of Traditional & Pinch Design Approaches (Source – Reference [4])

In the traditional design approach, the design of core process is done with fixed parameters such as flow rate, temperature, etc. while achieving the heat and mass balance for the process. Then, the design of a heat recovery system is completed followed by the matching of remaining duties with the use of the utility system. On the other hand, process integration using pinch technology generates targets for minimum energy consumption before heat exchanger system design, so that utility system constraints and interactions with the heat recovery can be considered in the design of the core process. Therefore, the pinch technology approach reveals opportunities to modify the core process towards the improvement of heat integration. As a result, this pinch technology is an expanding research area because it applies to all processes with heat exchangers which can be methodologically employed to optimize the heat transfer equipment during the design of the processes.

Heat exchanger network and utility requirement design have become very systematic and methodical with the advent of pinch analysis concepts. The key concepts and their significance in pinch analysis are very important for the success of this study. Combined (hot and cold) composite curves are one of such concepts in pinch analysis which is used to predict targets for the required minimum energy (both hot and cold utility), minimum network area and minimum number of heat exchanger units. Pinch point or the minimum allowable temperature difference (DT_{min}) in the stream temperature profiles of a heat exchanger unit determines how closely the hot and cold composite curves can be 'pinched' or squeezed without violating the Second Law of Thermodynamics or without having a temperature crossover in any heat exchanger. Furthermore, Grand Composite Curve is another key concept of pinch analysis which is utilized to select appropriate levels of utilities to come across all energy requirements. The major intention of pinch analysis is integrating the economic evaluation with design approach. Therefore, energy and capital cost targeting are performed in pinch analysis to calculate total annual cost of utilities and capital cost of heat exchanger network so that the optimum level of heat recovery or the optimum pinch point can be determined by balancing energy and capital costs. In addition, when reviewing the available literature, new theories like 'regional energy analysis', 'network pinch', 'top level analysis', 'optimization of combined heat & power', 'water pinch' and 'hydrogen pinch' are being developed with continuous research studies [4]. So, the pinch technology is a key research area in a technological world where energy conservation is precious day by day.

In pinch analysis, either it is integrated into a new design or a retrofit, there will be a stepwise procedure that is generally followed. This pinch analysis procedure is illustrated in Figure 3.

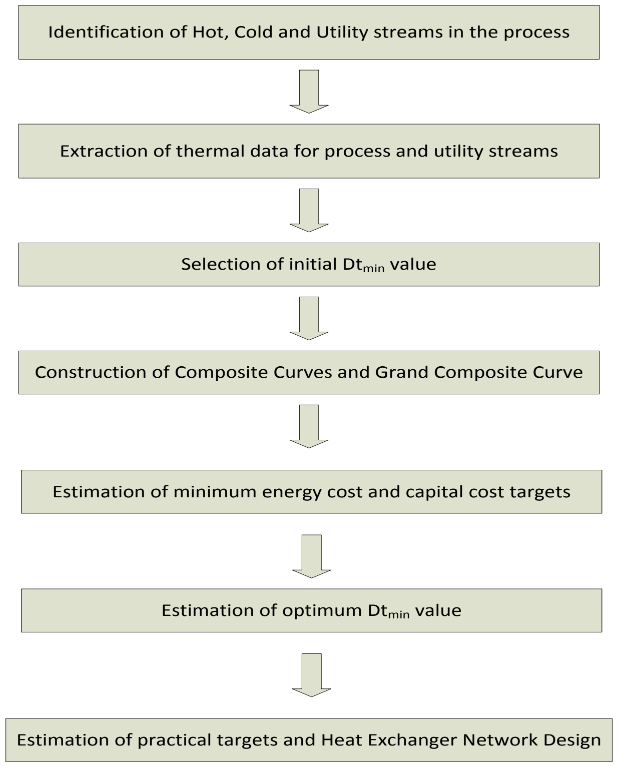


Figure 3: General Stepwise Procedure for Pinch Analysis (Source -Reference [4])

According to the literature review there are some theories and concepts in pinch technology, and as it is a complex procedure, application simulated with computer aided tools will be important [5].

Scope of study and Methodology

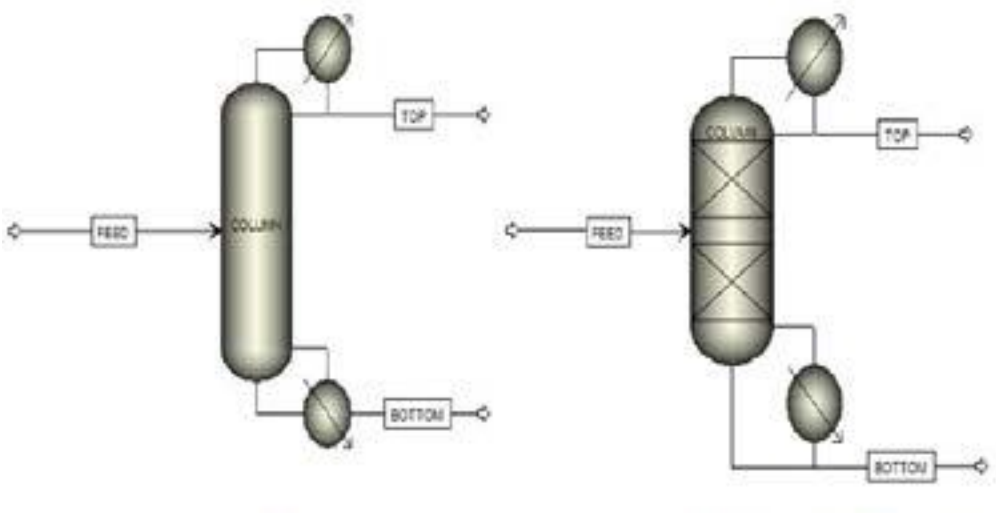
This study is devoted towards the separation of Methanol/Water/Sodium Chloride/Sodium Glycolate mixture by continuous distillation at high methanol recovery of 90% by mass. The main reason to select this separation process is that not only distillation is the primary energy intensive unit operation in process industry, but also all the bio-chemical applications related to the processing of natural polysaccharides such as starches involve recovering methanol from such a by-product mixture [6]. In the synthesis of natural polysaccharides and starches with Sodium Hydroxide, Sodium Chloride and Sodium Glycolate form in reactions and when those natural polysaccharides and starches are processed industrially with Methanol and water as a solvent, Sodium Chloride and Sodium Glycolate move into Methanol and Water solution resulting to recover methanol content by means of continuous distillation for reutilization back for the same process. According to such industrial applications, the feed composition of methanol

impure mixture is taken as methanol 70%, water 22.5%, Sodium Chloride 5% and Sodium Glycolate 2.5% mixture at atmospheric pressure of 1 atm, at room temperature of 30 ^{o}C and total flow rate of feed solution is taken as 100 kg/hr.

The aim of this study is to investigate the energy saving potential of distillation scheme by process integration via pinch technology. The tools which are utilized in this study to model and simulate the relevant distillation column are shortcut methods of continuous distillation in ASPEN PLUS software based on minimum vapour flow rate at infinite number of stages using shortcut equations, such as Winn–Underwood and Gilliland equations to find out minimum reflux ratio, for minimum number of stages, for theoretical number of stages and for feed stage location. First, this distillation column scheme is modelled in ASPEN PLUS software to solve all shortcut equations where the input data are feed composition, feed flow rate, feed temperature and feed, top and bottom pressures. The number of stages is taken initially as an assumption of 10 stages. After mathematical modelling and steady state simulation with shortcut methods in ASPEN PLUS, a table of the reflux ratio over corresponding number of stages can be obtained where the exact reflux ratio can be determined and rigorous modelling and simulation is executed in ASPEN PLUS using a rigorous distillation column equipment model. Then the simulation results are exported to Microsoft Excel where the final cost calculations for optimizing the economic number of stages for the distillation column can be easily executed. Thereafter pinch analysis is done by utilizing ASPEN HX NET software.

Modelling and simulation in ASPEN PLUS by means of shortcut and rigorous distillation is carried out with the following assumptions. DSTWU equipment model is selected for the shortcut continuous distillation methods and RadFrac equipment model is selected for rigorous distillation methods whereas for both methods ELECNRTL thermodynamic property method issued because the selected application involves electrolyte solution to be undergone distillation process. Pressure drop across distillation column is taken as 5 kPa. In addition, during the pinch analysis for optimization of heat exchangers affiliated with this distillation column, as assumptions, pumping was not considered in cost calculations and the total cost for the configuration was assumed to be the sum of utility costs (steam and cooling water) and equipment costs (purchase and installation). Utility cost data and equipment capital costs are approximately estimated according to the given cost indices in ASPEN HX-NET software.

The simulated ASPEN PLUS flow sheet models for both methods are indicated by Figure 4.



(a) Shortcut Distillation Model (b) Rigorous Distillation Model

Figure 4: Simulated ASPEN PLUS flow sheet models for the selected distillation column

Results and Discussion

The output results obtained by the ASPEN PLUS shortcut simulation is indicated in Table 1.

Table1: Simulation results obtained by ASPEN PLUS modelling by shortcut method

Results

Minimum reflux ratio:	0.31584775	
Actual reflux ratio:	0.39588471	
Minimum number of stages:	3.35511182	
Number of actual stages:	10	
Feed stage:	5.8184873	
Number of actual stages above feed:	4.8184873	
Reboiler heating required:	33.1863393	kW
Condenser cooling required:	28.7583373	kW
Distillate temperature:	66.9826941	C
Bottom temperature:	96.7652441	C
Distillate to feed fraction:	0.58992374	
HETP:		

Profile

Theoretical stages	Reflux ratio
4	3.33458756
5	1.14077085
6	0.79811927
7	0.53941937
8	0.44673621
9	0.41423494
10	0.39588998
11	0.38368997
12	0.37484582
13	0.36808199
14	0.36270574
15	0.35833369
16	0.35469151
17	0.35160645

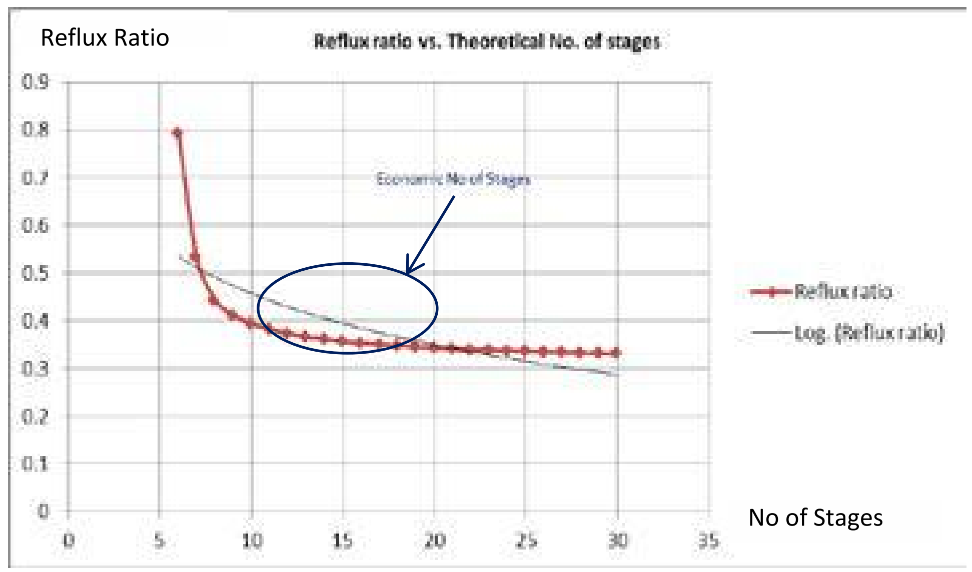


Figure 5: Graph of Reflux ratio vs. Theoretical number of stages by ASPEN PLUS shortcut distillation simulation results

The economic number of stages for the rigorous simulation was determined by means of plotting the graph of actual reflux ratio deviation with respect to the actual number of stages depicted by figure 5.

According to Figure 5, the economic number of stages can be observed in between 10 to 20. Therefore, for the Rigorous simulation, the optimum number of stages was determined as 15 because the reflux ratio has become approximately a plateau after 15 number of stages. The simulation results obtained by the ASPEN PLUS rigorous simulation is indicated in Table 2 and Table 3.

Table 2: Simulation results for condenser and re-boiler obtained by the ASPEN PLUS rigorous simulation

Condenser / Top stage performance

Temperature:	66.6353691	C
Heat duty:	-27.653809	kW
Subcooled duty:		
Distillate rate:	65.2499984	kg/hr
Reflux rate:	23.3012727	kg/hr
Reflux ratio:	0.35833369	
Free water distillate rate:		
Free water reflux ratio:		

Reboiler / Bottom stage performance

Temperature:	96.4719521	C
Heat duty:	32.0543487	kW
Bottoms rate:	34.7500016	kg/hr
Boilup rate:	68.408178	kg/hr
Boilup ratio:	1.96858057	

Table 3: Simulation results for streams obtained by the ASPEN PLUS rigorous simulation

		FEED	TOP	BOTTOM
From			COLUMN	COLUMN
To		COLUMN		
Substream: MIXED				
Phase:		Liquid	Liquid	Liquid
Component Mass Flow				
WATER	KG/HR	22.50	1.60	20.90
METHANOL	KG/HR	70.00	63.65	6.35
NACL	KG/HR	5.00	0.00	5.00
NAGLYC	KG/HR	2.50	0.00	2.50
Component Mass Fraction				
WATER		0.23	0.02	0.60
METHANOL		0.70	0.90	0.18
NACL		0.05	0.00	0.14
NAGLYC		0.03	0.00	0.07
Mole Flow	KMOL/HR	3.54	2.08	1.47
Mass Flow	KG/HR	100.00	65.25	34.75
Volume Flow	L/MIN	1.85	1.46	0.57
Temperature	C	30.00	66.64	96.47
Pressure	ATM	1.00	1.05	1.11
Vapor Fraction		0.00	0.00	0.00
Liquid Fraction		1.00	1.00	1.00
Solid Fraction		0.00	0.00	0.00
Molar Enthalpy	MJ/KMOL	-256.02	-236.14	-273.33
Mass Enthalpy	MJ/KG	-9.07	-7.51	-11.56
Enthalpy Flow	KW	-252.08	-136.13	-111.56
Molar Entropy	MJ/KMOL-K	-0.19	-0.22	-0.12
Mass Entropy	KJ/KG-K	-6.70	-7.08	-5.22
Molar Density	KMOL/CUM	31.89	23.72	42.88
Mass Density	KG/CUM	899.64	745.74	1014.05
Average Molecular Weight		28.21	31.44	23.65

The main intention of modelling and simulation of this distillation process in ASPEN PLUS software was to identify the hot and cold utility streams in the process and extraction of thermal data for process and utility streams as to perform the pinch analysis for the heat exchanger network that consists of two heat exchangers named as the condenser and the re-boiler. Therefore, next part of this study is the optimization of utility requirements by means of pinch analysis carried out with ASPEN HX-NET software. The identification of process streams and utilities by the computer aided pinch analysis are indicated by Table 4 and Table 5.

Table 4: Identification of process streams for pinch analysis by ASPEN HX-NET

Name	Inlet T [C]	Outlet T [C]	MCp [kJ/C-h]	Enthalpy [kW]	Segm.	HTC [kJ/h-m2-C]	Flowrate [kg/h]	Effective Cp [kJ/kg-C]	DT Cont. [C]
Bottom Stream	96.5	40.0	[illegible]	116.0		720.0	34.75	[illegible]	Global
Top Stream	66.6	40.0	1.642e+004	136.1		720.0	65.25	282.4	Global
Feed Stream	30.0	70.0	[illegible]	252.1		720.0	--	--	Global
New									

Process Streams | Utility Streams | Economics | Options | Notes

After the extraction of thermal data of process and utility streams is finished, the initial DT_{min} value was taken as 10 ^{o}C and composite curves and grand composite curve were plotted with the help of ASPEN HX-NET software. The plotted composite curves and grand composite curve are depicted in Figure 6 and Figure 7 respectively.

Table 5: Identification of utility streams for pinch analysis by ASPEN HX-NET

Name	Inlet T [C]	Outlet T [C]	Cost Index [Cost/kJ]	Segm.	HTC [kJ/h-m2-C]	Target Load [kW]	Effective Cp [kJ/kg-C]	Target Flowrate [kg/h]	DT Co [C]
Cooling Water	20.0	25.0	[illegible]		[illegible]	22.14	4.183	[illegible]	Glo
LP Steam	125.0	124.0	[illegible]		[illegible]	23.09	[illegible]	37.84	Glo
<empty>									

Process Streams | Utility Streams | Economics | Options | Notes

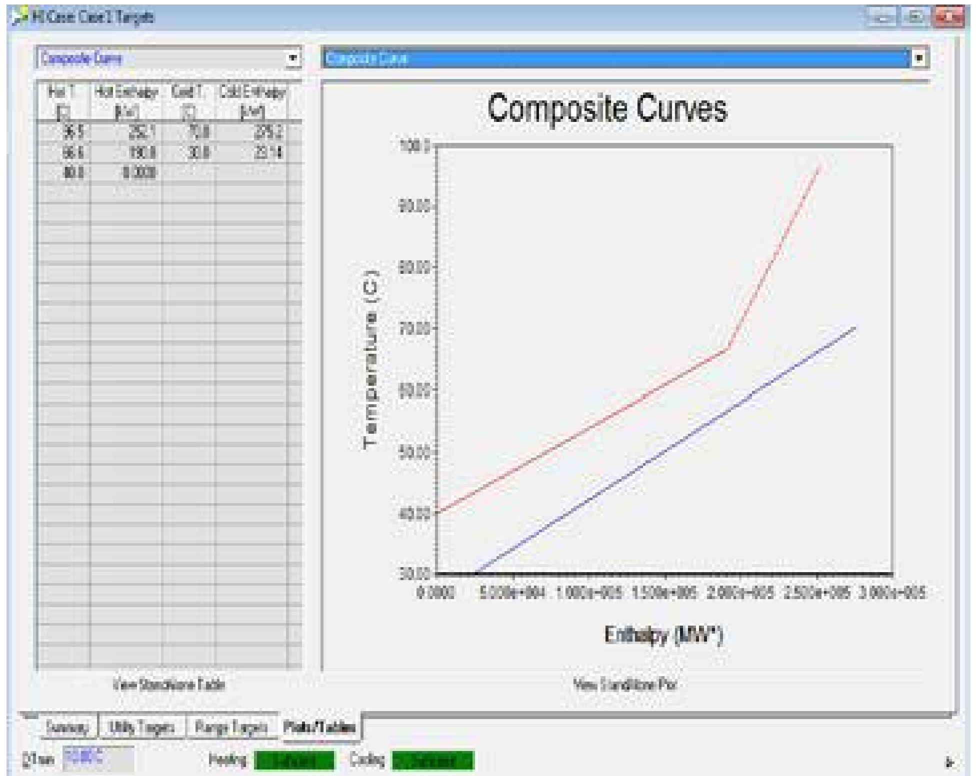


Figure 6: Composite Curves plotted by pinch analysis in ASPEN HX-NET software

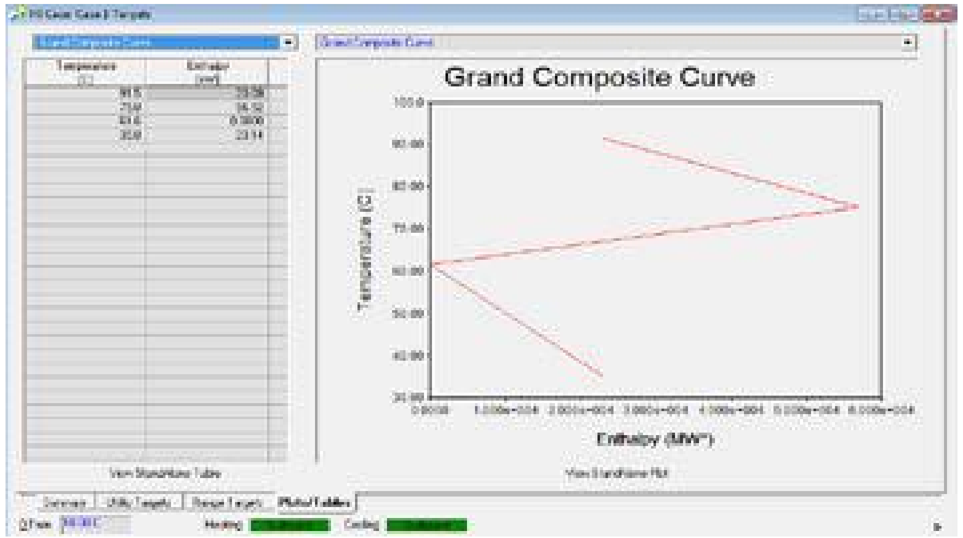


Figure 7: Grand Composite Curve plotted by pinch analysis in ASPEN HX-NET software

As discussed in the introduction, pinch analysis is done step by step even though it is carried out as a computer aided simulation. After constructing the composite curves the estimation of minimum energy cost and capital cost range targets are performed. As a result of range targets, the optimum DT_{min} value can be calculated. In ASPEN HX-NET software, range target calculation option and the required cost indices are available. So, the plot of range targets shown by Figure 8 reveals that the optimum DT_{min} value is 20 °C. According to this optimized value, the relevant heat exchanger network can be designed.

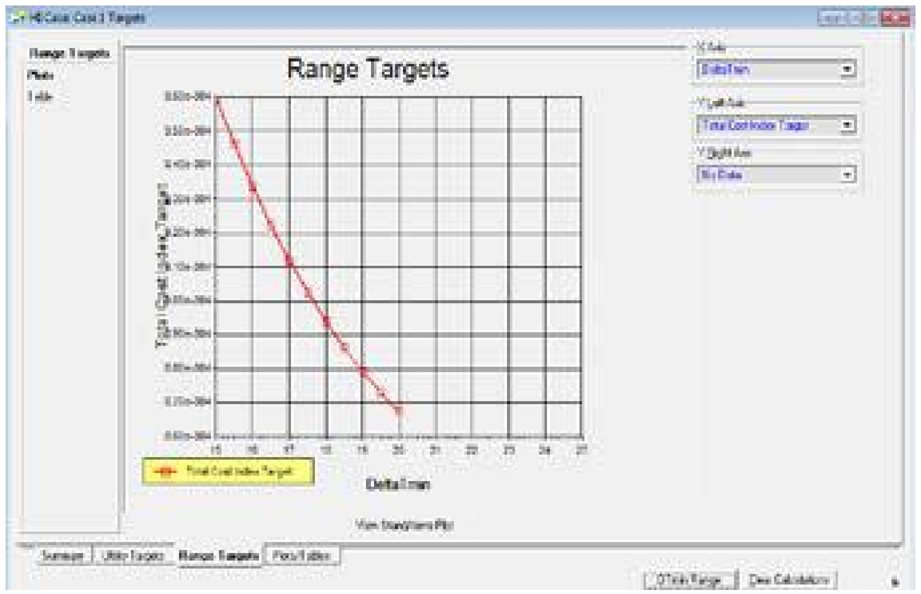


Figure 8: Total cost index targets to optimize DTmin value in ASPEN HX-NET pinch analysis simulation

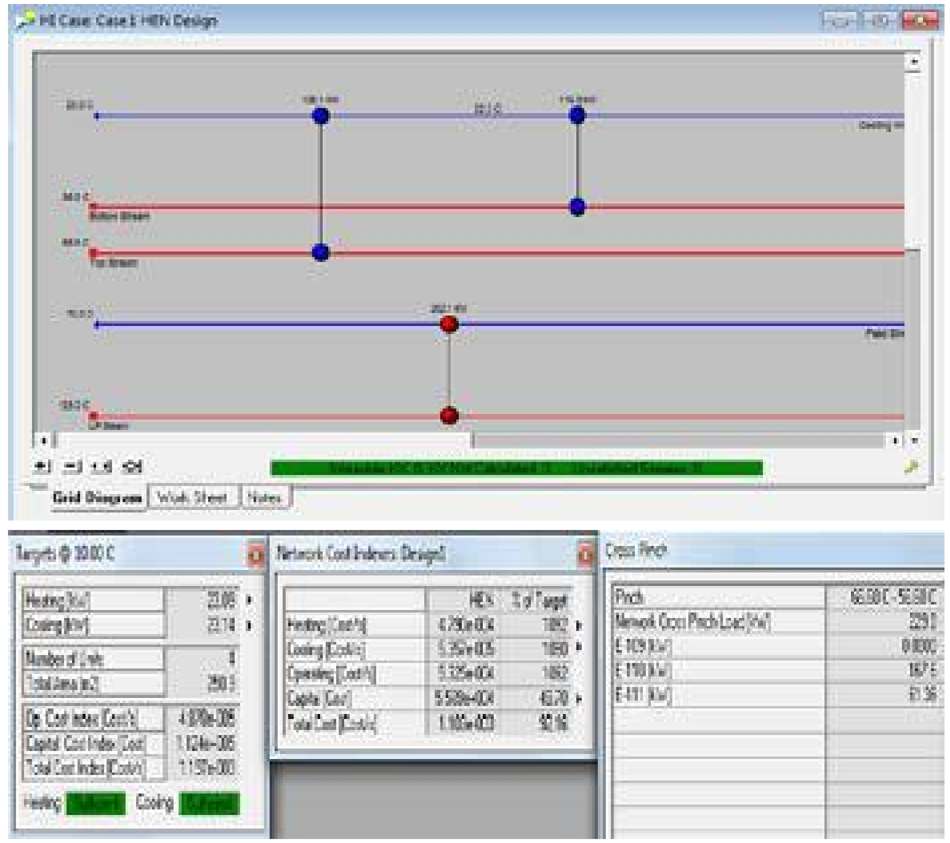


Figure 9: Heat Exchanger Network design optimization by pinch analysis in ASPEN HX-NET

According to pinch analysis simulation acted upon by means of ASPEN HX-NET energy optimizing tool to the distillation column application initially formed in this research investigation, a percentage of 92.16% of the total cost target has been achieved with 3 units which are actually targeted for 4 units. Meanwhile, a cross pinch load has been achieved accurately by meeting the optimum DT_{min} value in this heat exchanger network.

Conclusion and Future work

This investigation which was based on computer aided modelling and simulation for a particular distillation application and thereafter, optimization of its utility requirements by optimizing the heat exchanger network involved in the same process has delivered an obvious methodology for process integration via pinch technology with the help of relevant computer tools. Not only this key objective of this study has been fulfilled, but also, a particular process application has been modelled extensively to be maximum energy efficient with minimum cost. Therefore, energy saving and cost effectiveness are prominent in this exploration. However, as far as the entire research study is taken into account, there are several points where future research potentials can be noticed.

Shortcut methods and rigorous simulation in ASPEN PLUS can be utilized to indicate parameters and simulate them for energy savings in distillation columns whereas, the feed conditions to the distillation column affect when analyzing a distillation column especially for the heat integration. Due to this, as a future research work it is worth studying how the energy savings would be when the feed conditions are varying. Moreover, all the investigations carried out in this study are based on the computer modelling and simulation software such as APEN PLUS for distillation column simulation and ASPEN HX-NET for pinch technology and process integration. These simulation results have not been validated by real world experiment results yet. Therefore, as a future effort, it would be beneficial to validate the findings and results of this study through an experimental analysis.

In due course, the process of methanol recovery from sodium minerals using distillation was successfully coupled with pinch technology to improve the quality of heat exchanger network reducing the utility requirements making the process more competitive while leaving some future research work for further validation.

Acknowledgement

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Street Light Controlling System using Existing Radio Broadcasting

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Abstract

Street lights are sources of illumination which are used to aid the pedestrians and drivers during the night time by illuminating the streets and surroundings. Ceylon Electricity Board incurs an annual loss of LKR 2,673 million in street lights due to improper attendance to switch off lamps. A system was developed to control street lights using an existing radio broadcasting network. Coded audio signals transmitted through an existing radio station were used as control signals. Coded audio signal pattern was identified based on the frequency, duration and the order of the tones. PIC microcontroller was used to detect and identify the signal and to trigger power control module which control the street lamps. Using an existing radio station as the transmitter reduced the implementation cost while providing an optimal coverage and security for the signals. Extra precautions were taken to reduce the mistriggering and to increase the robustness against the factors such as power failures and power surges. Units were tested in the laboratory and are currently being tested for the outdoor environment and observed to be functioning properly under average conditions.

Keywords: Automated, Street lights, PIC, Frequency, Radio broadcast, Audio signal

Introduction

Street lights are sources of illumination which are used to aid the pedestrians and drivers during the night time by illuminating the streets and the surrounding. These lights serve a vital role by not only helping the drivers and pedestrians to see better but also to reduce some of the street crimes. However these lights use high intensity bulbs such as high wattage sodium and mercury lamps and consume large amounts of electricity. It is estimated that the average usage of electricity for street lighting in Sri Lanka is 138 GWh [3]. Having the street lamps switched on for an extra hour in a city can be considerable as a waste of electricity. Ceylon Electricity Board incurs an annual loss of LKR 2,673 million due to improper attendance to switch off lamps [2]. Therefore it is necessary to control these lights effectively to guarantee the safety of the people while minimizing wastage.

At present, most of the street lamps are controlled manually. A single switch may control cascaded lamps in a street or each lamp may have a dedicated switch. This process is not only labour intensive but also inefficient. As an example Colombo Municipal Council at the moment has only 59 staff members to control large amounts of street lights within the city limits while it is estimated that at least 80 employees are needed for the task. If it takes one hour for a person to complete the task, lamps at the end of the route would be switched on for an extra hour. But the most problematic scenario is shear negligence may lead street lamps to switch on throughout the day which is not a very uncommon sight.

Automating the light controlling system can solve most of the above mentioned problems while reducing the costs in long term. Automated street light control systems can be categorized as follows.

1. Timer based controlling
2. Ambient light based controlling
3. Remote controlling

Timer based controlling uses a Real Time Clock (RTC) to determine when to switch on or off the lamps. This clock may be an internal clock which is built in to the circuit, or it may use an external clock signal such as GPS clock time, to determine the time. Since different seasons have different times for sun rising and sun setting it is required to take these differences into account for efficient controlling.

A light sensor based controller samples the intensity of the outside light level and determines whether the light should be switched on/off. These controllers can compensate for the daily weather changes such as the cloudy sky since they rely on the external feedback. However these sensors are more prone to be misfired due to the collection of dust and rusting of the shields.

All the above mentioned automated methods have one disadvantage. They do not allow a person to micromanage the lighting. An example may be a decision to switch off street lamps from 1.00 a.m. to 3.00 a.m. during a power shortage period. Although timer based controller may be programmed to do so it would require reprogramming all the devices which would be a major drawback.

A more convenient method would be to have a central place where all the lights can be managed. Remote controlled light management was based on this concept. Remote controlling can be wire based, infra-red (IR) light based or radio frequency (RF) based. Wire based methods would require additional wiring to the street lamps which is definitely an upgrade to present infrastructure and it is costly. Further, damage to a single point along the line can cripple the full system. IR based methods only works for a short distance which makes them unsuitable for a wide area. Radio frequency based controlling eliminates all these disadvantages. However the conventional radio frequency controlling methods require a dedicated powerful transmitter to send the control signal. Objective of this research is to overcome this obstacle. Therefore it was decided to use the existing radio transmission service as a transmitter.

Methodology

System Overview

Street light management system consists of a central transmitting tower, which is a radio station, signal receiver and decoder modules also known as the controller modules and the lamps themselves. Figure 1 illustrates the overall design of the system.

Switch of the street lamps is replaced by an electronic module which is referred as the control unit. This unit mainly consists of an FM radio, a microcontroller and a latch switch which is connected to the street lamp. Microcontroller is capable of identifying the predefined controller signal from the audio signal received from the FM receiver and triggers the latch switch.

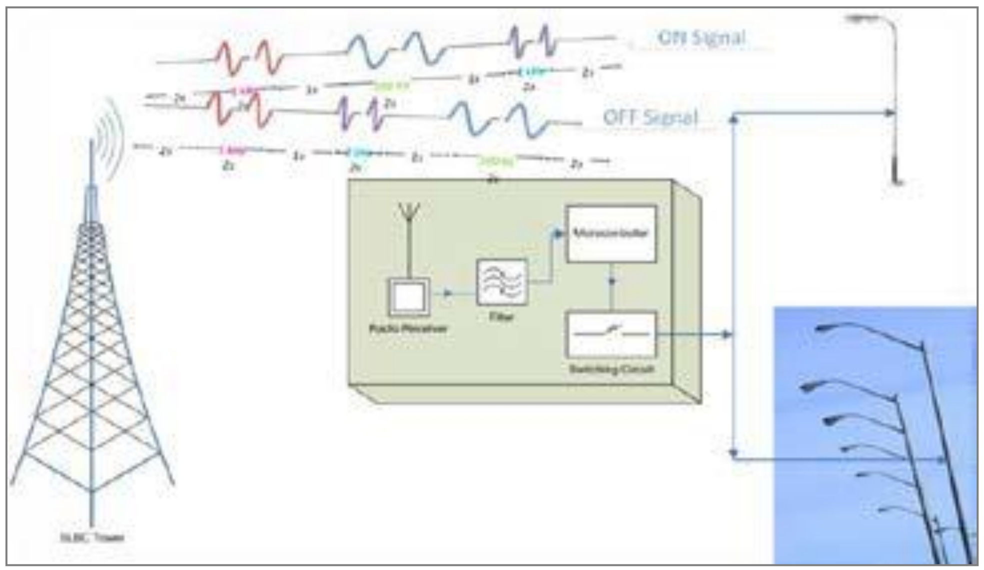

Figure 1: Overall design of the system

Control Signal

Control signal consists of a sequence of frequencies which are encoded to an audio pattern that can be transmitted through a standard radio channel. Several factors are considered when designing the control signal. Since the signal was transmitted using a system designed to transmit signals in audible range. it was necessary to keep the signal in the audio range. Most of the other frequencies were filtered during the intermediate steps in the transmission process. As a result control signal is audible and it is necessary to minimize the interruption to the audience. This is handled by making the control signal brief and pure tone. Duration of the pattern was 7 seconds. Three base signals used were 200 Hz, 1 kHz and 2 kHz. Using pure tones distortions due to unequal equalizer settings were reduced. The final control signal was a collection of pure tones which was transmitted in a sequence with a predefined set of durations and intervals. It was artificially generated using a computer program. Control signal is illustrated in Figure 2.

Measurements to Prevent Misfires

Unlike a dedicated transmitter which would transmit only the controller signals, using an existing radio service exposed receiver to other audio signals such as music, news and advertisements. Hence it was necessary for the controller program to identify the controller signal from all other possible audio signals. Identification was based on the following three key characteristics of the signal.

1. Frequency of the tones
2. Duration of the tones
3. Order the tones

For a control signal to be identified it is necessary to satisfy all the conditions, reducing the possibility of a false positive.

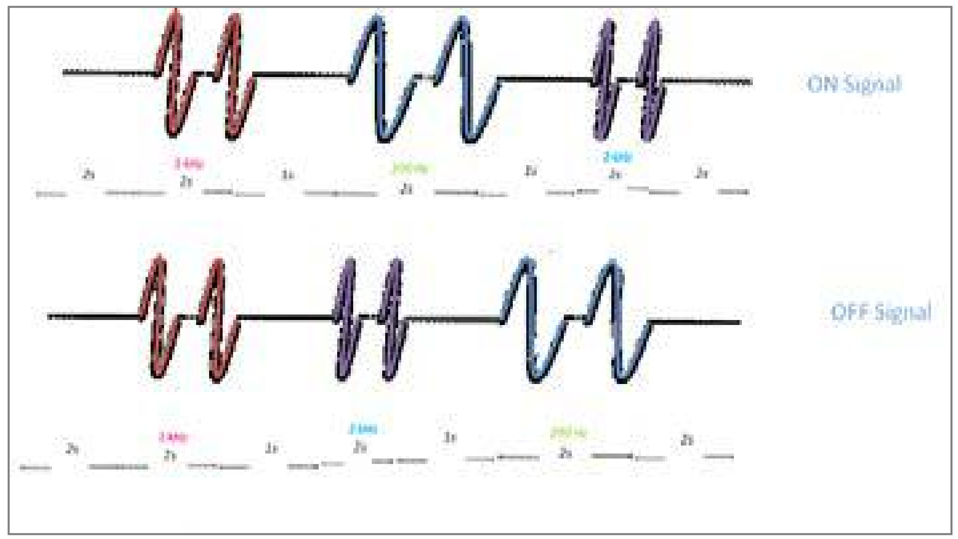

Figure 2: Control Signal Pattern

Transmission Process

Frequency Modulation (FM) band is chosen due to the availability of the RF receivers and the number of radio stations active. Standard frequency range approved by the Telecommunication Regulation Commission is 87.5 MHz to 108 MHz. Several test transmissions were carried out to determine the efficiency of the transmission process and was found to be highly successful. Signal was transmitted in raw wave file format as well as the compressed mp3 format and found to be effective regardless of the compression method. Audio sampling rate was 44,100 Hz with 16 bit resolution.

Electronic Circuit Block Diagram

Circuit was designed and implemented in modular architecture. Figure 3 illustrates the seven sub modules and their interconnections.

Power Supply Module

Power module is used to supply regulated low DC voltages required for other modules, including 12 V and 5 V. It was also designed to act as a protection unit. Since the unit would be directly connected to the national grid, possibility of a voltage surge is high. These surges can damage the electronics used in the controller. Therefore the surge protection unit is installed in the power controller module to filter power line voltage spikes.

Receiver Module

RF receiver used was an FM radio circuit designed to receive signals from 87.5 MHz to 108 MHz. Several modifications were made to the design to make it more robust. Most of the radio receivers used an inductor capacitor tank unit to resonate with the transmitted frequency [1]. By changing the capacitance and inductance it was possible to tune to a different frequency. In early designs it was noted that changes in temperature and humidity can affect the value of these components and hence the receiving frequency can be changed. As the controller signal was transmitted from a fixed radio channel this was undesirable.

It was amended by using a solid state receiver with a digital tuning circuit. It was noted that changes in the environment had minimal effect on the frequency of these units. It was also necessary for the units to be properly initialized after a power failure. Microcontroller unit was used to handle the initializing process once the power returned. Captured audio signal was filtered from the noise and was amplified using the amplifier sub module.

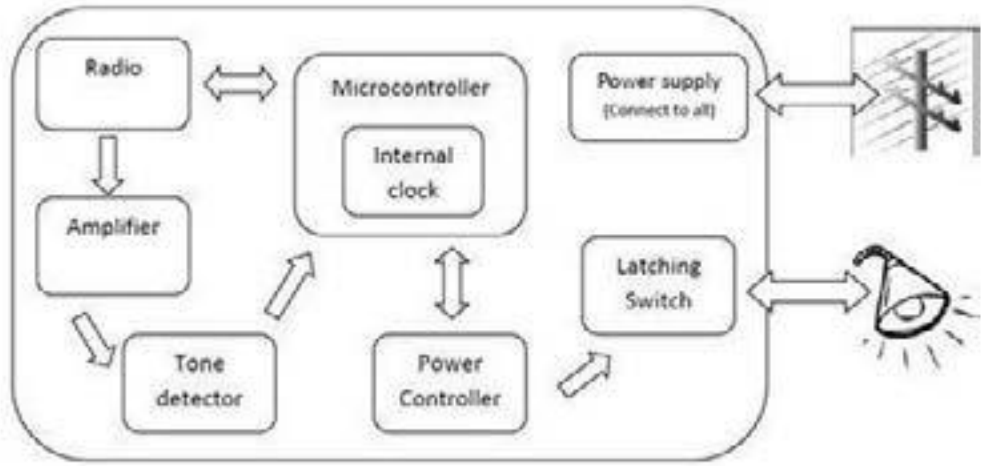

Figure 3: Design of electronic sub modules

Detecting Pattern

One of the key concepts in the design was the pattern detection. Control signal was identified using frequency of the tones, their durations and the sequence of the tones. Since control signal consisted of pure tones it was logical to have three tone detector circuits with each one tuned for a unique frequency. Each time the audio signal contained the relevant audio frequency component; these circuits would send a signal. Tolerance of 10% was provided to compensate for any abnormalities that may occur during the transmission and receiving process.

A clock inside the microcontroller unit measured the duration of each of the tone detector circuit's signals. Tone detectors were queried in 100 ms periods for the frequencies. This data was then used to detect the controller signal.

Microcontroller Module

Identification of the signal included several steps. If any of the steps failed, it would be considered as a non control signal and system would return to the previous state. First step was the detection of silence to initialize the detector circuit to detection mode. This also prevented controller signal being mixed up with a fading audio from a previous track. Then 1 kHz signal of 2 second period is detected by the microcontroller and the process continued. Since controller signal consisted only of a single frequency, it also confirmed that none of the outputs of other tone detectors are high. If so it would be considered as a misfire and system would reset. Tolerance of duration of a single tone was 20 ms. this was to minimize any cross fading effect and to handle any short period signal losses. Once the first tone was identified microcontroller would be detecting the second signal. This process was continued until either the controller signal was identified or a signal resets. Once the controller signal was identified, using two special bits encoded to the signal, microcontroller would identify it as an 'on' signal or as an 'off' signal. This on/off signal was then communicated to the power controller sub module. Power controller sub module would send a signal to switch the latch switch. Since the state of the latch switch is non volatile once the status change was made microcontroller can switch off the power controller unit. Another advantage of the latch contactor is, it would not reset during a power failure and would remain in the state until a controller signal is received making it more robust against power failures. The logic behind this process is illustrated in Figure 4.

Identification of the signal was handled by a microcontroller. Selected microcontroller was from the PIC family due to the competitive price and the range of functions available. The program was written in C language.

Mechanical Design

Since this was an outdoor unit special care was taken when designing the enclosure. It was designed to withstand extreme weather conditions while providing a good insulation for the internal electronics. It was also necessary to be economically feasible and environmentally friendly. The box design shown in Figure 5 was used as the prototype.

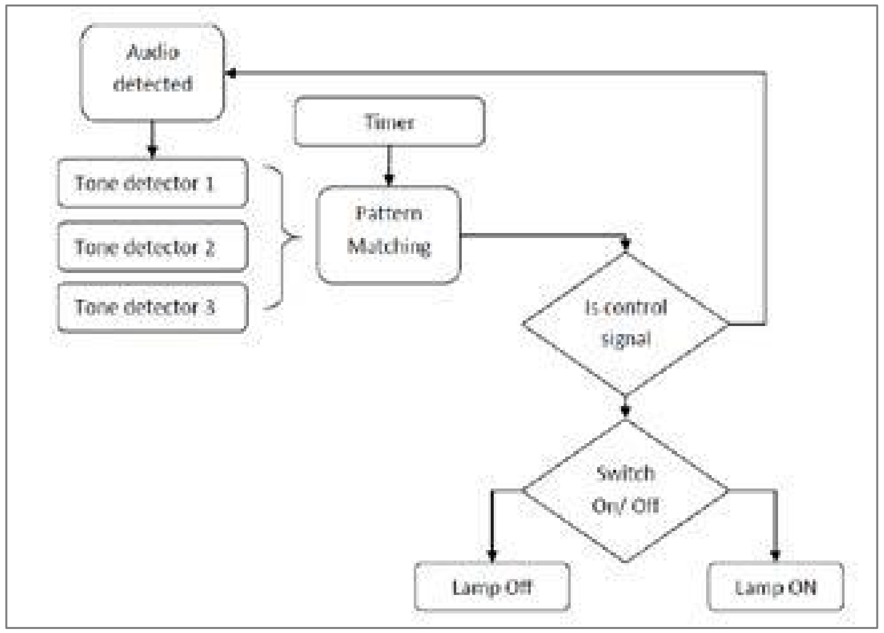

Figure 4: Flow chart of signal identification

Figure 5: Controller unit inside the casing

Results and Discussion

Four modules were tested in the laboratory and were found to be successful. They were put to continuous operation for over 96 hours and were found to be operating in the same efficiency without any noticeable change in frequency shifts, degradation of amplification or excess heating. Same modules were exposed to frequent power failure scenarios and all the units were found to be functioning properly even after multiple power failures.

Although frequency detection module shifted its detection frequency in extreme temperatures (60.0 ± 0.1) ^{o}C, it returned to previous value once the module returned to room temperature. By logging the temperature and the humidity inside the metal box it was found that the maximum temperature inside the box was (39. 0 ± 0.1) ^{o}C. The temperature variation during a 24 hour period inside the box was found to be in the range from (24.0 ± 0.1) ^{o}C to (39.0 ± 0.1) ^{o}C. All the modules were operating successfully in this temperature range. Modules were also tested against extreme humidity levels from (20 ± 1) % to (70 ± 1) % relative humidity.

Conclusion

Main objective of the research was to develop a low cost robust street light management circuit which can be deployed island wide. Use of an existing radio station had made it possible to transmit a signal island-wide without having to invest on a separate transmitter. A controller signal embedded as audio frequency was transmitted and was captured by an FM receiver. It was decoded for composition frequencies and the result was submitted to the microcontroller for the identification of controller signals. Once identified a signal was used to control the bulb. System was tested for various conditions and was found to be practical and reliable. Successful implementation of this system throughout the island would save around LKR 2,673 million to the country annually.

Acknowledgement

During the testing of the system the field trial was conducted in the site with the help of Colombo Municipal Council street lamp division and the ON/OFF signal was transmitted by the Sri Lanka Broadcasting Corporation. We wish to acknowledge the support extended by them during this research work.

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A Study on Cast Iron Components of Air Heaters of Tea Dryers

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Abstract

Five pass air heaters are commonly used in tea factories to generate hot air for drying fermented wet dhools. Failure of cast iron components, especially cast iron tubes of air heaters are quite common. Failures invariably lead to smoky teas and sometimes a fire that can have serious consequences. A study was done by visiting tea factories to find out reasons for failures. Observations revealed poor maintenance and operational practices, aiming for higher operating temperatures beyond the capacity of the air heater and poor firewood management practices as the main causes of failures.

Samples of damaged cast iron tubes collected from air heaters were analyzed for their chemical composition. Chemical composition of the cast iron is the key parameter which determines the ability to withstand high temperature. Temperature regime inside the air heater and status of the flue gas were recorded using data loggers and flue gas analyzer with dry (15% moisture content) and wet fire wood (40% moisture content). Temperatures as high as 830°C were recorded. This study confirmed that temperatures inside the air heaters are primarily related to operational practices. It also revealed that the quality/chemical composition of collected cast iron samples from the failed components of tubes in air heaters may not be satisfactory to withstand the temperatures observed.

Key words: Five pass air heater, Cast Iron chemical composition, Temperature, Firewood

Introduction

Tea dryers require clean air for drying fermented wet dhools of harvested tea shoots in order to eliminate any risk of smoke taste in processed tea. Heat is transferred from hot flue gases to fresh air using tube type heat exchangers. Over the years, designs have achieved higher efficiencies by incorporating additional heat exchange areas. "Five - Pass Heater" which is popularly used at present has five flue passes through tubes, first pass through cast iron tubes (oval cross section) and the other four through steel tubes (round cross section). Recent concerns of tea processing factories have been primarily related to frequent failure of cast iron tubes, which are the hottest, and on occasion failure of the coldest steel tubes, obviously due to low flue gas temperature.

In an air heater such as those used in the industry, tubes are considered failed when there is contamination of fresh air supply by flue products due to damage to tubes. When fresh air supply is contaminated, it leads to an undesirable smoky taste in tea which requires immediate rectification. Maintenance is costly and down time caused by frequent breakdowns of a heater can lead to overall disruption of process and therefore significant losses. Smoky tea leads to lower prices and if unattended eventual rejections by tea buyers and at worst a fire which can damage the asset causing severe financial losses.

Unlike in the past, at present nearly all tea dryers and heaters as well as most spare parts are imported from India. There is reliable evidence that some of the foreign suppliers of these tubes get casting work done via smaller sub-contracting units who probably lack quality control and assurance. Casting facilities available in Sri Lanka, particularly those serving tea industry have not expanded over time, primarily due to difficulties in competing with imported products in an open import policy environment.

Tea processing organizations requested Tea Research Institute to examine this problem and come out with remedial measures. This study is a result of that request.

Material and Methods

Literature survey revealed that standards on Grey Iron castings such as BS 1452:1977 –British Standard Specification for Grey Iron Castings [1] specifies the requirements for several grades of cast iron based on the tensile strength only. This standard as well as its 1990 version [2] and the Indian Standard IS210:1993 [reaffirmed 1999] – Grey Iron castings –Specification [fourth Revision] [3] are silent on suitability of casting for use under high temperature environments. Further, these standards have refrained from stating the chemical composition of castings and leave it to be decided between the purchaser and the manufacturer.

Handbooks on cast iron, for example FOSECO Foundryman's Handbook [4] clearly explains the role played by component elements of cast iron and provides guidelines for compositions suitable for use in high temperature environments.

In order to assess how widespread the problems are, tea processing sector associations were requested to assist in collation of information on failures. On receipt of that information, few selected factories were visited to assess the severity, observe operational practices, gather photographic evidence and collect samples of failed tubes for analysis of chemical compositions. Reports on carbon, silicon, manganese, sulphur, phosphorus and chromium contents of cast Iron of a few failed tubes were obtained from the Industrial Technology Institute, Colombo and Ceylon Steel Corporation Limited, Athurugiriya.

Two local foundries that produce cast iron tubes for the tea industry were visited to examine the facilities available and to assess their efforts in quality control and assurance.

On completing above two tasks, it appeared that there is hardly any knowledge on temperature regimes actually present inside an air heater. Information on this aspect was generated by measuring temperatures in a five-pass air heater used at Tea Research Institute's St Joachim Tea Factory in Ratnapura. Following measurements were made.

- Ambient temperature
- Temperature of hot flue gas entering each tube pass
- Temperature of fresh air in two locations inside heat exchange area
- Temperature on the outside surface of cast iron arch
- Temperature of final hot air
- Firewood consumption and frequency of feeding
- Flue gas analysis which included measurements of temperature, oxygen content andcarbon monoxide content

Temperature measurements were made using insulated K-type thermocouple wires coupled to data loggers [Testo 175-T3], industrial thermo probes and flue gas analysis using analyzer [Testo -340] supplied by Sri Lanka Sustainable Energy Authority, Colombo.

Results and Discussion

a) **Based on observations made during visits to factories following were identified as possible causes of frequent failures**
   - Casting defects such as,
     - Uneven thickness of tubes. While on average thickness is around 8mm, cross section of a failed tube revealed the thicknesses as low as 3 mm [Figure 1]. This is due to core shift defect in casting.
     - Pinholes in the casting sometimes visible in the surface
     - Blow holes surreptitiously hidden by applying a covering paste and painting thereafter.

Figure 1: Photograph showing uneven thickness of an oval tube

- Installation defects such as,
  - Not balancing the flue path to get an even flow on Right and Left sides. This omission leads to live flame getting sucked into one side causing accelerated decay.
- Operational and maintenance weaknesses such as,
  - Targeting temperatures higher than the design level
  - Operating the heater for long continuous periods ignoring the need for cleaning of tubes and ash removal from collection points. [Figure 2]

Figure 2: Photograph showing a large quantity of ash collected, probably due to long hours/days of work

Figure 3: Photograph showing blocked oval tubes

- The practice of temporarily blocking defective tubes which increases the work load of other tubes [Figure 3 - above]
- Use of poor quality firewood, particularly wet or raw firewood having high moisture level which require overloading of the combustion area, switching OFF of main fan for short periods, etc.. These unwise practices lead to exposure of tubes to high temperature.

b) Analysis of composition of failed cast Iron tubes:

Results of composition of some important elements are given in the Table 1.

Table 1: Elements present in failed Cast Iron tubes

Element	Fraction present (%)		
	Sample 1	Sample 2	Sample 3
Total Carbon	3.04	2.91	3.21
Silicon	1.17	1.35	1.16
Manganese	0.33	0.25	0.23
Sulfur	0.09	0.11	0.11
Phosphorus	0.05	0.05	0.05
Chromium	0.02	0.09	0.02

As per Foundryman's Handbook (Ref 4), heat resisting cast iron is classified as follows.

- White cast iron:
  Not suitable due to rapid scaling under oxidizing conditions

- Low silicon iron:
  With about 1.2% silicon and about 3.2% total carbon
- High silicon iron:
  Silicon content 4% to 10% and about 2.5% total carbon
- Austenitic Iron:
  High silicon iron with added chromium, nickel and manganese
- High chromium cast iron:
  With 16% chromium

When compositions of failed cast iron tube components are compared against above classification, it appears that all samples tested fall into the category of low silicon irons. However, as per Foundryman's Handbook [4] recommendation, low silicon cast iron without any chromium is suitable for use up to a temperature level of 600 °C only. For the sake of managing cost of energy in operating the cupola the carbon equivalent will have to be close to 4.3%. Further, to exploit in full the buffer or cushioning effect of the higher graphite precipitation, Handbook recommends high total carbon content in applications where there is heat shock. Such composition is close to the low silicon category with suitable additions of chromium and nickel.

Handbook also recommends the following composition [Table 2] for temperatures up to 700 °C. This composition more or less tallies with the composition used decades ago by one of the leading tea dryer/furnace manufacturing companies in Sri Lanka.

Table 2: Composition of Cast Iron recommended for temperatures up to700 °C

Element	Recommended Composition
Total Carbon	3.4 - 3.7%
Silicon	2.3%
Manganese	1%
Sulfur	<0.12%
Phosphorus	0.3% max
Chromium	0.6%

Further for temperatures up to 850°C, Handbook recommends addition of 1% aluminium to above composition. Through this it is expected to reduce oxidation and scaling losses and increase the life to about five times that of unalloyed cast iron. With higher aluminium content, Handbook cautions about defects caused by entrapment of aluminiumoxide in the castings.

c) Observations on local Foundries visited:

It appears that,

- The level of competency and resources available seen at the two foundries are adequate for the purpose of casting tubes for tea industry. Quality awareness is found to be adequate.
- They are producing castings for other industries and also produce other machinery for tea Industry.
- Factories using their products appear to be satisfied with the quality of the products though they are marginally expensive compared to imported products. Absence of assurance of steady orders appears to be the only reason why these firms are not carrying stocks of finished castings.
- Even they do not addchromium in making cast iron tubes for the tea industry. However they can easily do require ladle additions of chromium if there is a stable demand for such products.

d) Temperature regimes inside the Air heater:

After a few preliminary trials, two final trials were conducted, first with good quality firewood, i.e. well-split dry firewood, and the second with well-split not so dry firewood. Firewood, kg per load and frequency of feeding had to be adjusted for best performance. Hot air temperature profile is depicted in Figure 4 whereas most important recorded temperatures are summarized in Table 3.

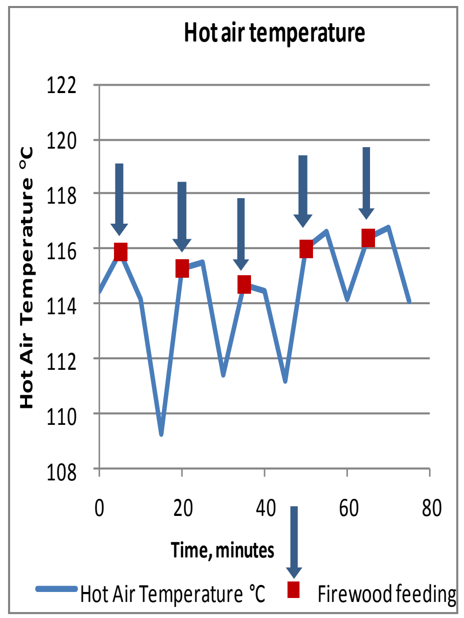

Figure 4: Hot air temperature, °C [Note: target =115 °C]

Table 3: Comparison of key parameters – Well split, dry firewood vs. Well Split, Not-so-dry firewood

Description	Trial 1 (Dry Firewood)	Trial 2 (Not so Dry Fire wood)
Target Air Temperature (°C)	115	115
Moisture Content of Firewood (%)	15	40
Firewood feeding interval (minutes)	15	10
Weight of firewood (kg/load)	45	50
Rate of firewood feeding(kg/hr)	187	300
Average air temperature achieved(°C)	115	103
Maximum air temperature achieved(°C)	120	108
Average flue temperature entering cast iron tubes(°C)	644	656
Maximum flue temperature entering cast iron tubes(°C)	805	830
Flue gas temperature (°C)	131	133
Fraction of oxygen (%)	13.9	8.6
Fraction of carbon monoxide (ppm)	2813	1070

Comparisons between normal dry firewood [15% MC] and not so dry firewood [40% MC] revealed the following.

- With dry firewood at 187 kg/hr, target air temperature was achieved [Figure 4] and it was maintained with acceptable fluctuations. With not so dry firewood even at 300 kg/hr target was short by 12°C, as evident in Table 3.
- While there was hardly any difference between the average temperatures of flue entering cast iron tubes, with not so good firewood, there were wide temperature fluctuations. Further there was a significant increase in the maximum, rising up to 830°C. At this higher temperature, there is a serious possibility of decay and scaling of unalloyed cast iron.
- There was no difference in flue temperature at the induced draft fan.
- In Trial 2, firewood had to be heaped up to get closer to the target air temperature. This may have reduced the excess air volume as apparent in lower oxygen % and carbon monoxide ppm. Though this implies higher efficiency of transfer of heat, unit is at a serious risk due to higher temperature flue, possibly live flame, entering the tubes.
- Further, it was also observed that if the main fan were to be switched off even for a few minutes, flue gas temperature entering the cast iron tube bank increases rapidly to a level well above the tolerable level. This may be due to absence of any fresh air to cool the cast iron arch.

e) Flue gas temperature entering First pass Cast Iron tubes

Air heater is fed batch-wise, every 10 or 15 minutes by opening the feeding door. Feeding of 50 kg of firewood takes one or two minutes to complete even under closest supervision. During this period, a large volume of air enters the combustion chamber, which brings down the flame temperature. Further, heap of burning firewood is stoked once midway during this period to encourage burning. Important stages of this cyclic process are marked as point numbers in Figure 5.

Point 5 - Doors opened and firewood fed

Point 6 - Temperature drops probably due to large quantity of ambient air entering the combustion chamber and due to heat utilized for removal of moisture from firewood.

Point 7 - Temperature increases after closing the door.

Point 8 - Temperature fairly constant. Slight drop in temperature may be due to ash coating on burning logs which prevents aggressive burning.

Point 9 - Doors opened and firewood stoked to dislodge ash and to loosen the fire bed.

Point 10 - Temperature drops due to large quantity of ambient air entering the combustion chamber.

Point 11 - Temperature increases after closing the door. More aggressive fire was visible.

Point 12, 13 - Temperature steady

Point 14 - Doors opened and firewood fed.

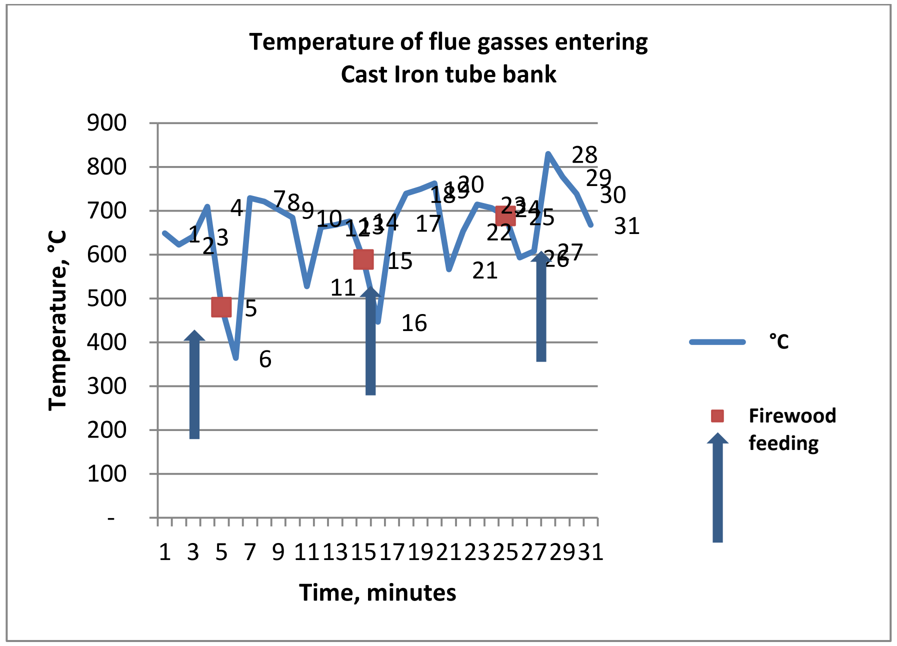

Figure 5: Temperature of Flue gasses entering Cast Iron tube banks

f) Measured temperatures inside the Furnace:

Flue gas temperatures [FT] as seen by each tube bank is shown in the following graph, [Figure 6], where

FT01 = Entering first bank [Cast Iron tubes] and

FT02 to FT05 = Entering steel tube banks, second pass to fifth pass.

Temperature variation of flue gas could be commented as follows:

- Hot end of the cast iron tube bank is likely to reach temperatures close to FT01, i.e. temperatures varying from about 500°C to about 800°C. Therefore, for long life composition of cast iron should be chosen to cope with this high temperature.
- On the other hand, steel tubes do not experience any such high temperatures.
- While cast iron tubes experience large fluctuations in temperature, much less fluctuations are experienced by steel tubes.
- Temperatures lost by each tube bank often falls within the following ranges.

  By cast iron bank [1st pass]
  -100 °C - 230 °C
  By steel bank [2nd pass]
  - 100 °C - 160 °C
  By steel bank [3rd pass]
  - 50°C - 80 °C
  By steel bank [4th pass]
  - 40 °C - 55°C
  By steel bank [5th pass]
  - 30 °C - 40 °C

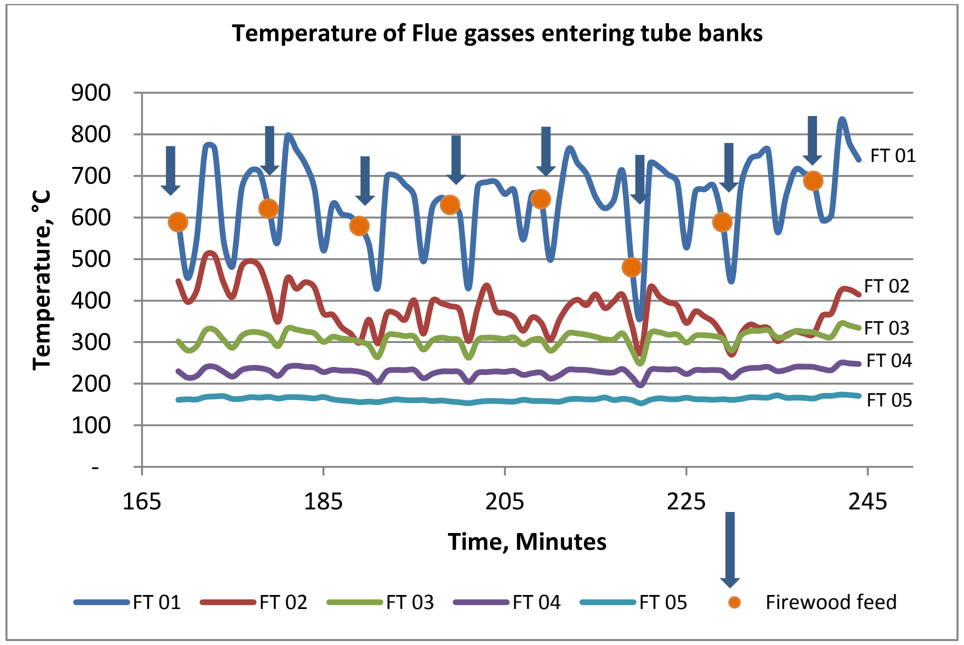

Figure6: Temperature of flue gasses entering tube banks

Conclusions

1. In order to minimize the failure of cast iron and steel tubes in air heaters, it is vital to employ good firewood management practices, regular air heater maintenance under proper supervision, correct operational practices and have calibrated temperature measuring equipment.
2. The composition of tubes analyzed falls into the category of unalloyed cast iron, for which recommended operating temperature is limited to 600°C.
3. As per temperature measurements made, hot end of the cast Iron tube bank often faces temperatures in excess of 700°C. This is the component of air heater that shows defects earliest during its life time. Therefore it is prudent to use a composition of cast iron which can withstand at least such temperature. Mere addition of 0.6% chromium appears to be adequate to satisfy this condition as given in Table 2. This composition will increase the tolerable temperature by at least 100°C over and above what is recommended for unalloyed cast iron.
4. Temperature measurements further show that, probably due to batch-wise feeding of firewood, temperatures can rise above 800°C within two or three minutes of feeding.Inclusion of 1% aluminium to the composition given in Table 2 satisfies this requirement.

5. One long term option industry has is to confine the selection of cast iron tubes to cope with much higher temperatures, say 850°C. Although such selection is possible, generating a sizeable volume of demand and providing an assurance of demand may be necessary to ensure continued availability. This will require industry-wide commitment.
6. Data generated during this study may be useful to designers of air heaters. Further, future designs will have to embody mechanisms to reduce fluctuations of temperature within the combustion space that should improve the overall efficiency and minimize fluctuations of hot air temperature for the tea drying process. This requirement may be met by a conveyor fed, fully enclosed combustion chamber.
7. More comprehensive study of temperature regimes inside the furnace no doubt would enable optimizing the designs of air heaters, particularly the effectiveness of the cast iron arch as a heat transfer surface and design of tube banks.

Acknowledgements

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Light Powered Mobile ID

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Abstract

Battery of a portable device has become one of the key considerations in the modern world. Nowadays the mobile phones don't limit its function to communication but it has the capability to deliver a vast number of services. A failure in the power source means that the total functionality of the phone will fail including communication. Many researchers tried to overcome this issue by investigating a suitable method to recharge the phone battery or increase the battery capacity [1], [2]. As a result they achieved extremely high standby time but yet they couldn't achieve a total continuous connection. So we tried with the "Light Powered Mobile ID" to implement a device which is capable of providing total continuous connection, not by extending the battery lifetime, but by activating the SIM card when the mobile phone is dead. This will enable the user to receive and retransmit the message to a nearby communication device wirelessly, so that the user will be able to receive the urgent messages without failure due to power difficulties.

Introduction

Battery of a portable device is the backbone of the device itself as each and every function of the device depends upon the charge it can carry and to what extent it can power up the device at a desired performance level. Same fate goes to mobile phones where it has become a must to have a powerful energy source to juice up all the heavy-duty functions which a present mobile phone can offer. Nowadays the mobile phone doesn't limit its function to communication but it has the capability to deliver a vast number of services to the consumer and through that it has become an essential part of life. A failure in the power source means that the total functionality of the phone will fail.

Many researchers tried to overcome this issue by investigating a suitable method to recharge the phone battery or increase the battery capacity in various methods [1], [2]. They achieved very much powerful solar panels which can greatly extend the battery lifetime [3]. But yet they couldn't activate the mobile phone completely without failure due to power drops. Since this will fail the total functionality, even the basic function of the mobile phone will fail. This will cause many problems by failing to receive urgent messages.

So we tried with the "Light Powered Mobile ID" to implement a device not to extend the battery lifetime of the mobile phone, but to activate the SIM card when the mobile phone is dead. Mobile ID will only activate the SIM card and allow the user to receive and retransmit the message to a nearby communication device. And it is energized by an internal battery and a solar panel which is capable of powering the device without depending on the time. This will enable the user to receive the urgent messages without failing due to power difficulties.

So with the "Light Powered Mobile ID" we established a flexible, continuous mobile connection by using solar power.

Meantime as an additional achievement we achieved a method to send emergency messages to a single or multiple unknown mobile devices with minimum cost since the Mobile ID is capable of retransmit the received message to a single or multiple number of mobile devices which are located in a certain range. This functionality can be achieved even in a moving vehicle by simply sending and retransmitting the message through the MOBILE ID.

About the device

The proposed "Light Powered Mobile ID" is in shape of a credit card which houses its own solar panel which will energize its functions and also charge the internal battery. Once a SIM card inserted to the MOBILE ID, It will receive messages. With the message delivery, the MOBILE ID will do the retransmission to a suitable communication device within the desired range, such as mobile phone, laptop, pocket pc, etc.. The battery and the solar panel are capable of activating the device without depending on the time. The battery consists of overcharge protector. Mobile ID also consists with manual/ automatic selector, a push button and a LED indicator.

Incoming messages will be indicated by a LED and the retransmission can be done manually or automatically. In the manual mode the device will store the message temporarily and as per the user requirements the message will be transmitted wirelessly to the desired device once a push button is pressed. With the push button the device detector will activate and it will connect with the nearest mobile device. Then transmitter will transmit the message wirelessly to the connected device. In the automatic mode the device will automatically select all the suitable receivers and will transmit the message. So with the delivery of a message device detector will automatically activate and connect with all the mobile devices within the pre specified range and then transmit the message wirelessly through the transmitter. And once the message had transmitted, Mobile ID will automatically discard the message from its internal memory.

Since this Mobile ID has its own power source the user would not have to pay any consideration on the device's battery level. It will not be fitted with a screen to reduce power usage but for the indication purposes, a LED light system will be used. So this will reduce the power consumption of the Mobile ID.

For the prototype we used an arduino uno, 12 cm x 12 cm solar panel, lithium polymer battery, arduino Bluetooth module, 1 LED, Push button and two way switch to demonstrate the MOBILE ID. As proposed the prototype is designed to transmit the received message wirelessly either automatically or manually. Bluetooth class two was used to reduce the power consumption [1]. Due to the technical difficulties in using a GSM module in the country we have bypassed the module and have sent the message directly to the arduino. The prototype consumes around 80 mW for its operation and it's still under further development.

Device operation

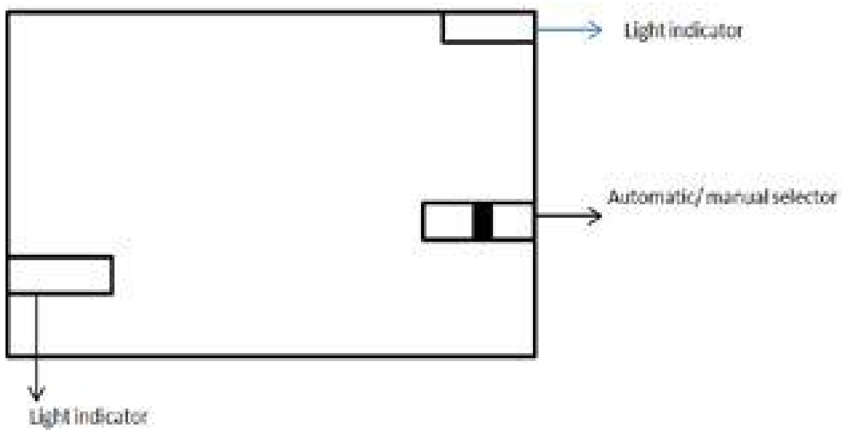

Figure 1: The front elevation of the proposed MOBILE ID.

Figure 2: The back view of the MOBILE ID.

Once the Mobile ID receives a SMS it will indicate it by the light indicator. Then the user has two options. First if he selected the automatic mode in the automatic manual selector the Mobile ID will automatically detect and connect with all the available devices in a pre – specified range, and retransmit the message to all. If the user selected the manual mode, the message can be send at any time user requires by using push button.
Whole back cover is consisted of a solar panel.

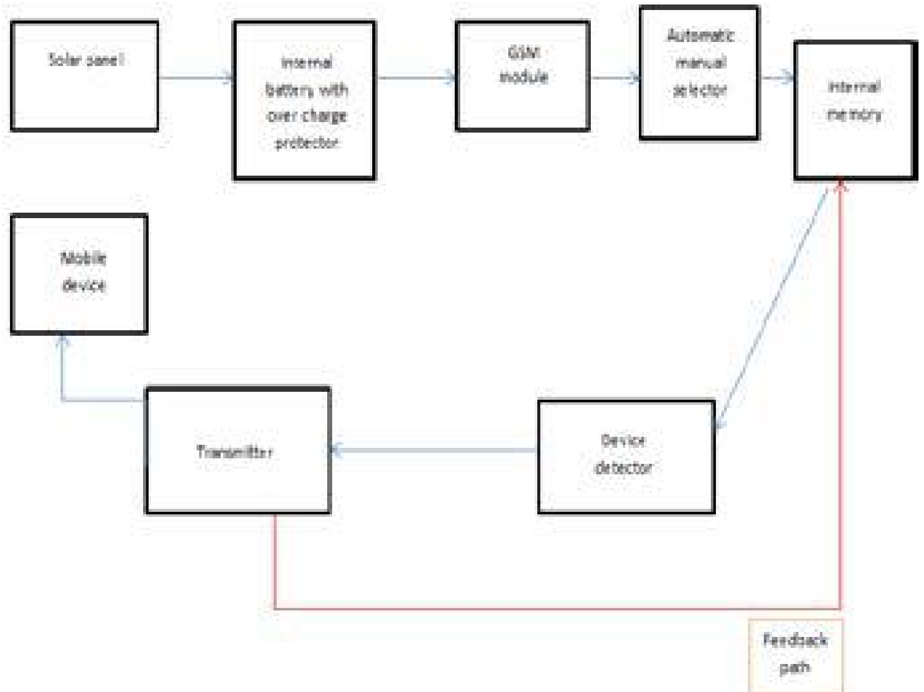

Figure3: The block diagram of the proposed MOBILE ID.

Solar panel charges the internal battery. Then the battery will energize the GSM module and activate the SIM card. Then the Mobile ID is capable of receiving messages. After that the user can re-transmit the received messages by either selecting manual mode or automatic mode using manual/ automatic selector. In the case of manual re-transmitting user can transmit the message by using push button whereas Mobile ID can store the message in its internal memory. The device detector is capable of detecting nearest device and transmitter transmits the message to that selected device. In the case of automatic re-transmitting, device detector will automatically activate and connect with all the available devices within a pre-specified range, and then the transmitter will re-transmit the message to all that devices. The feedback path will ensure that the message has transmitted successfully and then the transmitted message will be deleted from the internal memory.

Conclusion

The proposed “Light Powered Mobile ID” is a device to overcome the difficulties caused by a power failure up to some extent. Mobile ID will activate the SIM card when phone is dead and the user will be able to receive and retransmit the message to a nearby communication device so that the user will be able to receive the urgent messages without failure due to power difficulties. Through the MOBILE ID, we can send messages to any unknown device which is nearby. We can place the ID in a place where we can monitor through cameras or any other method. Then by sending messages to Mobile ID we can send messages to any person’s personal mobile phone who can observe through the camera without knowing its mobile identity (number). And have the ability to send a message of instructions, directions and advising to the any observed person. If we place the Mobile ID in a commercial complex or even a public vehicle (i.e. bus), we can send any kind of commercial instructions, directions and even bills directly to the customers’ personnel mobile phone with minimum cost.

Mobile ID is also capable of transmitting the same message to a number of devices simultaneously and this feature will be much effective in awareness programs, emergency situations etc. where the user may not know the mobile numbers of each and every person around.

In future we can place wireless readers which can connect with the Mobile ID in working complexes and send messages to workers through Mobile IDs, in very much accurate manner. It will increase the working efficiency of the workers by limiting the mobile usage and will save an additional cost for the internal communication. And also the management can have a confidence that workers will get the message without failure. We can use the same method in Universities, Libraries and public places etc..

In future, we hope to implement the Mobile ID with the capability to transmit full duplex connection to a suitable device nearby such as wireless hands free. And also we hope to implement the Mobile ID internally to the mobile

phone. Since the Mobile ID is internally fixed to the mobile phone, as soon as the phone turns off, Mobile ID will automatically activate and start its functions. This will enable the user to have the continuous mobile connection in very much accurate manner. And also in this method we can use the same solar panel to charge the mobile device battery when MOBILE IDs battery is fully charged.

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A Case Study on Near Shore Wave Energy Utilization in the Coastal Regions of Sri Lanka

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Abstract

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies. Hydro power, solar and wind are the main renewable energy sources currently used in Sri Lanka but the sea waves have a big potential to become a good source of renewable energy which is relatively inexpensive, reliable and environmentally friendly. This paper considers using the near sea waves for generating electricity in Sri Lanka. Our literature study shows that there are at least 14 coastal regions in Sri Lanka, which may provide a considerable amount of electrical power. There are several methods used for sea wave energy conversion. However, this case study is about concentrating very wide sea wave fronts into a tunnel which somewhat stabilizes the water flow and increases the rate of flow. Afterwards, a suitable rotor assembly converts both the kinetic and the potential energy of waves into mechanical energy. Then, a generator driven by this mechanical energy generates electrical energy. The advantage of this method is that it enables to utilize the wave energy over a 100's of meters by using a rotor with dimensions in the order of some meters.

Key Words: Wave energy, Kinetic wave energy, Potential wave energy, WECs, Wave energy conversion.

Introduction

It is predicted that the world is running out of electrical energy, which is derived from burning fossil fuels and coal. Sri Lanka, in particular, does not produce fossil fuels and is dependent on imports. This will be a problem in the future and needs solutions. There is a high potential for energy efficiency measures, but growth of population and boosting of living standards make it essential to increase the energy production as well. The most suitable solution may be to find new, sustainable and renewable energy sources. A complete and stable dependence on renewable energy sources would bring about economic, social and environmental sustainability to the country. Sri Lanka has been using the renewable energy sources such as hydro energy and wind energy for many years. Although it is possible to increase the efficiency and then the capacity of the existing power plants, there is a practical limit set by the maximum efficiency and the cost efficiency of the corresponding systems and also the available water resources inland. Sri Lanka has not been using sea wave energy as a source of electricity, which can make a major contribution to the energy market in the future. Therefore, this case study is about the utilization of near sea waves for generating electricity in Sri Lanka.

In our preliminary study, we designed a very simple wave energy conversion mechanism which would convert sea wave energy. It is a heave-surge point absorber composed of two distinct elements, a buoy with a rotor and a swinging-arm connected to it, which allows conversion of the energy of sea waves with fluctuating average heights. In addition, this set up has the capability of converting both the travelling wave energy and the potential wave energy of a sea wave to electrical energy.

To facilitate testing, we also designed a wave simulator to simulate waves in the water tunnel in the laboratory. Testing involved measuring the energy and the power of the water waves and the generated electricity, enabling the calculation of the efficiency of the whole electro-mechanical system. By creating waves with different heights and velocities, we found that the conversion efficiencies ranged from 20 to 40 % with respect to the power of the oncoming wave.

A review on wave energy convertors (WECs)

Although, many kinds of wave energy devices are at the research and development stage, only a small range of devices have been tested at large scale, in the oceans. There are a large number of concepts developed for wave energy conversion. Over 1000 wave energy conversion techniques have been patented in Japan, North America, and Europe. Despite the large variation in design, WECs are generally categorized by the location, type and the modes of operation as listed in Table 1 [1], [7], [8], [9] and [10].

Table 1: Classification of wave energy converters

Location	Near shore, Off shore
Type	Attenuator, Point absorber, Terminator
Mode	Submerged pressure differential, Oscillating wave surge converter, Oscillating water column, Overtopping device

Wave energy research is being undertaken in many countries and it is time consuming to evaluate all the progress made therein. However, one of the main driving forces is their environmental benefits compared to the conventional generation. These power plants can be either coastal structures or are of floating type and make use of either the kinetic energy of waves or the differences in temperature at varying depths. Most importantly, they do not pollute the environment as they are found in the near shore and offshore areas. They do not make any disturbance to the public by means of noise or by using the space.

Among other researchers who have been involved in doing research in this area, Gunawardane [2] has studied on "Pendulor type wave energy devices for utilizing ocean wave energy in Sri Lanka" and described the use of a flap to harvest energy from the ocean waves. He has shown that the model has 40% efficency in converting energy. In addition, [7], [8] and [9] describe more research relevant to ocean wave energy conversion.

Sea wave conditions in coastal Sri Lanka

In this case study we have practically found out that the energy from the sea waves can be converted in to electrical energy with an efficiency of about 20 to 40%. As Sri Lanka is an Island surrounded by the Indian Ocean, powerful sea waves are available along the coastal line, as shown in Fig. 1, [3]. Especially, recent researches show that there are 14 such potential sites in Sri Lanka. In addition, sea waves are enhanced by the south-west monsoon, which is the stronger of the two and covers the western coast, and the north-east monsoon, which covers the northern and eastern coast. Apart from that the coastal tip on the southern belt is influenced by both the monsoons. Therefore, the wave energy is more or less available throughout the year.

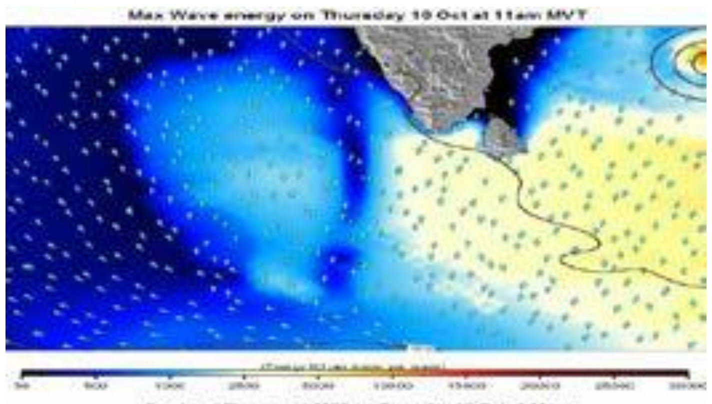

Figure. 1: Wave energy map of Sri Lanka [3]

In addition, the southern and the western areas have higher wave energy in the ocean. Therefore, harvesting of sea wave energy will be a good step toward sustainable energy generation in Sri Lanka reducing the dependency on importations and inland waters.

Estimation of the wave energy, power and the rate of flow

Energy of the sea waves has been estimated by many other researchers. For example, in [4], water waves are considered to travel along the surface of the sea with an approximate sinusoidal profile. They can be characterized in terms of the distance between successive crests (the wavelength, *λ*) and the time between those crests (the period, *T*). In deep water these parameters are related as follows,

$$\lambda = \frac{gT^2}{2\pi} \qquad \text{Eq. 1}$$

Where,

g = acceleration due to gravity.

In this way, the velocity of the waves, *C*, is given by,

$$C = \frac{\lambda}{T} \qquad \text{Eq. 2}$$

Hence, longer waves travel faster than shorter ones. This effect is seen in hurricane areas, where long waves generally travel faster than the storm which generates them. Therefore, the arrival of the hurricane is often preceded by the heavy surf on the coast.

The power (*P*) in such waves can also be expressed by these parameters and the wave height, *H*, as

$$P = \frac{\rho g^2 TH^2}{32\pi} \qquad \text{Eq. 3}$$

Where,

ρ = Density of sea water

P = Per unit width of the wave.

Most of the energy within a wave is contained near the surface and falls off sharply with the depth. Therefore, most wave energy devices are designed to float (or in the case of bottom standing devices, to be in shallow water) and pierce the water surface in order to maximize the energy capture.

Momentum of the travelling waves

The cross section of a sea wave is most likely to have the shape of a raised-cosine function, a triangle or a similar function as mentioned in Section 2.1. Because the shapes can change from time to time in practice, any estimation procedure would result in approximate quantities in the long run. Therefore, the following estimations are supposed only to provide some guidance in the design procedure.

Energy of a triangular wave front travelling at a velocity of *v* m/s with a momentum of *mv* may be given by,

$$E_1 = 0.5mv^2 \qquad \text{Eq. 4}$$

Where,

m = the mass of the water in kg in the section of the wave being considered.

In this case, the wave is assumed to travel independently from the rest. Then, for the wave dimensions illustrated in Fig. 2,

$$E_1 = 0.5(0.5bhw\rho)v^2 = 0.25\rho bhwv^2 \qquad \text{Eq. 5}$$

Where,

ρ = The density of water (kg/m^3)

If all the dimensions are in meters, E_1 is in Joules.

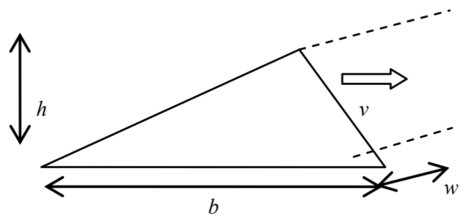

Figure. 2: A single wave front

If there are n wave fronts observed over a long enough time window of T, the total energy is given by nE_1. Therefore, the average power available can be given as

$$P_1 = \frac{nE_1}{T} = \frac{0.25n\rho bhwv^2}{T} \quad \text{Eq. 6}$$

For example, if a certain w = 1 m wide unit wave with a height of h = 1 m and a breadth of b = 1 m travelling at 1 m/s occurs n = once per T = 1 s,

$$P_1 = \frac{0.25(1)(1000kg/m^3)(1m)(1m)(1m)(1m/s)^2}{1}$$
$$= 0.25\,kW \quad \text{Eq. 7}$$

Note that this is the available power per meter of the width (w) of the wave. Therefore, for a given wave to carry higher power, it is necessary to consider a higher width. As an example, the width of the waves must be 200 m, if they are to carry 50 kW. This implies that any electro-mechanical apparatus which utilizes wave energy must have the dimensions in the order of 100's of meters, if they are to be useful. This sets a practical limit to any attempts to utilize wave energy for generating mechanical or electrical power. For this reason, it is required to accumulate wave energy by concentrating them into a smaller area. Fig. 3 shows a structure that could be built in the near sea to funnel, tunnel and diffuse the waves. The funnel section concentrates very wide (w_1) waves into narrow waves (w_2), where w_1>>w_2. The tunnel allows these narrow waves to stabilize, for example, with respect to the direction of the movement, velocity and the frequency. Once the wave power is converted using an appropriate electro-mechanical assembly, the diffuser disperses the remaining power of the waves without flooding the shore considerably.

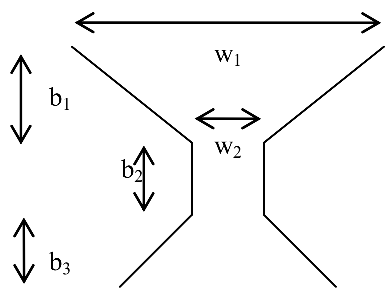

Figure. 3: Funnelling, tunnelling and diffusion

If the w_1 wide wave fronts are funnelled into a filtering tunnel of width w_2, assuming a uniform depth, the flow rate is increased by a factor of approximately $\frac{w_1}{w_2}$. This is an approximation because some portions of the waves are reflected back and forth from the walls resulting in a loss of flow.

The peak rate of flow at the entrance to the structure, at wave peaks, is given in m^3/s by

$$R_1 = hw_1v \quad \text{Eq. 8}$$

Then the peak flow rate in the tunnel becomes, approximately,

$$R_2 = hw_1v\left(\frac{w_1}{w_2}\right) \quad \text{Eq. 9}$$

assuming a uniform depth. If the depth decreases towards the tunnel, this rate should further increase.

In this way, energy of a very wide wave front can be accumulated into a tunnel with dimensions suitable for an appropriate mechanical rotor. However, some proportion of the energy, L, of the original waves is lost due to reflections and the resulting turbulences over the time of T.

Therefore, using Eq.6, the available power in the tunnel is increased to

$$P_2 = \frac{0.25n\rho bhw_1v^2}{T} - \frac{L}{T} \quad \text{Eq. 10}$$

compared to just $\frac{0.25n\rho bhw_2v^2}{T}$ of a w_2 meter wide wave front. If the funnel entrance is 200 m wide, waves described in the previous example would result in a power of

$$P_2 = (200m)(0.25kW/m) = 50\,kW$$

neglecting the losses.

This power would be available in the tunnel if the dimensions of the structure (w_2, b_1, b_2 and b_3), for a given w_1, are such that the turbulences are optimal and L is small. Allowing a loss in the order of some 20% by using a certain optimized structure for w_1 = 200 m, approximately 40 kW can be made available in the tunnel.

The peak flow rate in the tunnel increases as given in (9). This provides a fundamental parameter for designing the tunnel and the rotor. If for example, w_2=10 m, the peak flow rate inside the tunnel would be

$$R_2 = (1m)(200m)(1m/s)\frac{200}{10} = 4000\,m^3/s$$

Note that this peak flow rate occurs only momentarily.

However, the possible generated electrical power could be readily estimated by using the average flow rate. This average flow rate could be mapped to the parameters of the suitable generator by using empirical data.

Because a volume of $0.5bhw_1$ enters the structure n times in T s, the average flow rate is

$$R_{1,ave} = \frac{0.5nbhw_1}{T} \quad \text{Eq. 11}$$

neglecting the losses.

Then, the average flow rate in the tunnel is approximately

$$R_{2,ave} = \frac{0.5nbhw_1^2}{Tw_2} \quad \text{Eq. 12}$$

which is $\frac{0.5(1)(1m)(1m)(200m)^2}{(1s)(10m)} = 2000\,m^3/s$ for the same example.

It should be noted that when the wave velocity increases by a factor of k, the available power increases by k^2. For example, if v = 4 m/s, the available power would be 4 kW/m, almost reaching 1 MW using a 200 m wide funnel.

According to normal observations, it is the case that there is a column of water underneath the waves, which also travels towards the shore, as illustrated in Fig. 4. Near the wave, this water column is likely to have a velocity similar to that of the wave but at a certain depth the velocity diminishes to zero. However, the velocity profile is really unknown and is a function of the wave velocity, wave mass, tides and currents. It is however possible to estimate the power of this travelling water column by assuming a linear velocity profile. In this case, the velocity vary from v to zero linearly as

$$\frac{v}{d} = \frac{v_x}{x} \quad \text{Eq. 13}$$

Where,

D =The total depth of the water column which moves

v_x = The velocity of an infinitesimally small sheet of water (dx) at a depth of (d-x), $x \le d$.

The available energy of the small section of the water can be given by

$$dE_1' = 0.5(\rho bwdx)v_x^2 \quad \text{Eq. 14}$$

Where,

w = width

b = breadth

Noting that the breadth of the sheet of water $b = v_x T$ and substituting for v_x,

$$dE_1' = 0.5\rho wT\left(\frac{vx}{d}\right)^3 dx \quad \text{Eq. 15}$$

Therefore, the total energy of the whole column of water is

$$E_1' = \int_{x=0}^{x=d} dE_1' = 0.125\rho wTdv^3 \quad \text{Eq. 16}$$

and the average power available is

$$P_1' = 0.125\rho wdv^3 \quad \text{Eq. 17}$$

For example, if the flow exists up to a depth of a meter below surface where the velocity is 1 m/s, the available power per meter of width is

$$P_1' = 0.125(1000kg/m^3)(1m)(1m)(1m/s)^3 = 0.125kW$$

This implies that a 200 m wide funnel would make another 25 kW available in the tunnel, in addition. Considering the third power relationship in (17), this increases to 1.6 MW if the velocity increases to 4 m/s. Note that these values result if the losses in the structure are negligible. Again, allowing an energy loss of 20% in the structure, these figures reduce to 20 kW and 1.28 MW respectively.

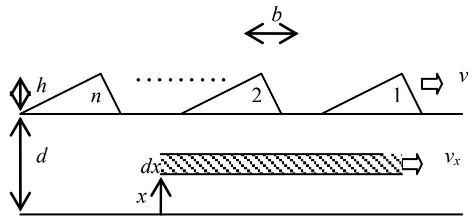

Figure. 4: Travelling water column underneath waves

About a few hundred meters away from the shore, it can be observed that the waves with a certain height, which are caused by the winds, travel towards the shore. Together with them a water column of a certain depth, below the level of waves, also travels towards the shore. As the sea floor gets shallower, the travelling column of water gradually starts impinging on it. The resulting disturbance increases the size of the waves, the height and the breadth. Therefore, in calculating the flow rate in the tunnel section, it is essential to consider this natural funnelling effect caused by the change in the depth of the sea floor. Although, there can be a few other parameters which influence the energy, power and flow rate derived and estimated in this section, the purpose here is to consider the main form of sea waves. These results should provide some guidance for further study.

Fig. 5 illustrates the total available power estimated considering both the waves and the flowing column of water underneath using (6) and (17). It includes the power for the eight different sea wave conditions given in Table 2. These estimations allow a possible loss of 20% due to the reflections and turbulences in a funnelling structure of w_1 = 200 m and w_2 = 10 m.

Table 2: Wave parameters in Fig. 5

	1	2	3	4	5	6	7	8
h **(m)**	1	2	2	3	4	4	4	4
b **(m)**	1	2	2	3	4	4	6	8
v **(m/s)**	2	4	4	6	6	8	10	12
d **(m)**	2	2	3	3	3	3	4	4

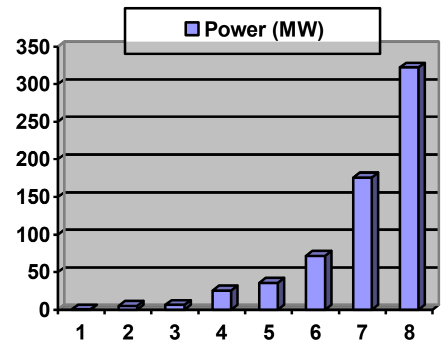

Figure. 5: Total available power with funnelling

According to Fig. 4, a vast amount of power, in the order of hundreds of megawatts, could be made available by using a funnelling structure which brings the dimensions of a mechanical system into practical limits. However, the efficiencies of the electro-mechanical system determine the amount of electrical power generated.

It should be noted that the triangular cross section closely approximate the shape of a real sea wave. The difference is that the falling edge is shorter than the rising edge and both the edges are somewhat curvier with a smoother crest. This implies that the cross section, volume and then the mass of a given wave can differ from those of the real one only by a small margin. In addition, considering the wide range of wave parameters used for the calculations, as given in Table 2, the estimates of the available power may well be within the actual range despite the approximations.

Main objectives of the case study

The aim of this case study is to determine the feasibility of utilizing the energy of near shore sea waves. The four main areas or approaches considered in this study are developing theoretical models, taking measurements of sea waves, using computer simulations and setting up a scale model.

It is necessary to improve the accuracy of the theoretical estimations described in Section 2.2. Any future work should include more parameters such as the gradient of the sea floor, reflections and turbulences together with a better model of the waves and the resulting flow of water. In addition, the study should include the limiting parameters such as the amount of coastal flooding, efficiency of the diffuser and the conversion efficiencies of the electro-mechanical system.

The measurements of real wave conditions in the near sea facilitate accurate theoretical estimations. The values of the wave parameters listed in Table 2 are only expected values. Therefore, it is necessary to search for and establish appropriate measurement techniques to measure the most important parameters such as the wave dimensions and shapes, velocities, depths of the travelling water columns and the slope of the sea floor.

Thirdly, a suitable computer software package could be used to simulate the travelling sea waves and also the funnelling structure. Such a simulation would provide estimations of the energy, power, flow rate and also the losses caused by the reflections and turbulences. This is also helpful in optimizing the shape and the dimensions of the structure, iteratively.

Fourthly, it is possible to assemble a scale model of the total system in the laboratory. In this case, it is necessary to synthesize sea waves in a certain water pool, build a funnelling structure of appropriate size, set up a rotor and a generator with suitable ratings. This kind of a study is expected to provide the quantities of interest with a higher accuracy. These, together with theoretical values, then are useful in determining those of a large system. Another advantage of this approach is that it helps understanding the problems associated with the practical implementation of a large usable system in the near sea.

As a first step towards building a scale model, a dc generator coupled to a simple rotor using a belt drive have been tested in the water tunnel in the fluids laboratory in the department of civil engineering, The University of Peradeniya. A separate wave maker powered by a motor has been used to create a range of water waves. Sections 3, 4, 5 and 6 describe the methodology and the results in more detail.

Simple Wave Energy Convertor (WEC)

Our case study involved implementing and testing a scale model of a WEC in the Laboratory water tunnel. For study purposes, before designing a detailed plan of a WEC, a simple model was tested in the laboratory. It had a rotating fan with 6 blades as illustrated in Fig 6 where the blades fitted into a rotating shaft. The shaft was connected to a fixed arm mounted on a stand, using bearings. In this Experimental setup, the fan was directly placed in a 15 m length water tunnel with oncoming wave fronts. In this case the apparatus only utilized kinetic energy of the waves but not the potential energy of the waves. Note that the horizontal movement of the waves and the vertical fluctuation in the water level results in kinetic energy and potential energy, respectively.

Figure. 6: Side view of partially immersed fixed rotating fan

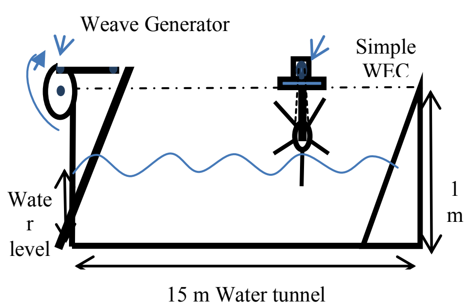

Figure. 7: experimental setup of the fixed arm rotating fan in the water tunnel

The height and the speed of the oncoming wave front were changed by changing the water level in the tunnel and using the aid of the wave generator. At the same time the performance of the WEC was observed. Using these observations, following improvements were made.

Number of blades were increased to increase the probability of contact with the wave front. Straight blades of the first model were replaced by the curved blades. Because of the aero dynamic shape of them [5], [6] they caused less turbulance and resulted in higher rotational speed. Further, it was necessary to use a movable arm which keeps the rotor at the correct vertical position when the wave height and the average water level changes. In addition, if the wave height increases higher than the shaft of the rotor, it stops rotating because the torque applies in both ways. This may also cause damages to the bearings and the lubrication.

This kind of a flexible mechanism is particularly required when considering the real sea waves with fluctuating wave heights and water levels.

WEC with a floating buoy

To address the improvements discussed in section 3, a new WEC was designed, which included a buoy and a moveable arm. As Fig. 8 shows the rotor is kept immersed in the water at the optimum level by the buoy and the movable arm.

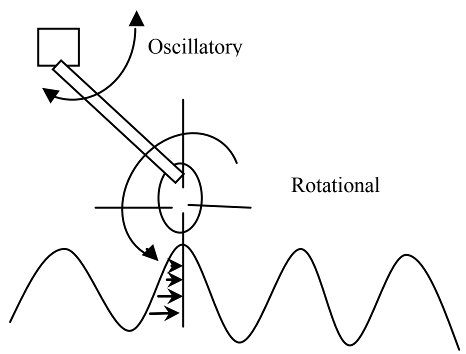

Figure. 8: An improved WEC

Design parameters

The size of the buoy was determined to keep the rotor in an optimum position as follows. The mass, *M*, of the assembly was 2.2 kg. If Styrofoam is used to fabricate the buoy and if half the width of the blades of the rotor is expected to be immersed in the water, then the volume of Styrofoam needed to float the rotor is given by

$$\frac{M}{\rho - x} \qquad \text{Eq. 18}$$

Where,

X = The density of the Styrofoam (kg/m^3)

ρ = The density of water (kg/m^3)

Design parameters of the rotor and the movable arm were mostly determined by the size of the experimental water tunnel. The corresponding drawings of these components are illustrated in Fig. 9, 10 and 11. Some important parameters are listed in Table 3.

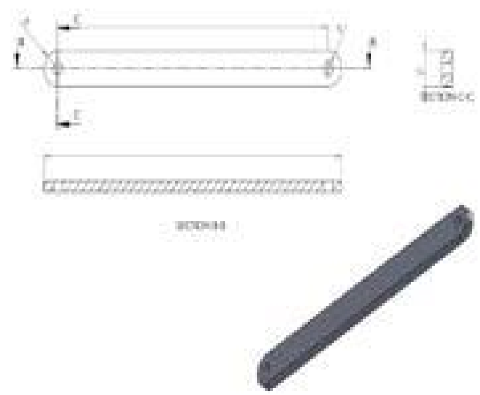

Figure. 9: Arm

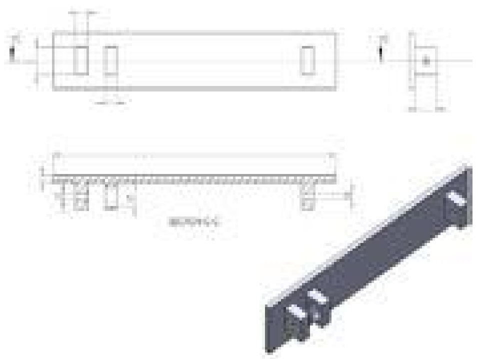

Figure. 10: Stand

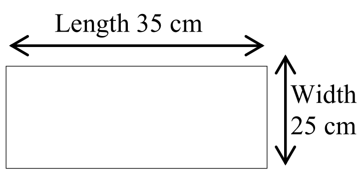

Figure. 11: Blade

Table 3: Important design parameters and dimensions

Design parameters	dimension
Length of the blades	35 cm
Width of the blades	25 cm
Length of the arm	50 cm

Using potential energy as well as kinetic energy of the water waves

The newly designed WEC enables us to use the potential Energy as well as kinetic energy of the water waves. The rotor converts the kinetic energy of the oncoming waves in the horizontal (*x*) direction. Because the buoy makes reciprocal motion in the vertical (y) direction with wave crests and troughs, a hydraulic pump or a linear generator connected to the arm could convert the corresponding potential energy.

Addition of a flywheel to the rotor

The rotational frequency of the rotor depends on the period, speed and the energy of the wave fronts that impinges on the blades. But the sea waves are not periodical and uniform causing a fluctuation in rotational frequency. The addition of a flywheel regulates the rotor speed by storing the peak energy and releasing it when there is no energy at wave troughs. The parameters of the flywheel were approximately calculated.

Energy transfer

The extracted energy using the rotor should be transferred to the generator in order to be converted into electrical energy. As shown in Fig. 12, either a gear drive or a belt drive can be used for this purpose. In our model, the belt drive has been used because of its simplicity. The trade off with the belt drive is that the power loss due to the slip.

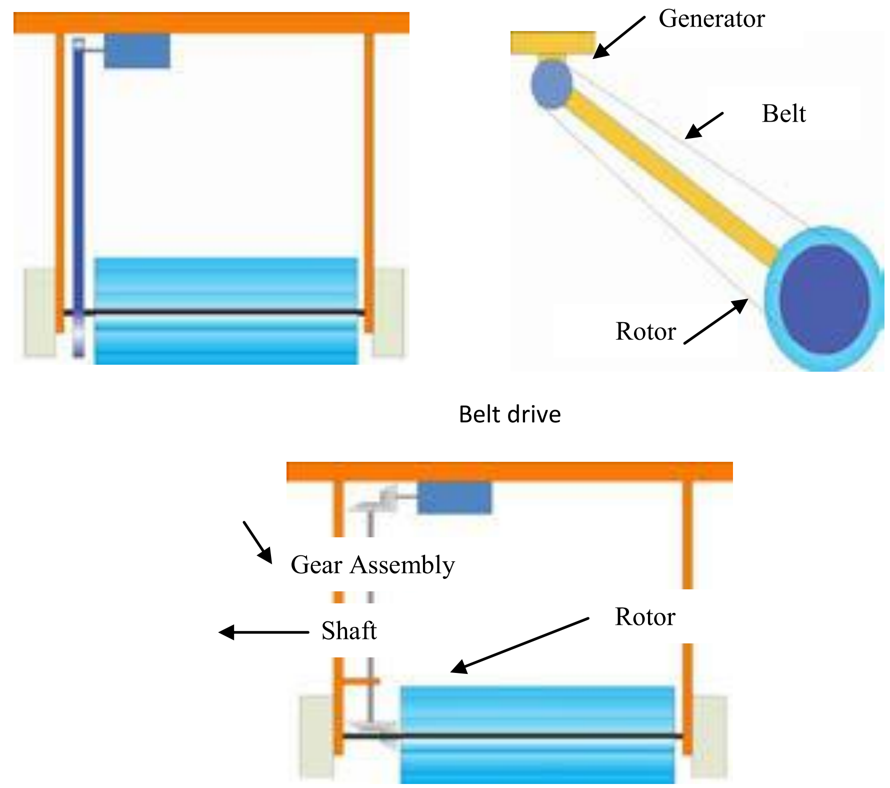

Figure. 12: Energy transfer techniques

Merits of the newly designed WEC

The improved WEC was constructed in the workshop of the Faculty of engineering, The University of Peradeniya. We tested the improved model and observed better performance. As expected, when the wave front impinges on the fan blades the fan started to rotate by changing its vertical position according to the wave. The speed of rotation increased considerably compared to that of the simple WEC. It adjusted itself also to the changes in the average water level and kept rotating. Therefore, this model we designed has the ability to work in different sea wave conditions. The photograph in Fig. 13 illustrates this WEC in the water tunnel.

Figure. 13: WEC with floating buoy

Converting mechanical energy to electrical energy

Generator

In this WEC, a permanent magnet DC motor was used as the generator because they are widely available, and reliable. By nature of their construction, they start generating electricity at almost any RPM (revolutions per minute). The same cannot be said of some other types of motors.

Table 4: Motor (Generator) parameters

Rated input voltage of the motor	12 V
Speed of the motor	200 rpm
Ampere rating	5 A
Efficient of the motor	70 %

According to the parameters listed in Table 4, the ratio of the voltage to RPM is $\frac{12}{200} = 0.06$ V/rpm. The volts-to-RPM ratio of a permanent magnet motor is defined as the voltage required to spin the motor at a given RPM. This is one of the most important specifications to check when selecting a motor. For our case study, the motor (used as the generator) is to charge a battery. This requires that it should generate at least the rated voltage. If it does not, then it can not overcome the impedance of the battery resulting in no charging.

For example, in order to charge a 6 volt battery we should generate at least 6 V. By considering the efficiency of the motor, the internal voltage to be generated is about 7.5 V. To generate that voltage, the required rpm of the generator is $\frac{7.5}{0.06} = 125$ rpm. The speed of the rotor depends on the velocity and the period of the wave fronts that impinge on the blades. Therefore, a suitable gear assembly was required to increase the speed to 125 rpm.

The ratio of the gear assembly was calculated as follows. The average wave period and the average speed of the rotor were measured to be approximately 1 s and 30 rpm. Therefore, in order to increase this speed to the required 125 rpm, the gear ratio should be (125/30) = 4. The gear ratio of the assembly is one of the important factors affecting the efficiency of the model and care was taken to keep the ratio exactly.

The ampere rating of the motor provides information regarding the peak current drawn from the generator. This helps determining the maximum load impedance.

Optimum load for the maximum power transfer

To obtain the maximum power from the generator optimum load was used in the experiment. The maximum power transfer theorem states that, to obtain maximum external power from a source with finite internal impedance, the load impedance must be equal to the conjugate of that. Therefore, first the generator parameters were measured experimentally. The resistance, inductance and the capacitance were 1.5 Ω, 0.47 mH and 0.23 µF respectively. However, the frequency of the generated voltage was found to be very small and we used a resistive load for the experiment neglecting the effect of the small capacitance.

Measurement set up in the fluid laboratory, water tunnel

The apparatus was tested in the 15 m water tunnel in the fluid laboratory by changing the wave parameters, such as the velocity, height, breadth and the frequency, as shown in Fig. 13 and 14. The height and wave length of the waves were measured using the scale on the water tunnel. The speed and the period of the water waves were measured using standard techniques. A given measurement was taken several times for each change and the average of the readings was used in the calculations to avoid the measurement errors.

Figure. 14: Testing in the Fluid lab water tunnel

Calculation of the wave power

Using the measurements explained in section 5.3, wave power was calculated using the wave energy equations given in Sections 2.1 and 2.2. For a given wave with a height of 0.011 m and a period of 1.111 s, using (3), the available power of the wave per unit width is

$(1000 \times 9.8^2 \times 1.111 \times 0.0111^2)/(32 \times \pi) = 130$ mW

Where the density of the water is 1000 kg/m^3 and the gravitational acceleration is 9.8 ms^{-2}. However, considering a 0.35 m wave front, the available power is

$130 \times 0.35 = 44.95$ mW. Here, the width of 0.35 m corresponds to the length of the rotor.

For the same set of measurements, by using (5), available power in a 0.35 m wide wave front is

$0.25 \times 1000 \times 0.15 \times 0.011 \times 0.35 \times 0.35^2 = 17.68$ mW,

Without considering the moment of water underneath the wave. This discrepancy is expected as the waves are described differently in the two cases.

Calculation of the converted power

For the purpose of the calculation of the converted power we connected a load across the generator and measured the voltage across the terminals and the current through the load. For example, when the voltage output is 5.7 V and the current through the load is 1.74 mA, the converted power is 5.7×1.74 = 9.918 mW.

Results

Table 5 lists the wave parameters and the corresponding converted power. According to these results, the apparatus has efficiency in the range of 30%. Fig. 15, in addition, illustrates the wave power, converted power and the conversion efficiency in a graph.

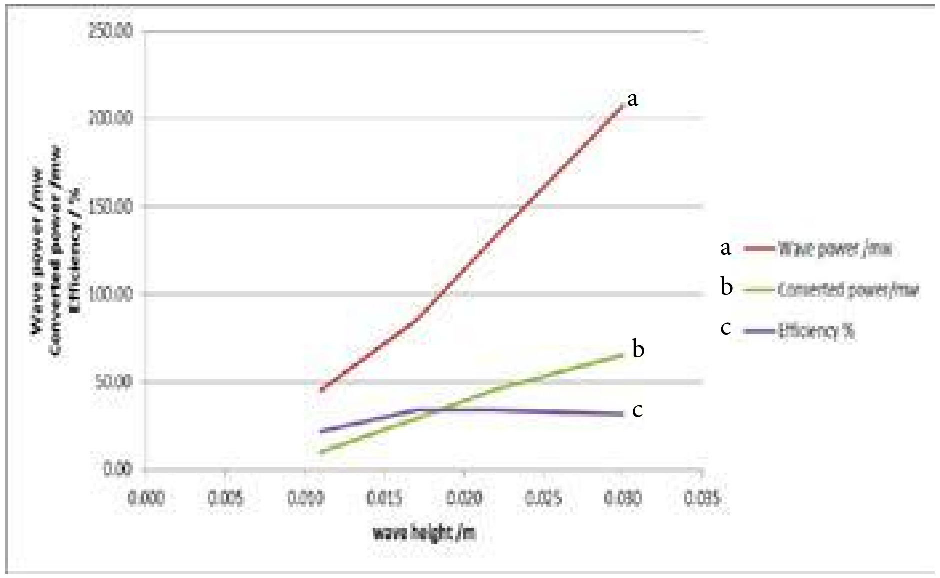

Figure. 15: Actual and converted power of waves

Table 5 Wave energy and converted electrical energy

Wave height/m	Wave period T/sec	Wave power /mW	Converted power /mW	Efficiency %
0.011	1.111	44.95	9.926	22.080
0.017	0.882	85.27	29.183	34.225
0.022	0.822	133.01	45.595	34.279
0.030	0.690	207.52	65.654	31.637

Future Directions

WEC with the piston assembly

Section 4.1.1 mentions that the potential energy as well as the kinetic Energy should be utilized. Fig. 16 shows a proposed design of a fully developed WEC where a hydraulic pump or a linear generator connected to the movable arm converts the potential energy of the waves. Note that a vast majority of WECs at the prototype or later stage, use either pneumatic or hydraulic power take-off systems presently [7], [8] and [9]. This eliminates the need for an interface between the wave energy device and an electrical generator, thereby reducing complexity and increasing the overall reliability.

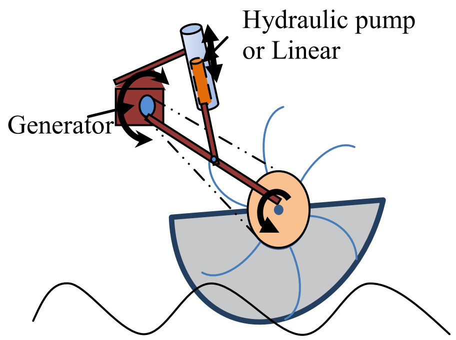

Figure. 16: Using both kinetic and potential wave energy

One of the next steps of our case study is to consider both linear machine topologies and piston/cylinder devices for conversion of potential energy.

Conclusions

Although, the research and development on the topic of the utilization of sea wave energy for power generation has been underway in developed countries, there is no real urge for implementing large scale systems because they have other energy sources such as fossil fuels, inland hydro and nuclear in abundance. On the other hand, Sri Lanka is dependent on expensive fossil fuel imports and unreliable supply of heady waters in the up-country and therefore is in real need for conversion of sea wave energy, which is available in most coastal areas.

The available power of 100's of meters wide wave fronts may amounts to 100's of MWs. To utilize this power, a coastal structure which funnels, tunnels and diffuses such wide waves needs to be constructed.

A case study on an electro-mechanical assembly which converts wave energy into electrical energy shows that the conversion efficiency however ranges from only 20% to 40%. An apparatus which could convert both the kinetic energy and the potential energy of the travelling waves has been proposed, which could improve this efficiency.

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Fossil Fuel & Sustainable Development

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Abstract

Discovery of fossil fuel has increased the rate of satisfying human needs at a rapid rate and also the varieties of human needs. This discovery has focused only on physical dimension of the development to fulfill the desires of five physical organs of human. This oil burning development has created chaotic problems to the world. Fossil fuel depletion, environmental pollution, natural disasters and socio economic unevenness have become the most challengeable problems to be faced by present world. It takes a million years to the formation phase of fossil fuels, but unfortunately the severe exploitation makes it last for only centuries, making it diminished from the world in the near future. The development of fossil fuel technologies has made the renewable power resource to be redundant as well. At the same time it exceeds the rate of formation of resources like water and trees. Final result would be a world of depleted resources and accumulated waste. Modern technology has a narrow perspective when it is applied to this problem. It provides solutions for only limited aspects of the problem like increasing the efficiency of an engine. But we are in a turning point to find a holistic solution for this problem, i.e. to apply the theory of natural cyclicity. Cyclicity is to adopt the cyclic behavior in the nature to the development. This paper aims on discussing the adoption of cyclicity concept in a holistic manner including energy to achieve sustainability.

Keywords: Development, fossil fuel, source, cyclicity, energy, sustainability

Introduction

Humans are in a process of satisfying their needs from the day of their birth on earth. Different cultures and attitudes have been developed within different parts of the world. It is this difference of attitudes which made the Asians to have more control over their desires than the Westerners who are in a process of acquiring their desires which is named as development. Recovery of fossil fuels accelerated the speed of satisfying the desires [1]. Different pathways were opened to please the desires of humankind.

Non-recyclable and recyclable material have been converted to products or used to support in the process of making a product i.e. homes, transport, aircrafts, weapons, clothing, machines, and communication. Even recyclable materials like biological matter have been consumed at an accelerated rate where the speed of consumption has exceeded their natural rate of recovery. Even the degradable biological matter has been used at a dramatic rate to produce massive amount of biological waste.

Existence of Sun, moon and earth or the whole planetary system is governed by the law of nature, where the law of nature is cyclicity. The humankind expects a permanent nature to their lives as well as the products they use. Hence we are against the law of the nature. Our creations or the products that we use tend to become of everlasting nature.

All these processes while satisfying the existence and desires of humankind accounts for resource degradation and pollution. We are in a critical stage to find solutions to this problem as it will be a massive challenge for our existence in the earth. Therefore the sustainability has to be redefined and the energy systems have to be redesigned with a new perspective of cyclicity.

What is Energy?

$\frac{1}{2}mv^2$, mgh, VQ, $\frac{1}{2}\sigma\varepsilon$, $\frac{1}{2}kI^2$……. are so called energy terms related to various physical systems such as kinetic, gravity field, electric fields, bodies under stress, magnetic fields etc (In these terms m is mass, v is velocity, g is gravitational acceleration, V is potential difference, Q is charge, σ is stress, ε is strain k is self inductance and I is the current). By using basic laws governing these systems (for e.g.: P=mf, 3rd law, Faraday law, Lorentz force law, etc.) it could be shown that (by mathematically) if effects such as friction, resistive losses, etc. are absent sum of above forms related to a system are constant (so called energy conservation law). Also another energy type is introduced as thermal energy with in which friction, resistance also could be encountered. With this new energy term although the energy conservation law is upgraded, a new concept known as quality of energy also emerged into the energy scenario. Unlike the previously said energy terms, thermal energy is little bit different. Although other energies could be converted totally to heat, conversion of heat into other energy forms is possible only with constrains put on by second law of thermodynamics. This is how the concept (mathematical entity) of energy has evolved. Now for all above said energy conversions $'\underset{\sim}{F}.\underset{\sim}{dr}'$ (Here $\underset{\sim}{F}$ is force and $\underset{\sim}{dr}$ is the displacement of the point of application in the direction of the force) becomes the intermediate link.

As said, above thermal energy is related with the temperature of a body. Also another energy form important in this context is chemical energy. This is said to be stored in molecules. This energy could be released as 'heat' in combustion. The other important energy form is electromagnetic energy (photons). This radiation can be converted in to chemical energy in fuel wood through the process of photosynthesis and also can be converted to heat or electricity in Photovoltaic cells. In fuel cells/batteries chemical energy and electricity are interchanged.

Therefore, it is clear that energy is a secondary concept related to all the above said physical systems (areas). This concept has evolved and has significance as it could be shown that for a complex physical system comprising of above said areas, the sum of terms related to different energy forms is constant.

Quality of Energy

Although the sum of different energy forms in a system is constant, some of the energy forms cannot be fully converted into other different energy forms. Kinetic energy, gravitational energy, electromagnetic energy, can be fully converted into each other and even into heat, where as heat cannot be fully converted into other energy forms. Degree of conversion of heat to other forms of energy for example mechanical energy depends on the temperature of the heat source with the surrounding temperature (for many practical purposes this is atmospheric temperature). According to the 2nd law of thermodynamics degree of conversion (η) of a quantity of heat (Q) at temperature T, if atmospheric temperature is T_r, is given by

$$\eta = \left(1 - \frac{T_r}{T}\right) \qquad \text{Eq. 1}$$

This quantifies the exergy of the heat and for mechanical potential energies value of η is 01.

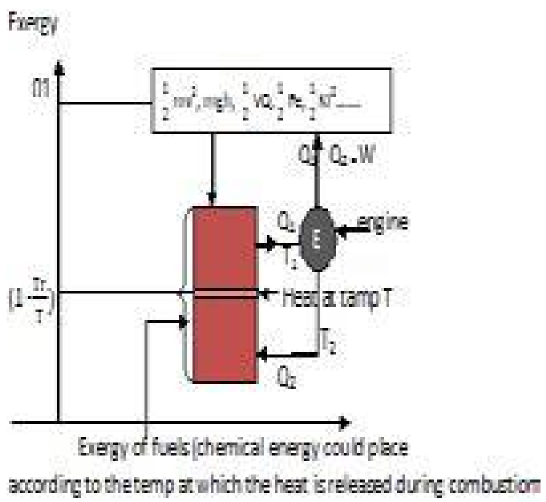

Figure 1: Exergy Concept Applied for a Thermal System

Therefore entity that should be conserved is not the energy but the exergy where as energy is conserved by the nature itself. If energies that has number 01 quality exergy, is converted to heat and if that heat is further converted to low exergy heat (i.e.at low temperature, Tr) no activity can ever be done.

But what would happen if the concept of energy was not developed? Then there would be no energy conservation, no exergy conservation and no energy efficiency. Human would shape up their activities by considering undesirable effects to the whole earth system.

Then conservation of other resources as well as fossil fuel will emerge. This will give a more holistic view which is not confined to "energy". The insight behind this explanation is not that the concept of energy and related concepts are not good but all our activities should not be based on this concept.

Fossil Fuel

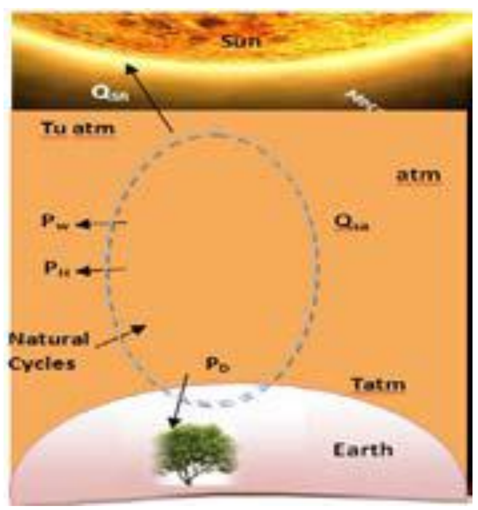

Figure 2: Solar Earth System

Q_{sa} = radiation from sun absorbed at lower atmosphere

Q_{SR} = radiation rejected at higher atmosphere

$T_{u\,atm}$ = Temperature at higher atmosphere

T_{atm} = Temperature at lower atmosphere

P_D = Energy in trees

P_w = wind power

P_H = hydro power

Some of Q_{sa} is converted into P_w (wind power), P_H (hydro power), P_D (Energy in trees). Generally Q_{Sa} and Q_{SR} can be quantified as below.

$$\frac{Q_{SR}}{T_{natm}} > \frac{Q_{Sa}}{T_{atm}} \qquad \text{Eq. 2}$$

Therefore if only natural cycles are considered there is an entropy decrease in the earth i.e. radiation from the sun is absorbed by the trees and converted into chemical energy where in the entropy decreases (Figure 2). This entropy decrease is balanced by the conversion of some of the P_w, P_H and into heat during various processes and by conversion of P_D into heat by burning wood. Then the entropy of the total system remains constant.

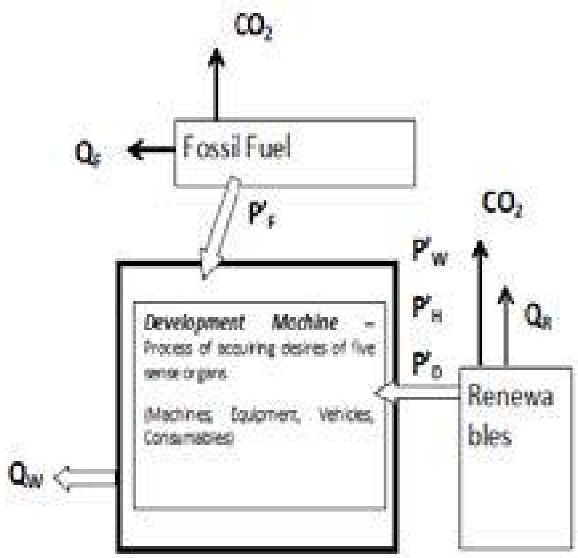

Figure3: Development Model

P'_W = Energy (Exergy) given to the system by wind power
P'_H = Energy (Exergy) given to the system by hydropower
P'_D = Energy (Exergy) given to the system by dendropower
Q_R = Heat rejected to the atmosphere by renewables (Due to2nd Law of thermodynamics & inefficiency)
P'_F = Energy (Exergy) given to the system by fossil fuel
Q_F = Heat rejected to the atmosphere by fossil fuel (Due to2nd Law of thermodynamics & inefficiency)
Q_w = Heat rejected to the atmosphere by Development Machine (Due to2nd Law of thermodynamics & inefficiency)
*Useful energy (Electrical, Mechanical) = Exergy

$$\frac{P'_H + P'_W + P'_D}{P'_H + P'_W + P'_D + P'_F} < 13.1\ \%\ \text{of energy to drive DM}[4] \quad \text{Eq. 3}$$

Figure 3 shows the "Development Machine" (DM) which emerged after the invention of industrialization. "Development machine" (DM) is driven by fossil fuel. Fossil fuel has been stored in the earth for millions of years without affecting the natural systems of earth. Usage of fossil fuel generates heat and CO_2. These two factors increase the disorder of the earth and the entropy balance in the earth has been interrupted severely (Figure 4).

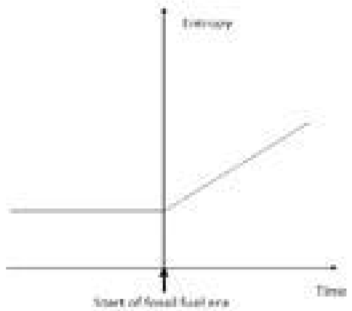

Figure 4: Entropy Variation in the World with Time

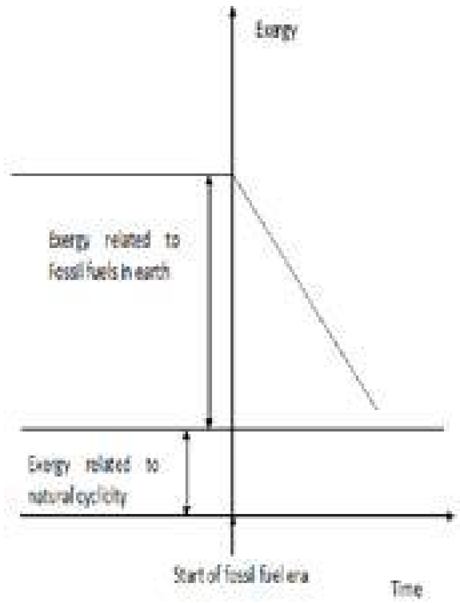

Figure5: Exergy Variation of World with Time

Figure 5 shows the exergy variation in world with time. To drive the DM large quantity of exergy (fossil fuel and renewables) stored in the world is been used. Exergy stored in natural systems remains constant throughout the history due to their cyclic nature. Accelerated usage of fossil fuel has decreased the total exergy in the earth system. Our next step is to extract the exergy in natural systems to drive the DM.

Extraction of energy stored in renewables is questionable. Only about 10 % of the energy requirement for DM is supplied by renewable energy sources where as 90 % of the energy requirement is supplied by fossil fuel (Figure 3). Non availability of technology to capture P_W, P_H, P_D, technology development in this area in future and the reasons for being unable to fulfill the present energy requirement by these massive renewable sources using the existing technology is uncertain.

Figure 6: The Potential of Renewable Energies

(Source-Eurec. Agency. Eurosolar, WIP. Power for the World- A Common Concept)

This gorgeous estimation on quantity of available renewable energy is a theoretical abstract value (Figure 6). There is no other restrictions that these P_W, P_H, P_D cannot be used for the activities of DM (such as 2nd law of thermodynamics). But these P_W, P_H, P_D are closely connected with natural activities of the earth i.e. water cycle, wind cycle and biological activities. If these sources are extracted beyond a limit, all the cycles will be destroyed [1]. Whether the humankind will be able to exist in such a situation with the produced energy is questionable. Therefore the above estimation should be interpreted carefully to prevent one from coming to the conclusion that even without fossil fuel this DM could be driven by renewable energy. The above comparison paints a picture in our mind that depletion of fossil fuel is not a problem to drive the DM further ahead using renewable.

Some critical issues have been covered by the devastation of the driving mechanism of DM which gives us the speed to satisfy our desires, which is fossil. The other major components in the earth's eco system i.e. water, soil, air, bio diversity have degraded by rapid consumption and accumulation of waste. We are neglecting the gruesomeness of our eco system. Eco system is the base of all the living being. We can live without fossil fuel but can we exist without air, water or soil? Natural cyclicity of the earth's eco system has been heavily affected by anthropogenic activities. Quality of the food, water and air is being reduced.

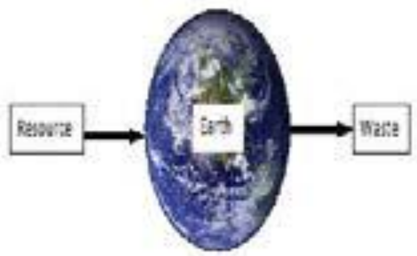

Figure7: Open System Model for Earth

In an open system (Figure 7) we can think of a continuous process of acquiring the desires of our five organs by converting the resources using modern technology and releasing waste out from our earth. But we are in a closed system where the situation is more complex.

In addition to all the above mentioned deficiencies DM has not been able to treat all the living beings in the world equally. Without being impartial the DM has increased the inequality between different parties of the world.

It is clear that the DM cannot further exist without fueled by fossil fuel. The DM has trained the human to neglect the other valuable resources on the earth and has been unable to bring the real development to many people on earth.

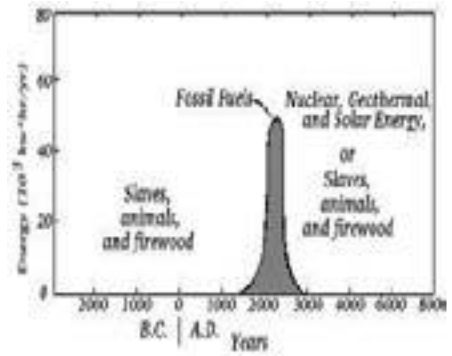

Figure 8: Fossil Fuel Consumption with Time

(Source- http://www.earthsci.org/education/teacher/basicgeol/fossil_fuels/fossil_fuels.html)

The science is based on Induction based on historical data. Within a very short period of time$\left(\frac{\delta T}{T} \ll\right)$ we have faced severe problems (Figure 8). When the theory of science (inductivism) is applied to the present situation, it intrinsically explains that the DM cannot proceed longer.

It is incorrect to predict the future of other systems of the earth i.e. water, soil, biological etc. based on the information related to minute period of time in the history.

Is the retardation of DM is a failure of humankind? The answer is no. Since to achieve the real development and for the benefit of all living beings the only thing which we should do is destroying this DM. This solution is clear when the law of induction is applied to the evolution of the world.

Cyclicity

To achieve the real sustainability the driving rate of DM should be reduced and new dimensions has to be introduced. This is the position where the renewable energy sources can take over. To achieve the objectives of sustainability renewables have to be used within the rules of cyclicity. If the renewables are not used within the rules of cyclicity, it will speed up the same DM. The important terms like energy efficiency, energy saving and exergy saving has less importance within the context of cyclicity. These terms have their value mainly in the context of non cyclic nature of fossil fuel and in modern energy management practices in which the main aim is to manage the fossil fuel. Increase in population who work less and increase in desires started to use resources in earth tremendously increased the pollution (Process of DM). Therefore energy is needed to satisfy these needs and to reinstate natural systems from the anthropogenic effects. Therefore activities of present world i.e. mechanization of agriculture, water pumping and water purification, maintaining indoor climate at comfortable levels, heavy transportation, heavy construction and mechanized manufacturing processes require energy. Acquisition of energy again devastates valuable resources and cause pollution.

If an unlimited source of energy with no bad environmental effects is found suddenly will the problems of pollution and problems of equity be over? The answer is no. We can go **against natural cyclicities** for limited time periods by using non renewable energies such as fossil fuel or extracting renewables beyond the cyclicity limit. But that is not sustainable. Only energy cannot make the existence of lives on earth.

Our plans and policies should be aimed at making our lives sustainable within the natural **Cyclicities of EARTH** then relevant energy will automatically be sustainable! To our minds, If we scientifically (not the science confined to 05 senses) understand the reality, the only thing which we can do is changing the DM! This is the only answer possible (logically) if we use the law of inductivism to the whole situation in the world in the history.

If this situation is neglected "Aswadha" in this DM will be converted to "Adheenawa". At this point it gives us the understanding of helplessness, selflessness of the reality [3].

Conclusion

Today development is based on fossil consumption. Extreme weather conditions due to climate change and increase in fossil fuel prices has drawn the attention of humankind to depletion of fossil fuel and fossil fuel induced climate change. But the problem is more diversified into deterioration of other valuable resources in the earth i.e. water, soil and air. Waste generated by the DM is intensifies pollution. When development is achieved the natural interrelation between human activities and the environment should be preserved to make the development sustainable. Economic benefits should be evaluated within this structure without being depending on the mere desire to please the five organs of human. Renewables extracted beyond the level of their cyclic limits are more disastrous as they are more closely interrelated with natural cycles like water cycle, wind cycle and biological cycles. Renewables used according to the cyclicity concept have the power to control the speed of DM and to correct the function of DM. Therefore cyclicity is an important concept based on controlling our desires which quantifies the real sustainability

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Modelling, Simulation and Optimization of a Distil Water Manufacturing Plant for Manufacturing and Process Industry by Solar Energy as the Energy Source

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Abstract

Distilled Water is widely utilized in different manufacturing process industries and unit operations as a raw material, a catalyst or a reactant. In such requirements, the respective process industries may have to purchase or to produce the required quantity of distilled water. The popular and economic method of distilled water manufacturing for those small scale requirements is the basic distillation plant. This plant mainly includes an evaporator and a heat exchanger or a condenser. The raw water from a water source is evaporated in an evaporator and the water vapor is condensed by sending through a heat exchanger. The condensed output is the distilled water required for other processes. Mostly, steam generated by boilers is used as the energy source for heating the raw water in the evaporator. The main objective of this research is to optimize this distilled water plant for maximum energy efficiency with replacing the energy source as solar energy. The computer simulated results can be validated for actual performance and the solar energy heating requirement is determined according to the optimized model. This optimized model can be utilized by any process industry either to upgrade or to convert their distilled water plants sourced by solar energy.

Keywords: Distilled Water, Manufacturing Processes, Energy Efficiency, Optimized Model, Solar Heating.

Introduction

Natural water usually contains microscopic contaminants, along with dissolved minerals, such as sodium, magnesium, calcium and iron. One method to remove these ingredients from water is by boiling it until it becomes steam or vapor. This process is known as water distillation process. When this boiled steam is allowed to cool down and condense into liquid form again, the result is a purified form of water called distilled water. Distilled water should ideally be nothing but hydrogen and oxygen molecules, with a pH level of 7 and no additional gases, minerals, or contaminants which has no conductivity and no hardness. This distillation process relies on the principle that most solid materials found in water are heavier than the water molecules themselves. When water is heated in an evaporator chamber, any dissolved solids, such as salt, bacteria, calcium, or iron remain solid while the pure water converts into much lighter steam and is drawn out for condensation. Distilled water has a noticeably bland taste because all of the minerals that give water its flavor have been removed. Distilled water can be taken for drinking purpose, but it is used more often for research purposes where water purity is essential or industrial applications where a pure and neutral solvent is mandatory for the product quality and required chemical processes. It may also be used as bottled water as the base diluents for electrolytes in batteries. In consequence of all these applications and requirements, the manufacturing of distilled water is a key requirement in most of the industries and research institutes. In this study, the effort has been made to model and develop a distilled water plant based on a simple and hassle-free distillation process that can be used by any industry or institute to be fit for their small scale distilled water requirements more efficiently and economically. (Sources – Reference [1] and [2])

The Percentage Water Quantity per Use Type

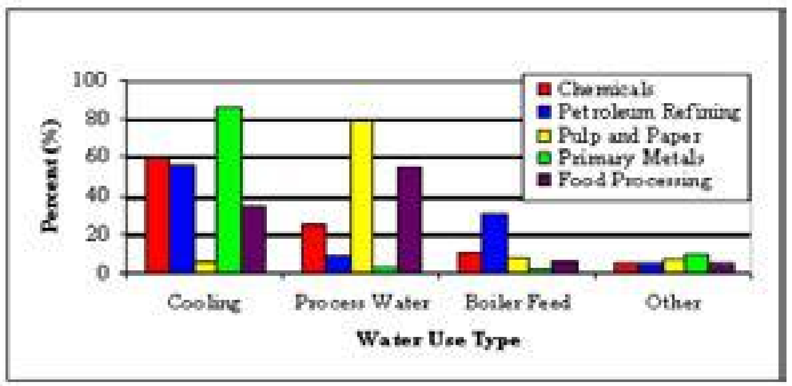

Figure 1: The industrial water consumption in the world (Source – Reference [3])

According to the Figure 1, although the water requirement for food processing does not cater to a large percentage use type of water, it is significant because, the process water in food processing operations should be distilled water in order to maintain the hygienic quality of the process and product. The affiliated literature reveal and emphasize the small scale distill water demand in these types of industries [3], [4]. As well, Lots of other literature sources are available which have been indicated in the References listed at the end of this research paper that can be referred as the guidelines in estimation of small distilled water generation methods for those applications. However, a less amount of research work could be observed on this simple & easy distillation method even though it's ideal for small scale requirements. This distillation method is the single stage distillation process.

Single Stage Water Distillation Process

The main operating principle of single stage distillation method is illustrated in Figure 2. In the single stage distillation system, evaporator tank is fed by raw water from wells, rivers or municipal water supplies through the incoming water pipe. This raw water is then heated by passing hot steam through heating tubes or coil, located in the evaporator tank, until it reaches the boiling temperature. Mainly, the hot stream is boiler generated steam which will pass through heating tubes or coil, condenses and returns back to the boiler while the raw water outside the tubes boils, and thus, evaporates. The water vapor rises and moves towards the condenser tank or heat exchanger. In the condenser tank, the water vapor in the tubes is cooled down by passing cold water through the tubes. Hence, water vapor will turn into pure liquid water as distilled water. Subsequently, this distilled water will be collected and stored in a storage tank. The remaining water inside evaporator is removed continuously during the distillation process or intermittently at the end of each process. The single stage distillation process is considered to be a good choice for water distillation when the compact size of plant is needed. This method is suitable for marine applications, small factories and big laboratories. It is also a suitable choice when the heating steam is abundant and cheap, like in co-generation applications with other electrical power plants or factories.

The flow rate of a single stage distillation process has been evaluated to produce distilled water when temperature and mineral concentrations in raw water are changed [5]. Other related literature reveal that, a single effect system with constant pressure has been utilized to control the operational conditions of the distillation process, under variable evaporation temperature and mineral concentration in the raw water [6], [7]. It has been confirmed by those studies that the production of distilled water depends on temperature and mineral concentration, whose effects are more significant as the temperature rises and mineral concentration lowers. Distilled water production can be increased to 100% by augmenting the raw water temperature, whereas lowering the mineral concentration in raw water by pretreatment can increase it by 33%. Therefore, a research study has a good potential, which is focused on a single stage distillation plant model with heating capacity for raw water is designed to maintain higher temperatures for raw water and the incoming raw water is considered to be pretreated to achieve lesser mineral concentrations.

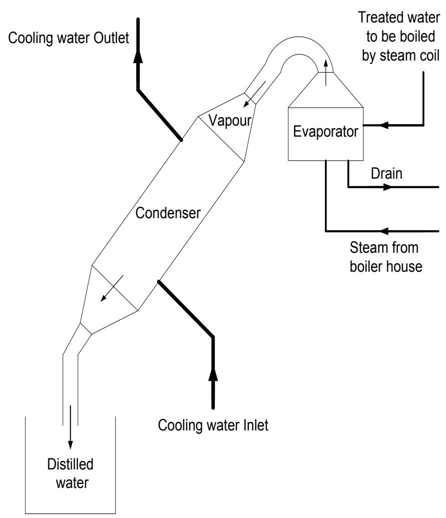

Figure 2: Diagram of a typical single stage water distillation process plant (Source: Reference [4])

When there is a necessity for producing large quantities of distilled water which is not economical by utilizing the single stage distillation process, or steam heating is very expensive, other methods have been developed to recover the heat released from water vapor during vapor condensation process. It would be better to consider the available literature about those methods that will make this study more effective.

These methods utilize nearly same amount of heat to evaporate a larger amount of raw water, increasing water distillation plant efficiency and reducing their running energy costs, that is one objective of this research.

Multiple Effect Distillation

Multiple effect distillation method usually consists of four evaporators, one boiler and one condenser. The water is converted to hot steam in the boiler. This hot steam boils the raw water in the first evaporator. The vapor coming out from the first evaporator is fed as a heating medium for the second evaporator and boils the raw water there. The vapor coming out from the second evaporator, also, boils the raw water in the third evaporator, and so on. Simultaneously, the raw water in the fourth evaporator serves as a cooling medium for the vapor coming from the third evaporator. Again, the raw water at the third evaporator, acts as a cooling medium for the second evaporator vapor and the second evaporator acts as a condenser for the first evaporator vapor. Therefore, a large latent heat of vapor condensation is reused several times before releasing it to the surroundings.

In such a series, each evaporator is called an effect. It is always necessary to keep the first effect at a temperature below the heating steam from boiler. For a good heat flow between the heating vapor and the raw water in each effect, they should be kept at different temperature values which is meant by another way is that the vapor pressure in each effect has to be lower than the vapor pressure in the previous effect and higher than the next effect. Because of this practical difficulty a typical multiple effect distillation process always involve water pumps to restore the distilled water at the ambient pressure and vacuum pumps to maintain pressure values, and to exhaust the non-condensing gases such as oxygen and nitrogen concentrated in such a closed system. Moreover, the vapor stream lines in all effects are connected to a steam ejector coupled with a vacuum pump and these vacuum pumps must keep working continuously or intermittently during the distillation process combined with throttling pressure valves, installed between effects to control effect pressures [4]. Figure 3 illustrates multiple effect distillation process.

The existing literature on multiple effect distillation processes denotes that although it is an efficient method for large distill water requirements, the initial capital cost for this kind of a process is somewhat high and cumbersome in operation due to the attached series of pumps and ejector vacuum system. In consequence of these matters, multiple stage distillation method is boycotted by small and medium scale industries, which makes them to implement conventional single stage distillation with lesser energy efficiency and lesser distilled water yield. There are various other distillation methods utilized for distilled water manufacturing throughout the world. They are multiple stage flash distillation, vapor compression distillation, refrigeration distillation, etc.. All these distillation methods are suitable for large scale applications where high capital cost is worth applying [4].

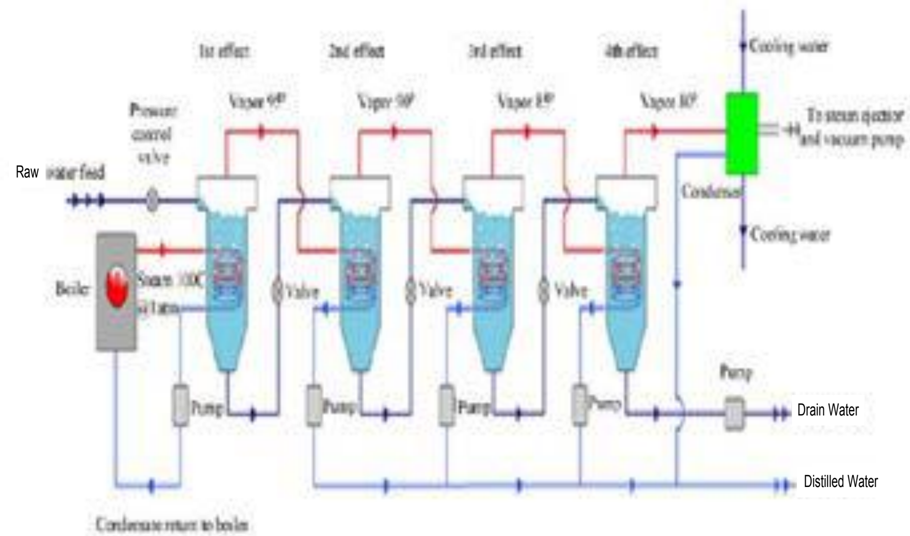

Figure 3: Diagram of multiple effect water distillation process plant (Source: Reference [4])

All these imply the importance of a research work that would seek for a more energy efficient method of distillation which can be applied as the most suitable distill water plant for the small and medium scale industry group, by amalgamating both the single stage distillation method and the multiple effect distillation principle. This is possible when the worst parts of each method are omitted by forming a simple practical model with maximum energy recovery. In this research study, mathematical modeling and steady state simulation will be performed based on this concept [8].

Mathematical Model

The mathematical model related to this study is developed by applying energy recovery concept from the multiple effect distillation method in to the single stage distillation method. This mathematical modeling is based on mass balance, energy balance and vapor-liquid equilibrium equations. This new model differs from the single stage distillation method because of the energy recovery executed for the outgoing cooling water by replacing the raw water to the evaporator as incoming cooling water instead of the additional cooling water for the condenser. Flash evaporation is a continuous process. The feed (F) is fed to the evaporator tank, where part of it is evaporated and leaves the tank as vapor (V), and the remaining liquid is removed from the tank as the bottom product (B). The liquid flows can be assumed to be uniform and product flows are in equilibrium with each other.

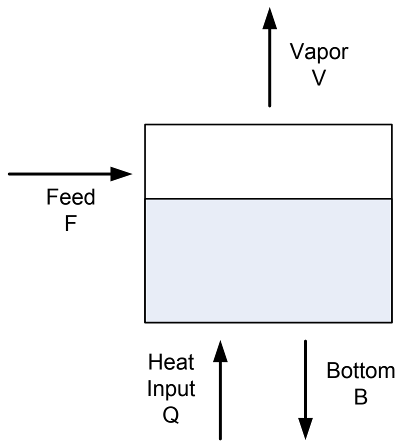

Figure 4: Schematic representation of two effect flash evaporation for simplified mathematical model

Evaporation is a result of heating the liquid in the evaporator tank. By changing the heat input (Q) to the system, the distillate/bottom product ratio can be varied. The following material balance can be written for the flash evaporation.

$\frac{dM_F}{dt} = \frac{dM_V}{dt} + \frac{dM_B}{dt}$ Eq. 1

If the composition of water, in the feed is z, in the vapor is y and in the bottom is x, the material balance equation can be modified as follows.

$z\dot{M}_F = y\ \dot{M}_V + x\dot{M}_B$ Eq. 2

By solving (2) for y, the "feed line" equation can be obtained.

$y = \frac{z}{f} - \left(\frac{1-f}{f}\right) x$ Eq. 3

Where,

$f = \frac{\dot{M}_V}{\dot{M}_F}$ = The vaporization ratio

The Required Heat Input rate can be written as follows. Where, C = Specific Heat Capacity of water, C_E = Specific Latent Heat of Evaporation of water and t_V, t_F are respective temperatures.

$\dot{Q}_{in} = \dot{M}_F\ C(t_V - t_F) + \dot{M}_V C_E$ Eq. 4

In this model, for the flash evaporation, the heated water outcome after condenser cooling is used as the feed water to the evaporator. In another way, raw water feed to the evaporator is preheated by recovering the energy of vapor coming from the evaporator by using raw water as the cooling stream in the condenser. Therefore, in equation (4), temperature difference $(t_V - t_F)$ will become very low causing to reduce the required heat input $\dot{Q}_{in}$ to the system.

The vapor which is coming out of the evaporator will be condensed in the tubes by means of a counter-current shell and tube heat exchanger that is called a condenser. The cooling medium in the shell is cooling water supplied by treated raw water plants. If the above energy recovery was not used, this model would be similar to a single stage distillation plant where the heat exchanger should be very large to obtain a higher yield of distilled water causing economically not viable process and also, the emitted out cooling water from the shell will be much higher in that case. But, according to the above equations (5) and (7) in this mathematical model, it is clear that the evaporation will recover a large portion of energy compared to single stage distillation and hence, the condenser cooling duty is lowered. Therefore, this condenser can be modeled and designed to match the economical bottom-line for small and medium scale distilled water requirements.

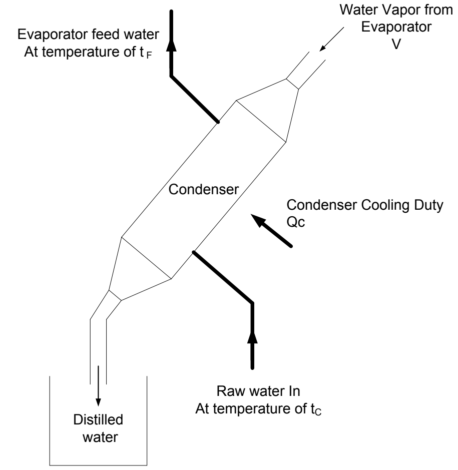

Figure 5: Schematic representation of Condenser for simplified mathematical model

The cooling duty of the condenser can be mathematically represented by applying energy balance to the condenser, where $\dot{M}_C$= the mass flow rate of raw water coming in, and C = the specific heat capacity of water, t_D = temperature of distilled water, t_V = temperature of evaporator vapor, $\dot{M}_V$= the mass flow rate of evaporator vapor, and C_E =Specific Latent Heat of Condensation of water.

$\dot{Q}c =$
$\dot{M}_V\ C(t_V - t_D) + \dot{M}_V C_E = \dot{M}_C C(t_F - t_C)$
Eq.5

Applying the material balance to the Condenser cooling process,

$\dot{M}_V = \dot{M}_D$ And $\dot{M}_C = \dot{M}_F$ Eq.6

For the Counter Current Shell and Tube Heat Exchanger which is used as the condenser, cooling duty can be written, Where,

U_o = Overall heat transfer coefficient,

A = Total Heat transfer area

LMTD = Logarithmic Mean Temperature difference.

$$\dot{Q}c = U_o A \text{ (LMTD)} \qquad \text{Eq.7}$$

$$\text{LMTD} = \frac{(\Delta t_1 - \Delta t_2)}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} \qquad \text{Eq.8}$$

Based on this developed mathematical model for this water distillation plant, the modeling and simulation can be performed using computer aided modeling and simulation tools. By means of the simulation results, the necessary geometric design for the evaporators and the condenser could be decided. In this study, ASPEN PLUS software was used as the modeling and simulation tool because, there are several strong distillation and heat exchanger unit operational models equipped with ASPEN PLUS which makes the modeling and simulation as well as design and optimization executable in a single workspace instead of using other open source software. Simulation results can be obtained for quick changing input data so that it will be helpful in comparing different simulation results and practical data for optimization and even validation.

Modeling and Simulation Results with Aspen Plus

The computer model for the above mathematically modeled process was developed in ASPEN PLUS software based on following input data in Table 1.

Table 1: Required input data for ASPEN PLUS modeling and simulation

Input Parameter	Raw Water Input Stream	Evaporator Equipment Model	Condenser Equipment Model
Aspen Plus Input Model	Material Stream	Flash2 (VDRUM1)	HeatX (GEN-HS)
Temperature	30 ^oC	130 ^oC	Not Required
Pressure	2 bar (Due to pumping)	1 bar	Not Required
Mass Flow Rate	25 kg/hr	Not Required	Not Required
Composition (Mass Fraction)	Water = 98% wt NaCl = 1% wt $MgCl_2$ = 1% wt (Pretreated Water)	Not Required	Not Required
Aspen Plus Thermodynamic Property Method	ELECNRTL	ELECNRTL	NRTL
Aspen Plus Calculation Method	Not Required	Not Required	Counter-current Shell and Tube Heat Exchanger Shortcut Design Pressure Drop = 0.2 bar Cold Stream Outlet vapor fraction > 0 Overall Heat transfer coefficient is based on Phase Specific Values Film coefficients = Const

The ASPEN PLUS process flow model for the simplified mathematical model based on above input data can be depicted by Figure 6.

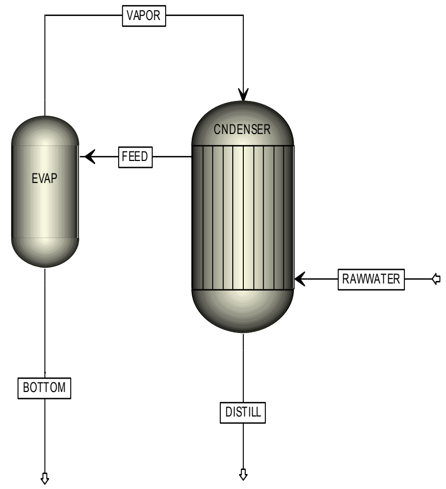

Figure 6: ASPEN PLUS process flow model for the simplified mathematical model

After the ASPEN PLUS simulation was run, the simulation results should be checked for the material and energy balance and real world results because, sometimes Aspen Plus will give simulation results for the extraordinary situations which are away from practical experimental results. However, this can be avoided by validating the simulation results with experimental results for a similar experimental model. In any case, when an experimental model is difficult to be constructed, the validation of the simulation results can be performed by comparing the manual theoretical calculations with the developed mathematical model.

The simulation results for output material streams obtained by ASPEN PLUS modeling are indicated in Table 2.

		BOTTOM	DISTILL	FEED	RAWWAT	VAPOR
From		EVAP	CNDENSER	CNDENSER		EVAP
To				EVAP	CNDENSER	CNDENSER
Substream: MIXED						
Phase:		Liquid	Mixed	Mixed	Liquid	Vapor
Component Mole Flow						
WATER	KMOL/HR	0.00	1.36	1.36	1.36	1.36
NACL	KMOL/HR	0.00	0.00	0.00	0.00	0.00
MGCL2	KMOL/HR	0.00	0.00	0.00	0.00	0.00
Component Mass Flow						
WATER	KG/HR	0.07	24.43	24.50	24.50	24.43
NACL	KG/HR	0.25	0.00	0.25	0.25	0.00
MGCL2	KG/HR	0.25	0.00	0.25	0.25	0.00
Component Mass Fraction						
WATER		0.13	1.00	0.98	0.98	1.00
NACL		0.43	0.00	0.01	0.01	0.00
MGCL2		0.43	0.00	0.01	0.01	0.00
Mole Flow	KMOL/HR	0.01	1.36	1.37	1.37	1.36
Mass Flow	KG/HR	0.57	24.43	25.00	25.00	24.43
Volume Flow	L/MIN	0.01	756.66	8.33	0.42	747.52
Temperature	C	130.00	93.86	100.14	30.00	130.00
Pressure	BAR	1.01	0.81	1.01	2.00	1.01
Vapor Fraction		0.00	0.89	0.01	0.00	1.00
Liquid Fraction		1.00	0.11	0.99	1.00	0.00
Solid Fraction		0.00	0.00	0.00	0.00	0.00
Molar Enthalpy	MJ/KMOL	-308.19	-244.03	-279.85	-285.58	-238.26
Mass Enthalpy	MJ/KG	-5.93	-13.55	-15.30	-15.61	-13.23
Enthalpy Flow	KJ/SEC	-0.95	-91.90	-106.26	-108.43	-89.73
Molar Entropy	KJ/KMOL-K	152.74	-47.06	-142.36	-159.39	-34.13
Mass Entropy	KJ/KG-K	2.94	-2.66	-7.76	-8.71	-1.89
Molar Density	KMOL/CUM	14.36	0.03	2.74	53.95	0.03
Mass Density	KG/CUM	746.76	0.54	50.04	986.72	0.54
Average Molecular Weigh		51.99	18.02	18.29	18.29	18.02

Figure 7: Simulation results for output material streams by ASPEN PLUS modeling

The simulation results for the evaporator heat duty and condenser cooling duty which are the most important to be analyzed are indicated in Figure 8 and Figure 9.

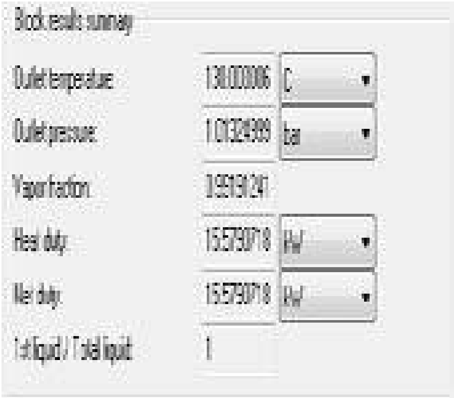

Figure 8: Simulation results for the evaporator heat duty

According to the simulation results for the evaporator as shown in Figure 8, the net heat duty for the evaporator heating is approximately 15.6 kW. A simulation was carried out in the same way for the conventional single stage distillation model using ASPEN PLUS where raw water at 30 °C is fed to the evaporator directly as the feed and no energy recovery is happened at the condenser resulting an evaporator heat duty of approximately 30 kW which is almost double in quantity as the above energy recovering new model. Therefore, this fact ensures that the above new simplified model is an energy efficient optimized model.

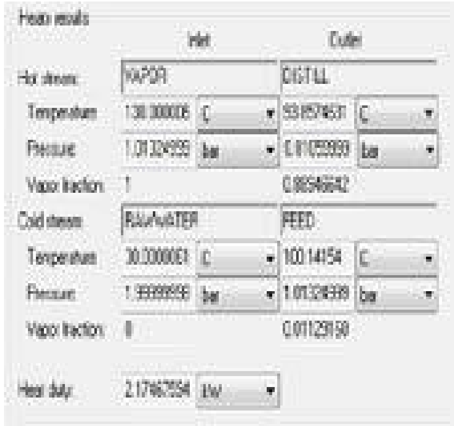

Figure 9: Simulation results for the condenser heat/cooling duty

Exchanger details

Calculated heat duty:	2.17467594	kW
Required exchanger area:	4.99982971	sqm
Actual exchanger area:	5	sqm
Percent over (under) design:	0.00340585	
Average U (Dirty):	0.0203019	kW/sqm-K
Average U (Clean):		
UA:	101.506043	J/sec-K
LMTD (Corrected):	21.4241021	C
LMTD correction factor:	1	
Thermal effectiveness:		
Number of transfer units:		
Number of shells in series:	1	
Number of shells in parallel:		

Figure 10: Simulation results for the condenser geometry

The heating /cooling duty of the condenser is the amount of energy recovered in this new process model. In the conventional single stage distillation method, this amount of energy also should be given as heat input to the evaporator and that results in higher operating cost and lower energy efficiency.

Solar Energy as Energy Source

One more objective of this study is the enquiring of renewable energy sources instead of conventional boiler heating for small and medium scale requirements of distilled water processing plants. Considering about renewable energy sources, obviously the most suitable renewable energy source for this application seems to be the solar power. Usually, in industries, the distilled water plants are established outside the process plant premises. Therefore, the roof covering the isolated distilled water plant in a fairly opened environment can be equipped with solar collectors to supply necessary heating power requirement for the evaporator. Figure 11 below depicts this concept of solar power driven distilled water plant with zero running energy cost. The required area of solar collectors for the evaporator heating requirement should be calculated for this concept.

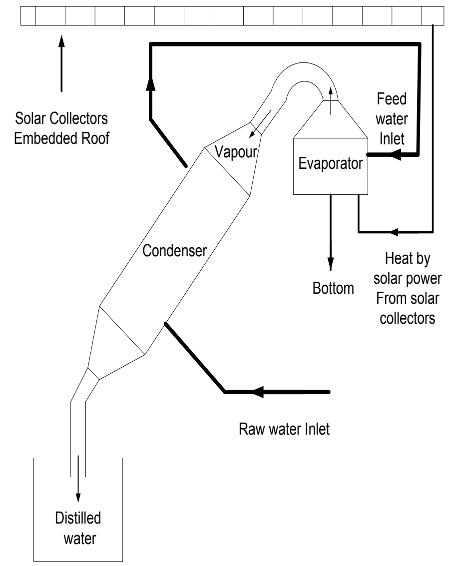

Figure 11: Sketch on the concept of obtaining solar energy for evaporator heating by solar collectors

The evaporator heating power requirement = 15.6 kW

Assuming that this plant is running for 4 hours per day using the day time solar power, (Daily distilled water output to be 100 kg/hr).

The total daily energy requirement for the evaporator heating = 15.6 x 4 = 62.5 kWh

According to the currently available literature, the average solar energy resource, per 1m^2 area in Sri Lanka can be taken from 4.5 to 6.0 kWh per day. (Source: Reference [9] & [10])

Therefore, for the calculations, the average energy resource per 1m^2 area was taken as 5 kWh per day which can be interpreted on the other hand as approximately 800 W/m^2. (Considering 8 hours of peak solar irradiation time per day)

Moreover, the available literature point out that solar thermal technology is more advantageous and more efficient than photo-voltaic (PV) solar technology. (Source: Reference [11]). As well, in comparison between the main two types of collectors of solar thermal technology, which are flat plate collectors and evacuated tube (vacuum tube) collectors, it has been indicated in the previous researches that, evacuated tube (vacuum tube) solar thermal collectors are more efficient with other advantages for temperature range of 100°C to 150°C eventhough, they are slightly more expensive than flat plate solar thermal collectors. (Source: Reference [12]).

However, the type of solar thermal collector as the solar energy extraction technique should be decided according to a proper analysis.

Several factors should be considered in the selection of solar thermal collector type. They are,

- Price of the collector
- Efficiency of the collector
- Operating temperature
- Location (available solar radiation, ambient temperatures)
- Installation feasibility

A comparison between flat plate solar thermal collectors and evacuated tube (vacuum tube) solar thermal collectors can be illustrated as follows. (Source: Reference [12])

Table 2: Comparison between Flat Plate collectors and Evacuated Tube collectors

Flat Plate Solar Thermal Collector	**Evacuated Tube (Vacuum Tube) Solar Thermal Collector**
	
Consists of an absorber plate, which is often a painted metal, such as copper, attached to copper pipes where heat transfer liquid passes through. This is encased in a metal frame, surrounded by thick insulation to help retain the collected heat, and protected by a sheet of glass, which also provides an insulating air space.	Employs the use of heat pipes surrounded by a glass tube that are under a vacuum. These glass tubes actually consist of two walls of glass. In between the two walls, all the air is removed, resulting in a vacuum. This vacuum is the best insulation that gives the evacuated tubes a much better heat retention than air space. As heat pipe is under vacuum, the liquid (water) boils very rapidly, at a very low temperature.

According to analysis of market prices of several flat plate collectors, the average cost per 1 m^2 area can be taken as $ 400.	According to analysis of market prices of several evacuated tube collectors, the average cost per 1 m^2 area can be taken as $ 500. (Nearly 20% higher in cost)
When output temperature of heat transfer liquid increases, the efficiency of collector drops dramatically.	When output temperature of heat transfer liquid increases, the efficiency drops but, comparatively with a lesser heat loss coefficient. (figure 12)
In consideration of installation feasibility and other factors, flat plate collector does not have distinct advantages over evacuated tube collectors for this application.	Since, it will account to a significant area of solar collectors at a higher temperature to cater 62.5 kWh per day, evacuated tube collector is the more efficient type of solar collectors for this application.
Figure 8 depicts that, when insolation rises, the efficiency of flat plate collectors is very low at high temperatures.	According to figure 13, when insolation rises, the efficiency is higher than flat plate collectors at high temperatures. Hence, more suitable for this application at Sri Lanka which has a higher insolation.

The efficiency of solar collector (η_c) can be determined using following formula. (Source: Reference [12])

$$\eta_c = \eta_0 - a_1 \frac{T_m - T_a}{G} - a_2 \frac{(T_m - T_a)^2}{G} \quad \text{Eq.9}$$

Where,

η_o = Maximum efficiency without any heat loss (Optical efficiency)

α_1 = 1st order heat loss coefficient

α_2 = 2nd order heat loss coefficient

G = Total irradiance on collector surface

T_m = Mean collector fluid temperature

T_a = Temperature of ambient air

If a high performing evacuated tube collector is selected, the parameters can be taken as, α_1 = 2 W/K.m^2, α_2= 0.005 W/K^2.m^2, η_o = 0.75, T_m = 130 °C , T_a = 30°C and G = 800 W/m^2

By substituting in Eq. 12, the efficiency of the selected evacuated tube solar thermal collector will be,

0.3125 ~ 0.31

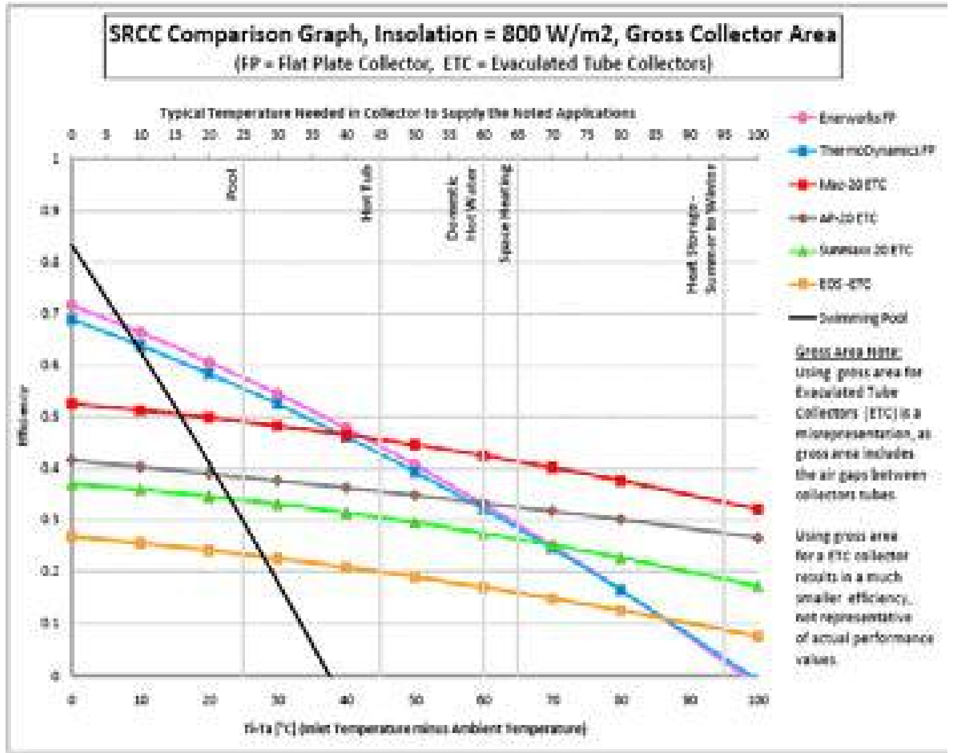

Figure 12: Comparison graph for efficiency of solar thermal collectors (Source: Reference [13])

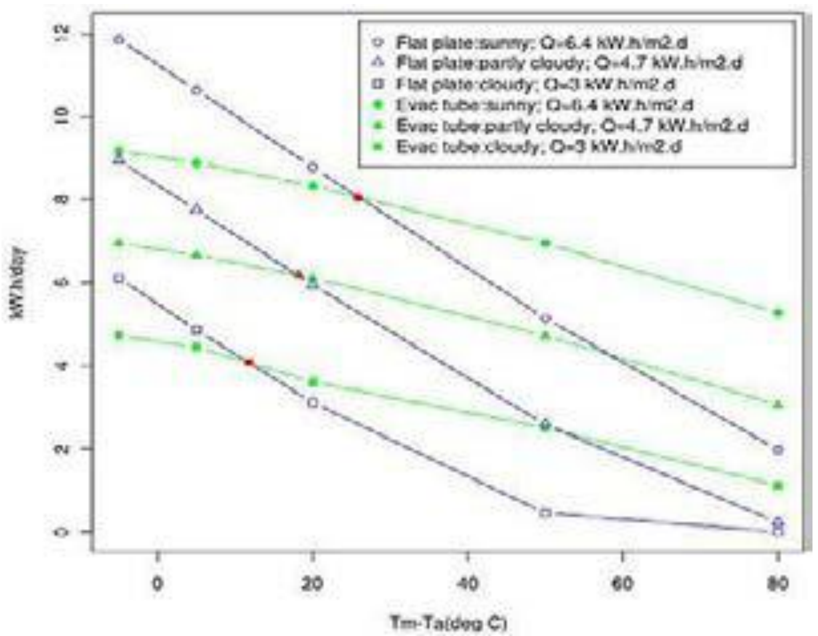

Figure 13: Comparison graph for solar thermal collectors at different insolation (Source: Reference [14])

The required solar collector area can be found by using following formula. (Source: Reference [12])

$$P_c = A_c . \eta_c . G \qquad \text{Eq.10}$$

Where,

A_c = Collector Area

P_c = Power output from collectors

According to the above equation, when P_c = 15.8 kW, the required area of evacuated tube solar thermal collectors amounts to approximately **60 m^2**.

If the roof is rectangular, the solar thermal collectors can be simply embedded in **10 m x 6 m** roof area.

The capital cost comparison between utilizing Photo Voltaic technology and Solar thermal technology can be carried out by means of present market prices. (Source: Reference [15])

According to the present market prices, a 1kW output PV solar panel costs approximately $ 8000.

For output of 15.8 kW of required power, total capital cost for PV will be approximately $ 120,000.

According to the present market prices, evacuated tube solar thermal collectors cost $ 500 per 1 m^2.

For output of 15.8 kW of required power, total capital cost for solar collectors will be approximately $ 30,000.

It is obvious that utilization of evacuated solar thermal collectors reduces the total cost four times rather than applying PV solar panels.

Discussion on Future Research Potential

During this study, there are several effective base assumptions those have affected directly to the output results. They are the assumption of uniform flows every time, assumption of steady state conditions, postulation of maximum energy recovery irrespective of condenser geometry and neglecting of heat losses from surface walls due to conduction and radiation. Also, the validation and optimization of simulation results has been performed on the basis of theoretical mathematical model instead of utilizing experimental results. Therefore, this research study has a good progressive future potential to take care of the effectiveness of those assumptions for the obtained output simulation results. Moreover, the equipment models that are the evaporator and the condenser should be designed for the required outputs. After equipment design, at least a prototype of this model should undergo experimental operation in order to identify practical difficulties and to experimentally validate the behavior of this simulated model. As to design the equipment models the design and simulation software like SOLIDWORKS can be utilized. The geometrical specifications can be simulated based on execution of a heat transfer analysis in ASPEN PLUS. The main objective of this study was not to design the geometrical model, but to figure out the energy recovery potential for a simplified model for small and medium scale requirements.

However, based on the simulation results of condenser geometry, the dimensional design can be executed for developing the experimental model. Furthermore, HOMER software can be integrated to model and check hybrid renewable energy supply is possible for this application. Due to these factors, it is inevitable that a progression of future research work is essential which has been founded by this research paper towards further optimization and validation.

Conclusion

Eventually, it is distinct that the small and medium scale distilled water plants can be integrated with both the improvement techniques enforced in this research paper which are firstly, recovering the energy in the vapor coming out of the evaporator in order to preheat feed water to the evaporator, secondly, replacing the evaporator heating source with solar energy by means of evacuated tube (vacuum tube) solar thermal collectors of 10 m x 6 m area on the same plant roof whereas, the implementation of these conclusions of this research paper can be either partially or completely activated by relevant industries and institutes.

This distilled water plant model has a distilled water output yield of approximately 100 kg per day by running only 4 hours per day with only solar energy as the energy source without any hassle of cooling back the heated water emitted at the condenser, maximum energy recovery and many more advantages than in the conventional single stage distillation. Hence, the key intended outcome of this simulation study which was identifying and highlighting more energy efficient and sustainable small scale distilled water plant has been thriven. However, it is comprised of future research potential as to experimentally validate the same results.

Acknowledgement

It is admirable to be organized an annual Energy Symposium by The Sustainable Energy Authority, in order to share the key aspects of research work among different intellectuals in Sri Lanka. Therefore, firstly, the authors of this research work are grateful to the organizers of this symposium. Moreover, all the researchers involved in the literature references cited in this study, are acknowledged with great respect.

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Development and Demonstration of Environmental Friendly and Sustainable Technology for Application of Fuel Wood Chips in Tea Drying

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Abstract

Tea processing is an energy intensive process and the thermal energy requirement is 80% of the total requirement. Tea drying is the highest thermal energy consumer in tea processing. In the Asian region India and Vietnam use fuel wood, diesel, furnace oil and also coal to generate heat for tea drying. In Sri Lanka more than 90% of tea factories use fuel wood to generate thermal energy requirement. One of the major problems the industry is likely to face in the future is availability of fuel wood. The cost of petroleum fuel would prohibit its' use for heating purposes.

In place of the conventional practice of manual feeding of unsustainably produced fuel wood for hot air generation in tea drying, new technologies were developed to feed, especially gliricidia fuel wood chips through semi-automated continuous biomass feeding systems. Two pilot units were operated to test and demonstrate the feasibility of replacing diesel burner with gliricidia fuel wood chips and to replace wood logs firing system with fuel wood chips. In replacing diesel fuel with wood chips, the testing of pilot units shows that the system operates at specific fuel wood consumption (SFC) of 1 kg fuel wood chips per kg of dried tea. The performance of pilot unit of continuous feeding semi-automated gliricidia fuel wood chips feeding system, in replacing the conventional practice of using wood logs in tea drying shows that the SFC is 0.73 kg wood chips at 20% moisture content per kg of dried tea. In comparison, SFC in using wood logs is 1.15 kg wood logs at 40% moisture content.

Key words: Tea drying, wood chips, Biomass feeding, gliricidia wood chips

Introduction

Tea manufacturing is an energy intensive process, where the ratio of thermal to electrical energy requirement is 85:15 [1]. In the Asian region India and Vietnam use fuel wood, diesel, furnace oil and also coal to generate heat in tea withering and drying. There are about 700 tea factories in Sri Lanka and more than 90% of them use fuel wood to generate heat in tea drying. The rest uses diesel or fuel oil. Tea industry of Sri Lanka accounts for about 70% consumption of fuel wood in agro-industrial sector, amounting to 620,000 MT annually [2]. In Sri Lanka the required amount of fuel wood for tea industry could only be supplied by about 210,000 hectares of forest area [1]. It has been understood that the rate of depletion of firewood is alarming and in the absence of equivalent afforestation, it is certainly matter of concern [1]. The cost component of drying of tea is as high as 30% of total production cost in most of the factories. Therefore a need has been arisen to promote and adopt Energy Efficiency and Environmentally Sound Technologies (E^3ST) in the tea sector to generate thermal energy.

Fuel consumption in tea drying

Average thermal energy requirement for drying of 1 kg of tea is 11.0 MJ [3]. Lower Heating Value (LHV) of fuel wood at the moisture content 20% by weight on wet basis is approximately 14.5 MJ/kg. According to these figures, specific fuel wood consumption (SFC) in tea drying, i.e kgs of fuel wood used to produce 1 kg of dried tea, should be less than 1 kg per kg of dried tea. But actual consumption of fuel wood in most of the tea factories vary from 0.96 to 2.20 kg fuel wood, per 1 kg of dried tea [4]. Table 1 shows actual and calculated thermal energy consumption in tea processing.

Table 1. Thermal energy consumption in tea processing (7)

Process	Energy (MJ/kg Made Tea)			
	Mid/High Elevation		Low Elevation	
	Actual	Lowest calculated	Actual	Lowest calculated
Withering	9.0	5.6	9.0	5.6
Drying	13.0	10.6	13.7	11.2
Total	22.0	16.2	22.7	16.8

Application of sustainably grown fuel wood for tea drying

Study conducted by National Engineering Research and Development Centre (NERDC) proved the feasibility of application of fuel wood (gliricidia, rubber or jungle wood) in the form of chips for tea drying with controlled and continuous feeding to the existing furnace [5]. Conventional practice is to feed wood logs manually into the furnace (Fig.1). In order to harness energy of biomass for energy purposes, the government of Sri Lanka has declared 'gliricidia' as the 4th national plantation after tea, rubber and coconut. Being a short rotation coppicing and nitrogen fixing plant, it is advantageous to grow gliricidia in tea states as a shade tree and also to provide nitrogen fertilizer [6].

Figure 1: Conventional manual feeding of fuel wood logs

As a Green House Gas (GHG), Carbon Dioxide (CO_2) is the single largest contributor to climate change. By the tea sectors in India, Sri Lanka and Vietnam annual generations of CO_2 emissions are 1.352 million tons, 0.708 million tons and 0.085 million tons respectively [1]. Therefore application of short rotation coppicing plantation such as gliricidia to generate thermal energy in tea drying would be advantageous both economically and environmentally.

Firing of wood chips in fixed grate type furnaces

There are many mechanisms that could be used in feeding wood chips or chunks into a furnace for combustion, which include under feed screw conveyor, through feed screw conveyor or over feed systems depending on the size of wood chips and the type of the furnace.

Effect of thickness of bed of fuel wood chips

Method of firing wood chips is quite different from that of wood logs. Wood logs can be fired after stacking to any height. But when firing wood chips, the maintaining of height of the bed of fuel wood is important. Stoichiometry of, especially overfeed bed is determined by the bed thickness. In a thin bed the primary product is Carbon Dioxide (CO_2), but in a thick bed Carbon Monoxide (CO) becomes the primary product and the system is essentially a gasifier (Fig. 2). Thus changing air flow only changes the rate of combustion but not the stoichiometry [7]. Therefore controlling of the bed height of wood chips on the fire grate is very important in wood chips burning systems.

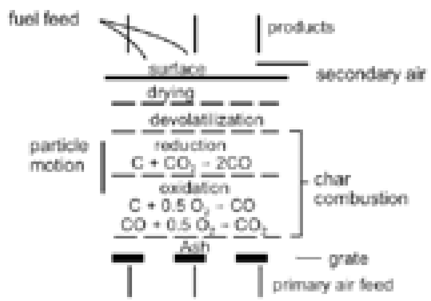

Figure 2: Combustion of fuel wood chips in an over feed system [7]

Objectives

The objective of this project is development and demonstration of technology for introducing fuel wood chips derived from short rotation coppicing plantations, such as gliricidia that could be retrofitted for increased efficiency and sustainability in tea drying.

Material and Methods

Development of continuous charging system for fuel wood chips in tea drying

NERDC developed the technology and conducted two pilot units to demonstrate the application of sustainably derived fuel wood chips by retrofitting them to

1). diesel burning tea drying system

2). fuel wood logs/ split logs burning tea drying system.

Development of technology to retrofit diesel burning system

Biomass pre-furnace is an accepted technology in switching oil fired burning systems to biomass. The technology developed for switching diesel fired hot air generation systems to fuel wood chips fired system, consists of

a). A pre-furnace to burn wood chips

b). A conveyor belt driven continuous fuel wood chips feeding system (Fig.3)

c). Biomass feed bin and chute

d). Controlling system (Fig.4)

Major specifications of the system

Rate of combustion of pre-furnace
: 100 – 180 kg/hr

Fire grate area of the pre-furnace
: 1 m^2

Diameter of feed chute
: 300 mm

Width of the belt conveyor
: 400 mm

Inclination of belt conveyor
: 55^0 to horizontal

Capacity of the conveyor motor
: 1.5 kW

Size of wood chips
: 12-60 mm (Ø) x 250 mm

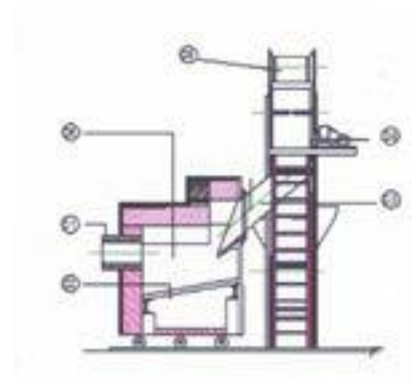

Figure 3: Pre-furnace and belt conveyor type feeding system

1-Flame outlet

2-fire grate

3-feeding chute

4-Feed bin

5-Conveyor belt

6- pre-furnace

Fuel wood chips are to be manually loaded to the hopper once in 20 minutes time. Conveyor belt picks wood chips and delivers into the pre-furnace at a desired rate determined by the speed of the belt conveyor set by the Variable Speed Drive (VSD) (Fig.4). Wood chips are burnt in the pre-furnace and the flame outlet of the pre-furnace is fitted to the burner port. This system can be retrofitted easily to diesel burning system and the system can be changed over to diesel burning mode at any time.

The pilot plant was tested at the Greenfield Tea factory at Thotulagala, Haputhale.

Controlling of excess air

The pre-furnace is attached to the existing heat exchanger / diesel burning system. The necessary negative pressure in the pre-furnace is created by the induced draft fan of the diesel burning system. By adjusting the draft of the fan, a slightly negative pressure is to be maintained in the pre-furnace to avoid suction of too much excess air through the feeding chute.

Safety of the system

Safety features were included in order to avoid back flow of flame through the feed chute. Alarm is activated through a temperature sensor so that the operator can close the feed chute manually. At the same time motor operated feed chute door is closed automatically within 45 seconds time.

Figure 4: Belt conveyor and controlling system

Development of technology to retrofit wood logs burning system

Traditional fire wood firing tea drying system consists of a fixed grate type furnace with built in heat exchanger with cast iron tubes and hot air is delivered to the dryer by an induced-draft electric blower. To generate heat, wood logs or split wood logs are fired by manual feeding. Technology is developed to charge wood chips continuously at a desired controlled rate through an 'improved screw conveyor' type feeding system. (Fig.5)

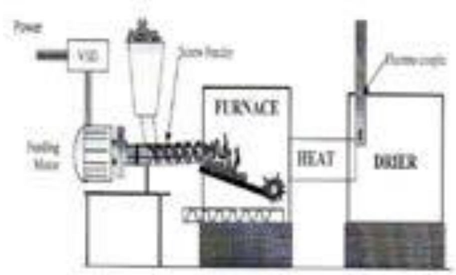

Figure 5: Fuel wood chips feeder, coupled to the furnace.

In order to meet the requirement of maintaining the thickness of the bed of fuel wood, two numbers of side screws are fixed (Fig.6).

Figure 6: Two side screws maintain the fuel bed thickness

These side screws move wood chips forward on the fire grate to maintain the height of the bed of fuel wood chips. In order to feed wood chips of different shapes, the screw shaft of the screw conveyor was given limited flexibility in radial direction (Fig.7). Speed of the feeding system is controlled through a feed back control system by monitoring the temperature of hot air. Manual controlling of feed rate through the variable speed drive is also possible.

Specifications of the fuel wood chips feeding system

Type : Screw conveyor
Power : 1 kW, 230 V
Speed control : Through variable speed drive
Feed rate : 200 – 350 kg/hr
Fuel wood size : 12-50 mm(Ø)x112 mm(L)
Moisture content of fuel wood : < 20% by weight (WB)

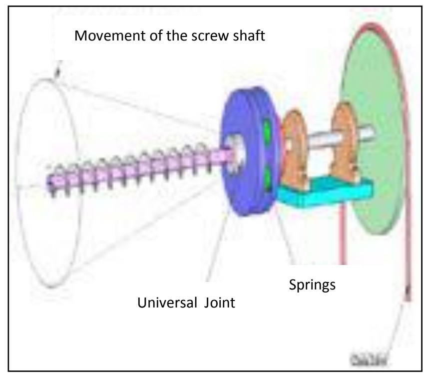

Figure 7: Flexible screw shaft to avoid flow stoppage

Preparation of fuel wood chips

Fuel wood chipping machine was developed to prepare wood chips out of fuel wood sticks of diameter 15 mm- 60 mm. The chipping machine consists of two cutting wheels of 300 mm diameter, which rotates 50 rpm. The machine is powered by 7.5 kW 3 Phase electric motor and the wheel rotates at 50 rpm. The machine generates 800 kg of chips per hour.

Evaluation of performances

In evaluating the performances, consumption of fuel wood, moisture content of fuel wood, hot air temperature and flue gas composition were the parameters monitored.

Moisture content of fuel wood (MC) : Moisture content is a key parameter that should be considered in designing of conversion devices. Moisture in wood acts as a heat sink because as water evaporates it absorbs 2.4 MJ/kg water at 25 ^{0}C.

Moisture content on wet basis;

$$MC_w = \frac{WH_2O}{(W_{dm}+WH_2O} \quad \text{Eq.1}$$

Where,
WH_2O = Weight of water;
W_{dm} = Weight of dry matter[8]

$$\text{Excess Air Ratio}(\lambda) = \frac{\%O2 \text{ measured}}{(20.9 - \%O2 \text{ measured})} \quad \text{Eq.2} \quad [9]$$

Oxygen presence in flue gases in excess of stoichiometric conditions represents excess air. Excess air, when exceed the accepted level, carries away heat.

Specific fuel consumption in tea drying (SFC) is the final indication of consumption of fuel wood or diesel to produce unit quantity of dried tea.

SFC = Quantity of fuel (fuel wood of known moisture content or diesel) used in tea drying (kg) / Quantity of dried tea produced (kg)

Results and discussion

Performance of the retrofitted system to diesel burner

Specific fuel wood consumption

The pilot unit fuel wood chips burning system developed to replace diesel burning tea drying system, consisting of pre-furnace and belt conveyor system was tested at the Greenfield Tea Factory at Thotulagala Haputhale. The capacity of ECP dryer of this factory was 130 kg/hr dried tea. The specific fuel consumption (SFC) of diesel burning system was 0.21 lts /kg dried tea. The SFC when using gliricidia fuel wood with moisture content ~ 20% by weight was 1 kg wood chips per kg of dried tea.

Excess air level

The Figure 8 compares the excess air levels in manual and continuous feeding of wood chips. In both systems the level of excess air is quite high. It is expected to maintain the excess air level when burning biomass at least around 160%-200% [10]. But there is a marked reduction in excess air level when operating the continuous fuel wood chips feeding system, which enhances the overall combustion efficiency of the system.

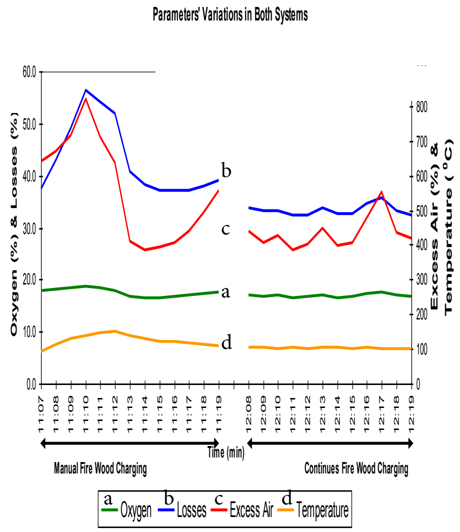

Figure 8: Excess air generated in manual batch feeding and automated continuous feeding

Advantages and disadvantages of the system

The biomass feeding system requires about 12 m^2 of area to install, in-front of the heat exchanger. In feeding biomass, it requires an attention of an operator to monitor the operation. While operating retrofitted biomass burning system the tubes of the heat exchanger have to be cleaned weekly due to carryover of particulates with flame. The factory has to have a separate storage facility in order to store fuel wood. A trained technician is required to attending to troubleshooting and maintenance of machinery and controlling system. Considering the cost of the new technology as LKR 2.5 million and

allowing LKR 1.0 million for incidental expenses, assuming cost of maintenance LKR 0.125 per kg dried tea and cost of additional labor LKR 0.5 per kg dried tea and assuming 10 yr life time, for a factory having annual production capacity 240,000 kg dried tea, the simple payback period is 3 years when diesel burning system is retrofitted with fuel wood chips burning system. Price of fuel wood chips was taken as LKR 7.00 per kg.

Performance of the retrofitted system to replace wood logs firing

Specific consumption of fuel wood

The Figure 9 shows specific fuel consumption (SFC) of tea drying operation with different types of fuel wood. Gliricidia and jungle wood chips (GJWC), gliricidia wood chips (GWC), rubber wood chips (RWC) were used in generating heat by feeding through the continuous feeding system and split rubber wood logs (SRWL) were fired through manual feeding. The pilot unit of improved screw conveyor type wood chips feeding system was tested at Deenside Tea Factory at Gampola. The feeder was coupled to an ECP type dryer of capacity 270 kg/hr dried tea. SFC when using gliricidia (GWC) and rubber wood chips (RWC) ranges from 0.7 – 0.8 kg fuel wood per kg Dried Tea when moisture content of GWC and RWC are less than 25% by weight (Wet basis). In comparison, split rubber wood logs were fired by manual feeding and SFC when using split rubber wood logs (SRWL) with moisture content 28 – 38% by weight (Wet basis) ranges from 1.00 – 1.30 kg fuel wood per kg Dried Tea. Wood chips dry faster than wood logs while storing.

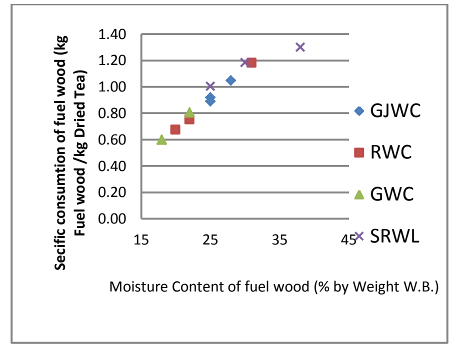

Figure 9: Variation of moisture content of fuel wood with SFC

Performance of the feeder

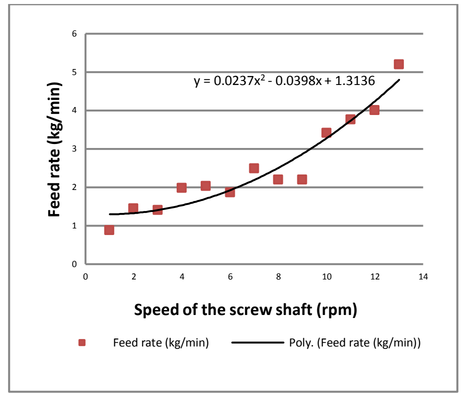

Figure 10: Variation of speed of the feeder with feed rate

The improved screw conveyor type feeding system consisting of a special screw having freedom to move in a radial direction, proved successful in conveying wood chips without 'interlocking' and flow stoppage. The two-side screws maintained the thickness of the bed of fuel wood approximately 400 mm, thus assisted towards maintaining an efficient system of combustion. Density of gliricidia fuel wood chips was approximately 200 kg/m^3. The Figure 10 shows the variation of speed of the feeder with the feed rate of gliricidia wood chips. The feeder shows a higher sensitivity when increasing speed.

Advantages and disadvantages of the system

When fuel wood is purchased in the form of sticks, a wood chipping machine has to be installed in the factory. The Figure 8 indicates that the highest economy of using fuel wood can be achieved by using dry fuel wood. Therefore it is advantageous to install a waste heat dryer to dry wood chips before using. It is also necessary to have a storage facility to keep stocks of fuel wood for more than one month requirement.

In comparison financial saving of application of GWC and SRWL, It is considered that gliricidia and rubber wood are purchased at 50% moisture content (WB) and they are used after processing at 20% and 40% moisture content respectively. Losses in processing are estimated as 1.5% by weight. SFC for GWC is 0.73 kg fuel wood per kg dried tea and SFC for SRWL is 1.15 kg fuel wood per kg dried tea. Therefore in order to dry 1 kg of tea, 1.17 kg of gliricidia fuel wood or 1.40 kg of rubber wood logs at 50% moisture content is to be purchased, thus there is a 15.36% by weight saving of fuel wood in using GWC in place of SRWL. The prices of gliricidia and rubber wood are taken as LKR 3.00 and LKR 5.00 respectively and the cost of processing of gliricidia and rubber wood are estimated as LKR 0.3 and LKR 0.5. Therefore the cost of fuel wood for drying 1 kg of tea are calculated as LKR 3.91 and LKR 7.01 respectively for gliricidia and rubber wood. Thus there is a financial saving of LKR 3.09 in drying 1 kg of tea using GWC in place of SRWL. The total capital investment in implementing this wood chips feeding system, including a wood chipping machine estimated as LKR 1.2 million and allowing LKR 0.3 million for incidental expenses, for a tea factory having annual production 300,000 kg tea, the simple payback period is 1.6 years.

Conclusions

By operating a pilot unit of the technology developed for fuel switching from diesel to wood chips, the technology was proved economically feasible. On average 1 kg of gliricidia wood chips was required (at 20% moisture content by weight) per kg of dried tea. A larger space is required to install the system when compared with the diesel burner and also a skilled technician to monitor and maintain the feeding system. Due to carryover of particulate matter, heat exchanger tubes are to be cleaned weekly. The safe operation of feeding system can be guaranteed by maintaining a sufficient negative pressure in the pre-furnace in order to avoid back flow of the flame.

The technology developed for retrofit the wood logs firing system in tea drying was proved successful, by operating a pilot unit. The 'improved screw conveyor type' wood chips feeding system was able to feed wood chips in a controlled manner in order to maintain conditions for efficient combustion. Using gliricidia fuel wood chips with moisture content approximately 20% by weight (wet basis) on average 0.73 kg fuel wood is required per kg dried tea.

Specific fuel wood consumption in tea drying depends greatly on the moisture content of fuel wood at the point of using them. Economy of shifting to fuel wood chips can only be achieved by making necessary arrangements to use dry wood chips with moisture content 20% by weight.

Apart from the direct financial savings, contribution towards reduction of GHG emissions by using sustainably planted fuel wood and thus contribution towards sustainability of generating heat in tea manufacturing are the other advantages.

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Performance Evaluation of Biodiesel Produced from Different Plant Oil Sources for Agricultural Power Tiller

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Abstract

Biodiesel or Methyl ester, produced from transesterification of plants oil or animal fats is one of the alternative fuels for diesel engine. The main objective of the research was to conduct the comparative assessment of the biodiesels with the mineral diesel (MD). The biodiesels were produced from oil extracted from the *Jatropha carcus*, Palm seeds and *Used Scraped Coconut* (kitchen waste). The single cylinder diesel engine was run from produced Jatropha Methyl Ester (JME), Palm Methyl Easter (PME), Coconut Methyl Easter (CME) and Mineral Diesel. Then Torque (τ), Break Power (P_B), Specific Fuel Consumption (SFC), and thermal efficiency (T_{Eff}) were measured. Kinematic viscosity (K_v), Specific gravity (SG), Flash point (FP), Heating value (HV), distillation curve (DC), pH, Copper strip corrosion (CSC), CO and NOx in the exhaust gas also were measured. Torque, P_B, and SFC of engine were not significantly different in CME and MD, but there were significant difference in JME and PME. Torque of the engine fueled by JME and PME were reduced by 17% than MD. The maximum T_{Eff} was shown by CME. Higher K_v was shown in JME and PME when compared to CME and MD. SG of the all biodiesels was higher than MD. pH of the biodiesels were higher than MD. Higher HV was in MD than biodiesels. The ASTM standards were fulfilled by all biodiesel when FP, DC and CSC were considered. CO reduction was recorded as around 45% in all biodiesel, but NOx was increased by 10%.

Keywords: Biodiesel, CME, Used Scraped Coconut, Torque, Break Power.

Introduction

Over the past three/four decades the greater part of the increase in world energy requirement has been fulfilled by fossil fuel (oil, coal and natural gases) burning. Now world is in a serious state due to continuous increase of fossil oil prices and uncontrolled emissions of CO_2, CO, NOx, NO, and SOx due to fossil oil burning. The fossil oil usage has very severely affected to the national development of any country around the globe.

To overcome these global effects resulting from fossil fuel burning, now world is turning to run by alternative fuels. Biodiesel is one of the greatest alternatives for diesel engine in future world.

The main objective of this research was to identify different feedstocks and evaluate performance of compressed internal (IC) engines with biodiesel.

Methodology

Following steps were followed during the experiment.

Collection and extraction of raw oil from different plant resources

Palm kernel oil, Jatropha oil and coconut oil were used for biodiesel production. The palm kernel oil was directly purchased from market. *Jatropha carcus* seeds were purchased from farmers for jatropha oil extraction. Those collected seeds were dried under sunlight then oil was extracted using a hydraulic press. The refused scraped coconut was collected from kitchen waste from households and was dried under sunlight. The dried refused scraped coconuts were expelled using screw type expeller for oil extraction. The extracted oil was kept for few days for purification.

Production of biodiesel from different plant resources

For biodiesel production, Biodiesel production System-Fuel Mistor 150 was used. During Biodiesel (Palm oil Methyl Ester – PME) production from palm oil, following steps were followed [2].

Sufficient amount of oil was put in to steel barrel heater. Then it was heated up to 60 - 65 ^{0}C. Oil fill line was priming and pump was turned on. After the oil level reached up to 35 l level, pump was turned off and input valve was closed. Then recirculation valve and mixed jet valve were opened. After that the pump was turned on and it was kept for 10 minutes to homogenize the oil for good sampling. The 0.01 % NaOH solution was prepared as a titration solution. The 10 ml of methanol and 1 ml of heated homogenized oil was added together and mixed thoroughly. Three drops of color indicator were added in to mixture of oil and methanol. Then required NaOH amount was calculated by using following formula.

Required grams (g/l) of NaOH for catalyze one liter of oil,

= 3.5 + Average Reading of Titration Eq. 1

Then the required amount of NaOH was calculated for 35 l of oil, which was

accurately measured by using electronic balance. The weighed NaOH was thoroughly mixed with 20% of methanol from oil volume (7 l of methanol for 35 l of oil). Then the pre-mixture was placed in to pre-mixed tank. The pre-mixed valve was opened to inject the pre-mixture to circulate the oil system. During mixing, timer was adjusted for 60 minutes to complete transesterification reaction. The mixture was kept still for three to four hours to separate biodiesel from glycerin. During this time, reaction tank was opened to evaporate excess methanol. Due to high specific gravity of glycerin, it settled down and PME appeared in the upper layer. After glycerin was separated, glycerin was removed and PME was separated for washing. PME was put in to reaction tank (In Model 150LE) again and water tap of the reaction tank was opened. Then it was kept for 1.5 hours until water was added (up to 50% by PME volume). After adding water the PME was left for three to four hours for sealing water. Then the water was removed by opening glycerin drained valve and PME were separated in to a cleaned container.
This procedure was followed for Jatropha oil and coconut oil to produce Jatropha Methyl Ester (JME), and Coconut Methyl Ester (CME).

Engine Performance Evaluation

The test was conducted in Agric. Engineering workshop in Faculty of Agriculture, University of Ruhuna, Sri Lanka. Brand new model R 180, single cylinder, water cooled four strokes with swirl (turbulent) combustion chamber diesel engine was used for brake power test and fuel consumption test. The stroke to Bore ratio was 80:80 and the maximum power was 6.18 kW at 2600 rpm. The compression ratio was 21:1. First, it was checked if the engine was in standard condition. Then a Prony Brake dynamometer was coupled to this engine. Then engine was run from using PME, JME, CME and Mineral diesel (MD) individually. Then Balance readings were recorded at rpm of 1000, 1500, 2000, and 2500 as three replicate, and simultaneously fuel consumption was measured. Then Torque (τ), Brake Power (P_B), Specific Fuel Consumption (SFC), and Thermal Efficiency (T_{Eff}) (Depend on high calorific value) were calculated.
After calculating torque, break power, specific fuel consumption and thermal efficiency, the results were analyzed by using SAS statistic software as two factor factorial. Then the mean data were plotted as line charts.

Property testing of biodiesel produced from different plant resources [1]

Viscosity measurement - Model Broofild DV-E viscometer was used for measuring viscosity of PME, JME, CME and Lanka Auto diesel at temperature of 25^{0}C. Spindle number 61 was selected and spindle rpm were adjusted at 100%. Dynamic viscosities that were obtained from this instrument were converted in to Kinematic viscosities.

Specific gravity measurement - Correct amount of fuel volume was measured from burette and then weight of that fuel volume was measured accurately as 3 replicate in two decimal points of grams by using electronic top loaded balance. Then density of fuel was measured by using mass volume relationship.

pH measurement - pH meter was used for measuring of pH of all the fuel types. Before measuring pH, the pH meter was calibrated.

Calorific value measurement - Model Parr 6100 Oxygen Bomb calorimeter was used for finding of calorific value (Gross calorific value).

Flash point measurement - Fully automated Martrns Flashpoint tester was used.

Exhaust gas analysis - Model Eurotron S.P.A gas analyzer was used for test exhaust gases. Yanmar, single cylinder, indirect diesel engine was used for this test.

Copper strip corrosion - Four copper strips were polished. Then 25 ml of fuel samples were taken in to beaker. Then fuels were heated up to 50^{0}C and copper strips were placed in the four fuels. After 3 hours, copper strips were cleaned from filter paper and color was checked.

Results and Discussion

Mainly the results can be divided in to two parts, as engine performance testing and fuel property testing.

Engine performance testing result

One of the performing criteria of the tractor is the “Lugging ability” of engine, or more precisely, the torque curve. The torque of the engine for different methyl esters is given in figure 1. According to that CME was not significantly different from mineral diesel at α level in 0.05, but PME and JME were significantly different from mineral diesel. The maximum torque was produced near 2000 rpm for all the biodiesel. But mineral diesel produced its maximum torque at 1800 rpm. In general, torque of the CME (R^2=0.762), PME (R^2=0.716), and JME (R^2=0.842) showed similar relationship with engine speed. Highest torque was produced from CME at lower rpm and higher rpm. The torque was reduced at 17.5% PME and JME were used, due that JME and PME were of high viscosity than mineral diesel and CME. Therefore atomization of the fuel in combustion chamber is poor and incomplete burning result of low torque and break power.

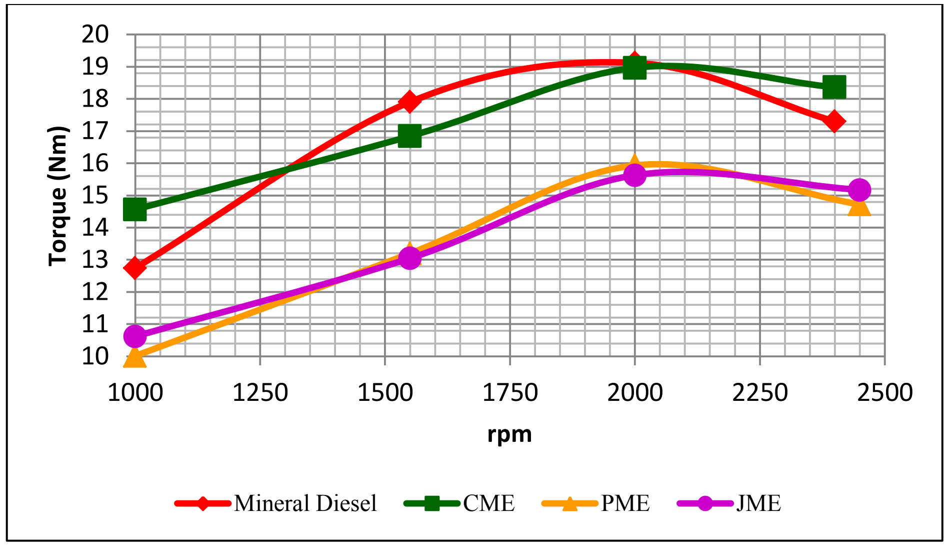

Figure 1: Variation of torque with engine speed in different fuels

The break power is proportionate with toque. According to the figure 2, break power of the CME was not significantly different from MD at α level in 0.05. The highest break power was given at lower and higher engine speeds from CME, as well as there was linear increasing of break power (R^2 = 0.992) in CME with engine rpm in between 1000 and 2500. The lowest break power was produced from PME and JME and 17.5% of P_B was lost from JME and PME comparatively with Mineral diesel and CME. When consider about break power, PME (R^2=0.977) and JME (R^2=0.997) showed almost same pattern with engine speed. Normally with increase of engine speed, amount of fuel supply to the engine is decreased. The ignition performance is also poor with increasing engine speed. Because of that, torque and break power is reduced after certain higher speed of the engine. When use of mineral diesel to the engine, the maximum torque was achieved at 1850 rpm, and increasing rate of break power was reduced at that engine speed. But CME has high torque engine speed. But CME has high torque and break power at lower engine speed and higher engine speed. The reason is that CME has higher cetane number like 70 [3], meaning a higher quality ignition. Therefore, uniform curve was shown by CME. Mineral diesel have high energy content; when mineral diesel came to the optimum ignition conditions (1450-1600 rpm), maximum torque and break power was seen.

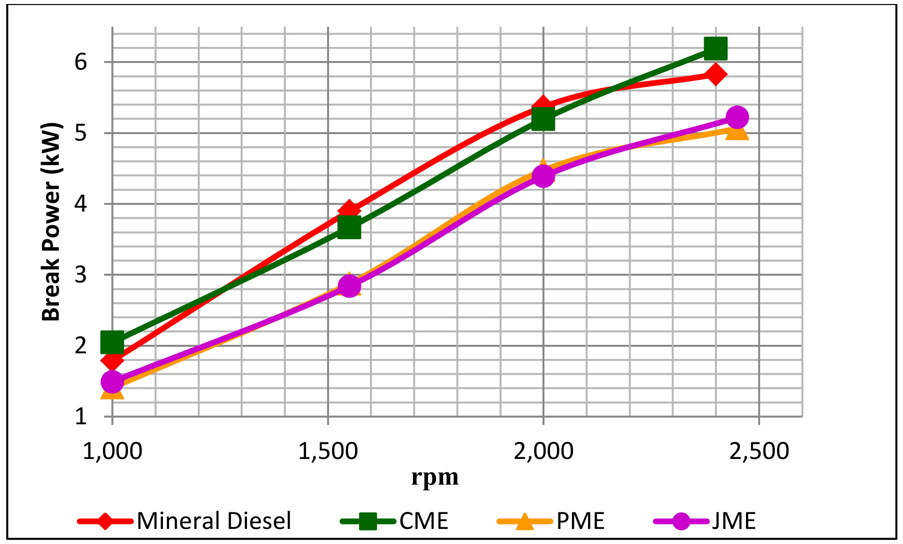

Figure 2: Variation of Break Power with engine speed in different fuels

In generally all the fuels showed the same changing pattern of SFC at different engine speed as seen in figure 3. SFC of the CME and PME were not significantly different from MD, but SFC of the JME was significantly different from MD. JME showed the lowest SFC with engine speed. But in lower speeds, PME and Mineral diesel showed higher SFC. Minimum SFC was shown by JME and CME. With increasing engine speed SFC had been reduced in Mineral diesel, whereas the minimum SFC was at 2000 rpm. There is higher SFC in CME at 2000 rpm. Maximum SFC was shown around 2500 rpm engine speed by CME and minimum SFC was shown by JME. In lower speed of the engine, the higher SFC was observed in PME and mineral diesel. Reasons for that, mineral diesel has low ignition condition at lower speed and high fuel consumption with lower power production. Because of that SFC was high at lower engine speed.

The SFC in PME was higher at low engine speed. The poor atomization and high fuel consumption was observed in PME as PME has higher viscosity than other diesel. But the amount of fuel in the fuel injection system was high with increasing engine speed. Then pressure of the fuel became high, then atomization was happened and PME has high cetane number. SFC was reduced as P_B increase. As well as the mineral diesel ignition quality was improved when engine speed increase and low SFC was observed at high engine speed. JME and CME have low SFC at low engine speed due to better ignition quality due to high cetane number, then high break power was produced at low speed with compared to fuel consumption.

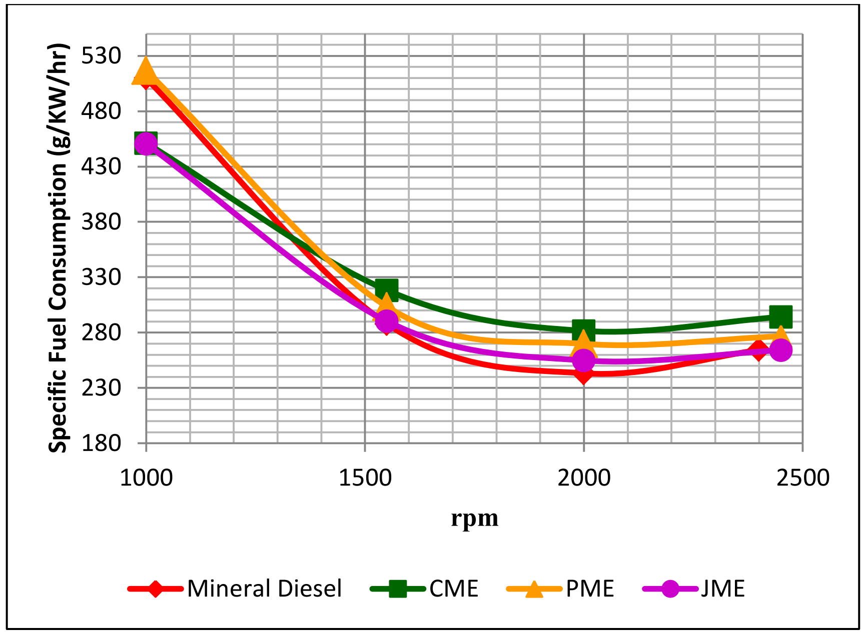

Figure 3: Variation of Specific Fuel Consumption with engine speed in different fuels

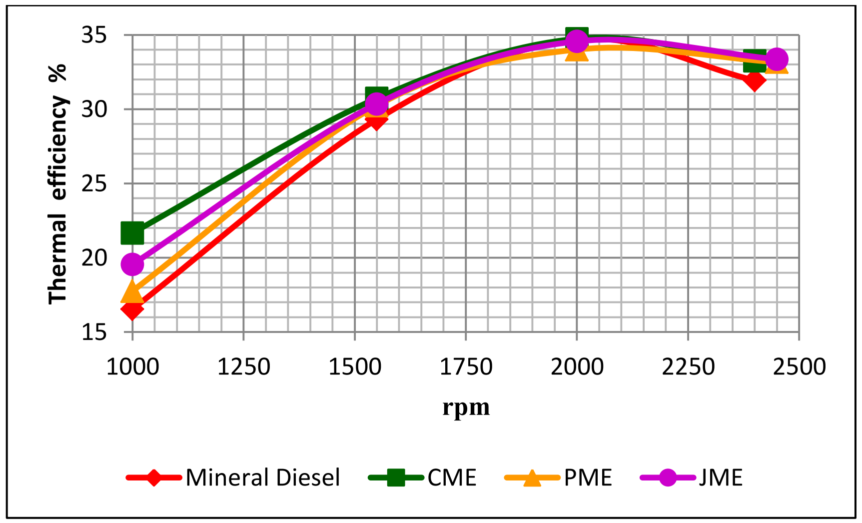

Figure 4: Variation of thermal efficiency with engine speed in different fuels

All fuels showed same changing pattern (linearity with engine rpm) of thermal efficiency (figure 4). Thermal efficiency of the CME and JME were significantly different from MD but PME were not significantly different from MD. Thermal efficiency of the PME was not significantly different from JME as well. The highest thermal efficiency was given by CME and minimum was given by Mineral Diesel. Thermal efficiency is the most important criteria in engine

performance. This study gave an idea about the overall performance of the engine when different oil sources were used. There was significant variation of thermal efficiency in engine with use of all the different biodiesel. Comparatively all the fuels have achieved thermal efficiency in between 25-27% at 2000 rpm.

Fuel property testing result

When diesel engine is used with biodiesel without any modification, the fuel properties should be compatible with mineral diesel. Therefore biodiesel should fulfill the ASTM stands when used for commercial purpose. The performance of the diesel engine fueled by biodiesel mainly depends on the properties of the biodiesel. The fuel property of the three different fuels is given in table 1.

Kinematic viscosity is mainly related with engine performance of any fuel. Objective of transesterification is to reduce kinematic viscosity of crude oil up to ASTM stands. High viscosity of crude oil is mainly due to triglyceride (TG), if the transesterification was successful biodiesel should contain methyl ester only. If biodiesel contains with TG, diacylglycerol (DG) or monoacylglycerol (MG), viscosity of biodiesel can be increased.

Table 1: Comparison of fuel property with compared to the ASTM standards

Property	**Fuel type**				**ASTM Limits for biodiesel (D 6751-01)**
	JME	PME	CME	Mineral diesel	
Kinematic Viscosity (mm^2/s)	6.9756	9.0763	4.8019	3.6912	1.9-6
Specific gravity	0.8659	0.8649	0.8642	0.8308	_
pH	8.8	8.7	8.9	6.3	_
Calorific value (kJ/kg)	40864.86	39229.8	36808.85	42667	_
Flash point (^oC)	131.5	141.5	125.5	83	1300
Copper strip corrosion	Brassy or gold (2e)	Magenta overcast (3a)	Claret red (2a)	Light orange (1a)	3 Max
Carbon monoxide (ppm)	667	547	489	1079	_
Nitrogen Oxide emission (ppm)	993	978	1045	918	_

There was a high viscosity for JME and PME, because of that still there can be TG, DG, and MG. Also viscosity affects the operation of fuel injection equipment, i.e. if the viscosity too high, pressure developing of fuel system is high and parts of the fuel system can be damaged and secondly atomization also gets poor, resulting in power losses. If the viscosity is too much low, lubricity of fuel is reduced and some parts of the fuel system can be damaged.

Specific gravity or density does not relate with engine performance but it is related with energy content of fuel. When consider about specific gravity or density of the fuel, bio diesel has high specific gravity. Normally fuels are used as volumetrically, so use of high density fuel is very important, because energy content of the fuel is representing on weight basis. Normally biodiesel has lower energy content than mineral diesel and energy value of JME (weight basis) was 4.22% lower than mineral diesel. JME has higher specific gravity than other fuel types (Table 2).

Table 2: Comparison of energy content in weight basis and volume basis compared to the MD

Fuel type	Specific gravity	Energy content (kJ/kg)	% of different from Mineral diesel in weight basis	Energy content (kJ/L)	% of different from Mineral diesel in volume basis
JME	0.866	40864.86	-4.22	35383.78	-0.18
PME	0.865	39229.76	-8.06	33929.57	-4.28
CME	0.864	36808.85	-13.73	31811.62	-10.26
Mineral Diesel	0.831	42667	0.00	35447.74	0.00

The pH value of the fuel is very important, but it does not give an idea about engine performance. Normally fuel should be neutralized (pH near 7). In biodiesel pH is very important because during biodiesel production, NaOH was used as catalyst resulting increased pH. During washing of biodiesel NaOH was removed, and then pH should be reduced up to near 7. Therefore pH gives an idea about amount of NaOH remaining in biodiesel and level of washing. The pH value of biodiesel was near 9 and that means still there may be remaining NaOH, so this biodiesel should be washed more to reduce pH up to 7.

Calorific values of the biodiesel were lower than mineral diesel and lower amount of energy release when biodiesel is burnt than mineral diesel. The energy content of fuel or calorific value is not depend on method of manufacturing of biodiesel. It is mainly depend on type of plant oil used to biodiesel production. Energy content of the same biodiesel can be different in different areas and during different seasons due to the condition of available feedstock.

Flash point of the biodiesel was higher than mineral diesel, which means that biodiesel are safer than mineral diesel. Flash point relates with flammability of fuel and not related with performance. Reason for the increased flash point in biodiesel is that the chemicals in methyl ester have high boiling point, requiring high temperature to produce vapor of biodiesel. Biodiesel should be opened to environment after it produced for removal of excess methanol, or during washing the excess methanol in biodiesel has to be removed. If the biodiesel did not fulfill this requirement methanol can be still in biodiesel, due to this flash point of the fuel can be reduced. Flash point of the CME was 125.5^{0}C, which was lower than ASTM limits. Then CME can be still having excess methanol, which was proved with pH of CME was high, so we can conclude CME not propoerly washed.

Copper strip test has given an idea about corrosively of the fuel. In all the biodiesel were fulfilled ASTM limits. Then these fuels can be used in engine without any problem.

In this research CO and NOx were only measured within the available facilities. When consider about CO, it was reduced by nearly 47%. CO emission is result from the incomplete burning of the fuels. Due to high cetane number of the biodiesel, ignition quality is high and due to that CO emission had reduced. Due to complete burning of the fuel, unburned hydrocarbon emission also reduced. It is extremely important since CO is a toxic and air pollutant gas. There is a disadvantage with biodiesel because of the NOx emission is increased by nearly 10%. NOx is also environmentally harmful gas contributing to acid rains. All the biodiesel had been produced from plant oils. Normally plant and animal oils contain high amount of N. Due to this N, NOx emission have increased. But, comparatively high reduction of CO, biodiesel gave an advantage in exhaust emission. Further introduction of NOx filters can be used with exhaust to minimize the release of NOx to the environment.

Conclusion

According to the test results, the performance of the engine, which was fueled by biodiesel, was mainly depended on the final quality of the biodiesel. The similar performance was shown in CME with mineral diesel; because of the CME fulfilled ASTM standard than JME and PME. According to the properties of JME and PME, there had been an incomplete transesterifcation processes. The performance of the engine was not affected when using biodiesel with standard quality. The emission of CO from exhaust was reduced by 45%, therefore biodiesels also environmental friendly. Therefore biodiesel can be used in agricultural tractor engine with replacing mineral diesel. But strong recommendation cannot be given for biodiesel without long term durability test of engine. During manufacturing, it is essential to maintain better quality control of biodiesel.

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Determination of Temperature Profiles inside Fruits and Vegetables during the Process of Drying

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Abstract

The purpose of this research work was to model the phenomenon of heat transfer across various fruits and vegetables during the process of drying with the aid of modern computational modelling and simulation techniques. The outcomes of the analysis were the temperature profiles across perishable crops during their drying process and rate of heat transfer. A mathematical model was developed using the equations for different modes of heat transfer and for different geometries of fruits and vegetables. This mathematical model was then incorporated with proper system characteristics and valid assumptions to simulate the phenomenon in MATLAB with an accordingly developed program. Via the simulation, the rates of heat transfer were calculated and temperature profiles were plotted. Eventually, the implications of the study, its possible contribution for further related research work and the ways of improving such an analysis were discussed.

KEYWORDS: Drying, temperature profiles, rate of heat transfer, fruits & vegetables, modelling & simulation, energy efficiency

Introduction

During the process of drying, heat is applied on and transferred through plant materials in order to reduce the moisture content and inhibit the microbial growth in order to decelerate the spoilage and increase shelf life (1). There are mathematical equations that govern the various modes of heat transfer like conduction, convection and radiation. The equivalent equation that governs heat transfer for a given drying process depends on parameters like the geometry of the fruit or vegetable and the type of heating process incorporated (2) (3). Once these parameters are determined and approximated, you could come up with a corresponding equivalent equation that governs the heat transfer throughout the process. By solving such an equation the temperature inside the plant material could be derived as a function of the position. Since these equations are too complicated to be solved manually, modern computational techniques could be used to solve these equations comfortably and accurately. A significant advantage of these techniques is that they have inbuilt tools which could represent the resulting temperature profiles visually and mathematically in ways that are very effective and efficient. These visual and mathematical representations could then be used as auxiliary tools to optimize these drying processes and hence increase their energy efficiency.

Methodology

Developing the Mathematical Model

The effectiveness and the efficiency of a drying process are directly correlated to the nature of the heat transfer associated. The nature of the heat transfer that governs the drying process is dependent on the geometry of the fruit or vegetable that's going through the process (2). Even though the actual geometries of these are complicated in nature, the possibility is there that we could analyze the transport phenomena associated by making few reasonable and yet effective approximations (3). In other words, it could be assumed that the geometry of a given fruit or vegetable is either rectangular or cylindrical or spherical or a combination of these. With this assumption incorporated with the fundamentals of heat transfer, the mathematical model for the drying phenomenon of a given perishable crop could be developed. The approximated geometry of the each and every fruit or vegetable that went through the calculations of this model is mentioned in Table 1.

When developing a generalized mathematical model for heat transfer during a drying process, there are few process parameters that should be stated and kept fixed for the sake of better comparison and understanding of results that you're going to obtain and visualize eventually. The first such parameter is the state of the heat transfer process (i.e. whether it's steady state or unsteady state). The larger part of an industrial drying process could be considered as steady state because the time period spent for unsteady, start-up and the shut-down of the process are negligible when compared to the steady part of the process. Therefore it could be assumed that the whole process is under steady state and consequently the mathematical model could be built according to the steady state analysis of heat transfer (4).

The second parameter that has to be stated and fixed here is the number of the dimensions to which the analysis would be extended. For the sake of clarity and effectiveness of the analysis, the heat transfer would be analyzed along only one main dimension when considering each of the geometries mentioned above. Length will be the dimension when studying the rectangular geometry and the radial dimension will be taken into consideration in both cylindrical and spherical geometries.

Mainly there are three fundamental modes of heat transfer. They are conduction, convection and radiation. Theoretically every phenomenon of heat transfer is a combination of all three (2) (3) (4). But more often than not, only the most dominant mode is taken into consideration because that would make the study more clear, efficient and effective. This could be mathematically justified as the impact of the less dominant modes becomes negligible despite their presence. Almost all the fruits and vegetables are solids. And in solids, the most dominant mode of heat transfer is conduction (2) (3) (4). Therefore in our analysis, mainly the conductive heat transfer will be taken into consideration.

According to these assumptions and fixation of parameters, this mathematical model would be under one dimensional, steady state analysis of conductive heat transfer.

Mathematical Model

Rectangular Coordinates

Heat Transfer Rate,

$$q = \frac{T_1 - T_2}{\frac{L}{kA}} \qquad \text{Eq.1}$$

Where,

q =Rate of heat transfer (W)

T_1, T_2 =Temperature at the boundaries (K)

L =Linear distance along the dimension under consideration (m)

k =Thermal conductivity (W/mK)

A =Cross sectional area perpendicular to the direction of heat transfer (m^2)

Temperature Profile,

$$T = \left[\frac{T_2 - T_1}{L}\right] x + T_1 \qquad \text{Eq.2}$$

Where,

x =Distance at which the temperature has to be determined (m) ($x \leq L$)

T =Temperature at distance x (K)

Cylindrical Coordinates

Heat Transfer Rate,

$$q = \frac{T_1 - T_2}{\frac{1}{2\pi k}\ln(\frac{r_2}{r_1})} \qquad \text{Eq.3}$$

Where,

q =Rate of heat transfer (W)

T_1, T_2 =Temperature at the boundaries (K)

k =Thermal conductivity (W/mK)

r_1 , r_2 = radii at boundaries (m)

Temperature Profile,

$$T = C_1 \ln(r) + C_2 \quad \text{Eq.4}$$

$$C_1 = \frac{T_2 - T_1}{\ln(\frac{r_2}{r_1})} \quad \text{Eq.5}$$

$$C_2 = \frac{T_1 \ln(r_2) - T_2 \ln(r_1)}{\ln(\frac{r_2}{r_1})} \quad \text{Eq.6}$$

Where,

C_1 , C_2 =integrating constants

r =Radius at which the temperature has to be determined (m) ($r_1 \leq r \leq r_2$)

T =Temperature at radius r (K)

Spherical Coordinates

Heat Transfer Rate

$$q = \frac{T_1 - T_2}{\frac{1}{4\pi k}(\frac{1}{r_1} - \frac{1}{r_2})} \quad \text{Eq.7}$$

Where,

q =Rate of heat transfer (W)

T_1, T_2 =Temperature at the boundaries (K)

k =Thermal conductivity (W/mK)

r_1 , r_2 =radii at boundaries (m)

Temperature Profile

$$T = -\frac{C_1}{r} + C_2 \quad \text{Eq.8}$$

$$C_1 = \frac{T_2 - T_1}{\frac{1}{r_1} - \frac{1}{r_2}} \quad \text{Eq.9}$$

$$C_2 = T_1 + \frac{1}{r_1}\left[\frac{T_2 - T_1}{\frac{1}{r_1} - \frac{1}{r_2}}\right] \quad \text{Eq.10}$$

Where,

C_1 , C_2 =integrating constants

r =Radius at which the temperature has to be determined (m) ($r_1 \leq r \leq r_2$)

T – Temperature at radius r (K)

Thermal Conductivities, Boundary Conditions and System Characteristics

For the development of a more accurate, reliable and realistic model to determine the temperature profiles & rates of heat transfer, calculations should be provided with accurate and reliable values of the thermal conductivities (k) and the boundary conditions. Published experimental data for the values of thermal conductivities for perishable plant food products is not rare. In these calculations a few of such published materials were used (5) (6) (7). Table 1 contains the thermal conductivity data gathered from those sources and they were adopted in the calculations accordingly.

Boundary conditions that have to be applied here are the distances or radii (L, r_1 ,r_2) and the corresponding absolute temperatures (T_1, T_2). For a rectangular coordinate system, a length would be required with two temperatures at ends of that particular length and for both cylindrical and spherical coordinate systems two radii at boundaries with respective temperatures would be the boundary conditions. Additionally, for the calculations in the rectangular coordinates, the cross sectional area perpendicular to the heat transfer (A) is going to be necessary. This analysis is based on the hypothesis that these fruits and vegetables are dried in a batch, heated-air dryer where a constant drying temperature of 60 ^{0}C (140 ^{0}F) maintained (1) (8). This is an empirically derived and proven temperature under which the moisture from the food materials removes efficiently without adversely affecting the desirable qualities of the food like texture, colour, flavour and nutritional value (1) (8). For a food material analyzed under a rectangular coordinate system, the distance that is required for the boundary value (L) could be directly measured using a scale of length. When it comes to the cylindrical and spherical systems, the outer radius (r_2) is the outer boundary value and even though an inner boundary could not be measured directly, for the sake of accurate calculations, valid assumptions were made. The boundary values used for each of the food products are mentioned in Table 2.

Algorithm & Dynamic Simulation

Thermal conductivities, boundary conditions, system characteristics with all the valid assumptions were incorporated into the developed mathematical model to construct the algorithm that was used for the dynamic simulation and to obtain the results. Similar to the mathematical model, the algorithm also had three separate sections dedicated to the rectangular, cylindrical and spherical coordinate systems. Each section started with the definition of system characteristics and boundary conditions appropriately. Then using the equations in the model, heat transfer rate and temperature profile could be derived simultaneously.

The computational tool MATLAB was used for the dynamic simulation of the model. Therefore a MATLAB program was developed using the algorithm that had been constructed. This program when run in a computer with adequate capabilities and performances, would take the inputs for the system characteristics and boundary conditions for a given fruit or vegetable from the user and then execute the calculations by itself. It would calculate the heat transfer rate and the temperature at a given valid position. Eventually it would plot the temperature profile for the defined context and depict it as a graph. Such graphs were plotted for every perishable food product mentioned in Table 1.

Table 1: Approximated Geometries and Thermal Conductivities of Selected Fruits and Vegetables ((5) (6) (7))

	Food Material	Approximated Geometry	Thermal Conductivity (W/m.K)	Reference
1	Apples, red	Spherical	0.513	(7)
2	Banana	Cylindrical	0.498	(6)
3	Beans, runner	Rectangular	0.398	(5)
4	Lemon	Spherical	0.592	(6)
5	Pineapple	Cylindrical	0.567	(6)
6	Carrots	Cylindrical	0.669	(5)
7	Onions	Spherical	0.575	(5)
8	Potatoes	Spherical	0.648	(7)

	Food Material	Temperature Boundary Conditions		Positional Boundary Conditions	
		T_1(inner)(^{0}C)	T_2(oven)(^{0}C)	r_1 or L(inner)(cm)	r_2(outer)(cm)
1	Apples, red	27	60	0.1	3.5
2	Banana	27	60	0.1	2.5
3	Beans, runner	27	60	18	N/A
4	Lemon	27	60	0.1	2
5	Pineapple	27	60	0.1	6
6	Carrots	27	60	0.1	2
7	Onions	27	60	0.1	3
8	Potatoes	27	60	0.1	3

Results & Discussion

For the fruits and vegetables in the above Tables 1 & 2, the calculated heat transfer rates are tabulated in Table 3 below.

Table 3: Calculated Heat Transfer Rates

	Food Material	Heat Transfer Rate (W)
1	Apples, red	-0.084
2	Banana	-13.106
3	Beans, runner	-729666.667
4	Lemon	-0.075
5	Pineapple	-9.050
6	Carrots	-10.483
7	Onions	-0.076
8	Potatoes	-0.067

The graphs that visualize the temperature profiles of the above perishable crops are also an important outcome of the modelling simulation process as already mentioned above. These graphs are in the Figures 1 to 8 below.

For the sake of clarification and better explanation, the interface that runs in MATLAB during the dynamic simulation is mentioned here in Table 4. It should be considered that this is merely the interface, not the program or the code.

Table 4: The Interface that Runs in MATLAB during the Dynamic Simulation

```
geometry(1-rectangular,2-cylindrical,3-spherical): 3
thermal conductivity(W/mK): 0.513
oven temperature(C): 60
inner temperature(C): 27
inner radius(cm): 0.1
outer radius(cm): 3.5
What is the radius you want to determine the temperature
at?(cm): 3
heat transfer rate in watts:-0.084
Required Temperature in degrees of Celsius:59.84
```

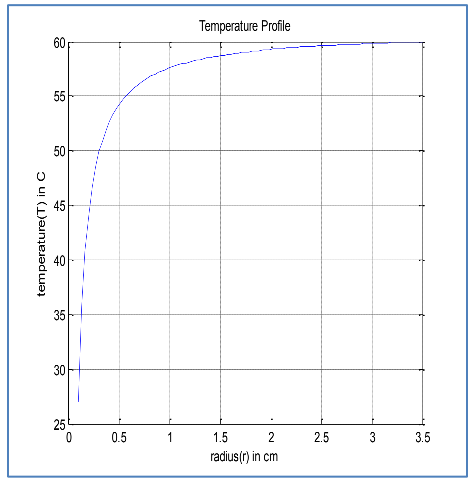

Figure 1: Temperature Profile for Apples, red

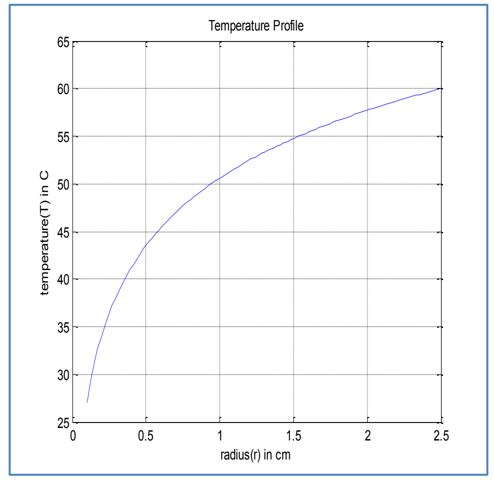

Figure 2: Temperature Profile for Banana

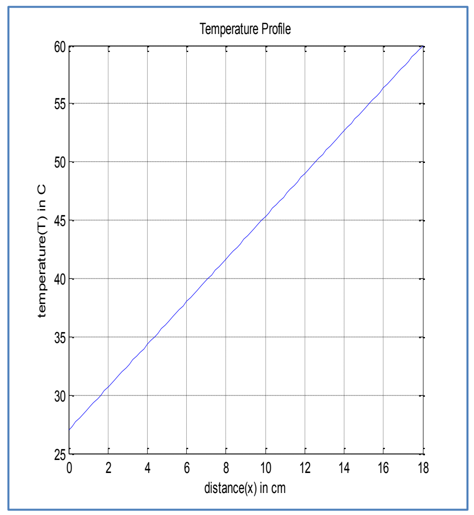

Figure 3: Temperature Profile for Beans, runner

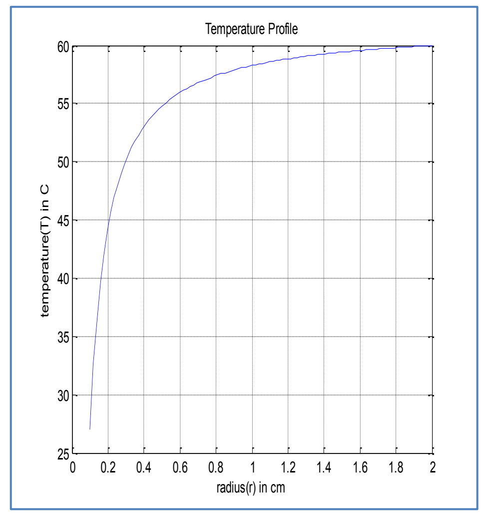

Figure 4: Temperature Profile for Lemons

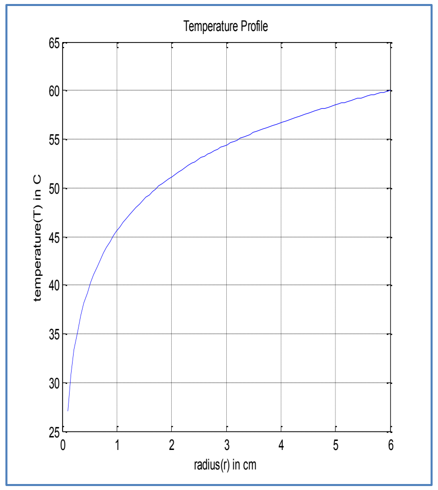

Figure 5: Temperature Profile for Pineapple

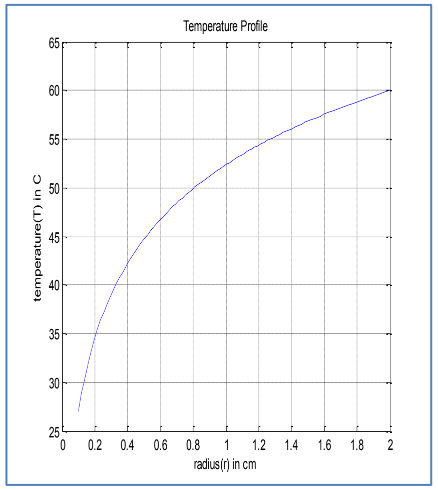

Figure 6: Temperature Profile for Carrots

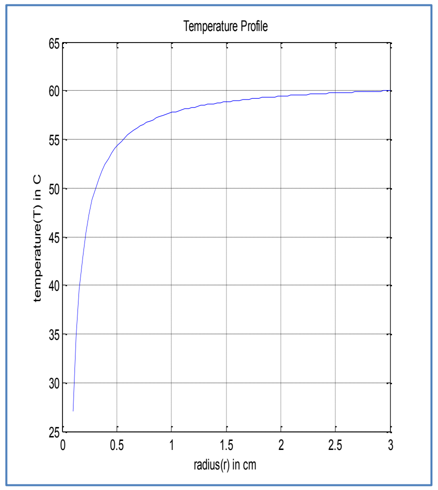

Figure 7: Temperature Profile for Onions

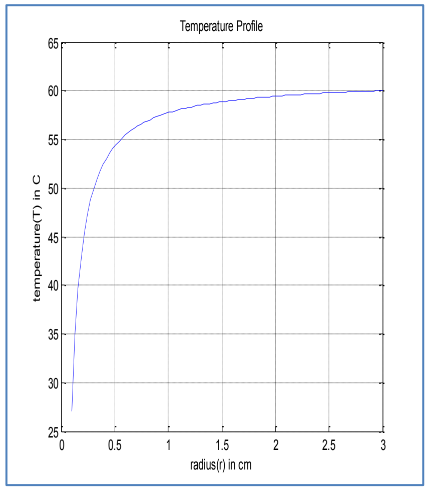

Figure 8: Temperature Profile for Potatoes

It seems that both heat transfer rate and temperature profile are significantly and considerably varying according to the geometry of the fruit or vegetable which is under consideration. When the system characteristics and the boundary conditions are fixed, the spherical geometry has the lowest heat transfer rate. And the rectangular geometry has a very high heat transfer rate while the cylindrical geometry is associated with a rate of heat transfer of intermediate magnitude. One main reason behind this phenomenon is that the length (a second dimension along which the heat transfer has not been analyzed here) coming into play when considering both rectangular and cylindrical systems. The total length is considered in the calculations of rectangular systems and a unit length is

taken into the calculations of cylindrical systems. There's no such length factor in the spherical systems (2). This emphasizes that there are specific and special things to be kept in mind when comparing the heat transfer characteristics of different geometries.

The negative sign of the heat transfer rate is something that should be discussed upon. According to the theories of heat transfer, the sign of the rate of heat transfer is an indication about the direction of heat transfer (3). A positive sign states that the heat transfer is occurring in the same direction as is considered while developing the mathematical model (I.e. heat transfers in the same direction as assumed in the analysis). A negative sign like here implies that heat transfer happens in the exact opposite direction as it has been assumed (2). Here in this analysis, while developing the mathematical model, it was assumed that heat is transferred from the inside of the perishable crops to the outer environment. But it's obvious that the actual scenario is that during drying, heat is supplied from the oven environment into the fruits or vegetables in order to take the moisture out (1). Therefore the heat transfer occurs in the exact opposite direction to which it was assumed in the mathematical model. This is symbolized by the negative sign of every rate of heat transfer in Table 3.

Similar to the magnitude of the rate of heat transfer, the nature or shape of the curve that represents the temperature profile is also directly dependent on the geometry. Fruits and vegetables with a rectangular geometry exhibit a linear behaviour. Even though both cylindrical and spherical geometries inherit temperature profiles of nonlinear nature, there are highly notable differences among their curves as well. In general, cylindrical systems show normal parabolic behaviour while spherical systems are more into the curves of rational functions. This could be explained and validated using the mathematical model as well. The physical outcome of this is that, in spherical fruits or vegetables, there is a drastic temperature variation occurring close to the centre. In cylindrical crops the variation is not that drastic though it's not linear. When it comes to rectangular systems, the temperature variation is directly proportional to the distance.

Even though it was assumed that the contribution of convective heat transfer and radiation is negligible here in this analysis, if there's a possibility to couple them into this mathematical model, it would only improve the accuracy of the results. When heat is being transferred from the oven into a particular fruit or vegetable, a thermal boundary layer is formed between the outer wall of the fruit or vegetable and the oven environment (2) (3). Because of this the true heat transfer is a combination of both conduction and convection. Although at room temperature and the lower temperatures the contribution of radiation could be considered as negligible, it increases drastically with the temperature increments (2) (3) (4). Therefore, at a temperature like 60 ^{0}C the impact of radiation could be at least of a considerable level. Hence, if the analysis could adopt these two modes of heat transfer and their impacts, it would enhance the effectiveness of the study by leaps and bounds.

Despite the fact that theoretically, thermal conductivity is a temperature dependent property, in this analysis it has been assumed that it is not (4). It is not a blind assumption made for making the calculations easier. But when you look deep into the phenomenon of temperature dependency of thermal conductivity, it could be observed that for the temperature range under consideration, the magnitude of variation of the property could be considered negligible. Therefore still, this assumption should be seen as cogent and valid.

Conclusion & Future Work

Via this analysis, both the heat transfer rate and the temperature profile for a fruit or vegetable, during the process of drying could be accurately determined given that all the correct system characteristics and valid assumptions are combined with the proper hypothesis for the heat transfer model associated.

- Heat Transfer Rate: the rate of transfer of energy as heat across any cross sectional area within the crop could be determined
- Temperature Profile: the temperature of any given position within the crop and along the dimension under study, could be determined

It could also be concluded that these heat transfer characteristics are very much dependent on the geometry of the fruit or vegetable under consideration. Perishable crops of different geometries possess temperature profiles of very different natures.

The heat transfer rate and temperature profile determination procedure could be incorporated with any study that intends to analyze the drying of fruits and vegetables with the aid of modelling and simulation. For any study like that, temperature within the crop and energy transfer rate across the crop are going to be very important characteristics and a model that derives these data accurately could only be immensely helpful.

The next stage of this study is to validate it with experimentally obtained data. The accuracy of this analysis could be checked and proven by measuring the actual heat transfer rate within the appropriate food material, measuring and plotting the temperature within the fruit or vegetable with the distance along the appropriate dimension and then comparing it with the values obtained via the computational program that was built on our mathematical model.

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Utilization of Hybrid Energy System for Drying Paddy

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Abstract

Rice is the staple food of the inhabitants of Sri Lanka. Moisture content of the paddy crop is around 24 and 26 % (WB) at harvesting stage and it should be reduced upto a safe limit immediately. The present study was undertaken to design a solar hybrid dryer with utilizing solar energy and biomass energy extracted from rice husk.

The drying bin was designed as thin bed dryer with the capacity of 200 kg by dividing into three longitudinal parts. The roof of the paddy husk furnace was designed as a solar collector with the area of 1.44 m^2 and the rice husk furnace was designed with rectangular shape for transferring heat to air which passed through solar collector. The performance of newly designed hybrid paddy dryer was evaluated to test the suitability of it for field conditions. Thermo regulator and blower were used to regulate the temperature inside the drier and generate air flow through drying bed respectively.

Ambient condition of air temperature and solar radiation were recorded continuously in every hour during drying period. The dryer was tested for unloading and loading condition. The temperature of the drying bin, solar collector and plenum chamber were recorded using thermo couple meter during half an hour interval. The performance of the dryer was evaluated using drying curves.

Drying air temperature can be increased up to 65 °C by designed solar collector and temperature inside the drying bin can be increased up to 39 °C. The hybrid dryer spent about 8.5 h time interval to reach the safe moisture level up to 14 %. Drying air temperature can be maintained around 45°C with the utilization of biomass energy under lower irradiation values.

Keywords: Energy, Paddy drying, Solar, Rice husk, Irradiation

Introduction

As a cereal grain, Rice is the most important staple food for a large part of the world's human population. Paddy is the single most important crop occupying 34 % (0.77 million ha) of the total cultivated area in Sri Lanka (Department of Agriculture, 2009). Paddy is usually harvested at grain moisture content (MC) in between 24 and 26 % (wet basis) [1]. The paddy with high moisture content should be dried quickly to reduce moisture content for safe storage. For storage beyond 3 months, the grain should be dried to 12-12.5 % [2]. Sun drying is the conventional method but some drawbacks are identified as poor quality due to contaminate with grit and dirt. Deterioration can also happen due to delay drying in unfavorable weather conditions. The alternative to sun drying is mechanical drying, which uses equipment for holding the paddy, blowing air through the grain mass and heating the air so it will absorb more moisture and drying process is completed within short time duration. Sri Lanka has a high potential for the production of solar energy and it lies within the tropical region. The annual daily average of solar radiation on a horizontal plane in Sri Lanka is 15-20 MJ m^{-2}d^{-1} [3]. Compared to sun drying, solar dryers can generate higher air temperatures thus consequential lower relative humidity which is a conducive feature for improved drying rates and lower final moisture content of the drying crops. This method has several advantages such as less spoilage and less microbiological infestation, thus leads to improved and more consistent product quality. Some disadvantages can be identified in solar drying like solar energy being an intermittent source.

Rice husk, a major by-product of the rice milling industry, is one of the most commonly available lignocelluloses material that can be converted to different types of fuels and chemical feedstock through a variety of thermo chemical conversion processes. The lower heating values ranged from 13·24 to 16·20 MJ/kg (dry weight basis) [4].

Most of the large scale paddy growing farmers use combine harvester for harvesting the paddy and they directly bring paddy to the mill without drying. Due to this reason, the milling operation of paddy and storage of paddy is badly affected. Therefore introduction of dryers using solar energy and biomass energy for the farmers in the rural areas is very important to maintain the quality standards of paddy milling industry.

The present study was mainly concerned with the design and development of the hybrid dryer (solar energy and biomass energy) for drying paddy and performance of the dryer was evaluated to check the suitability.

Methodology

Locally available material was used for the design of solar hybrid dryer for paddy drying. The heat energy for drying process was extracted through solar radiation and combustion of rice husk as biomass energy. The dryer has three main parts as the drying chamber, solar collector and furnace. These parts were constructed separately and finally fixed together at the site.

The roof of the furnace was modified as a solar collector. The area of the collector was 1.44 m^2 with square shape and it was oriented with 14° to the horizontal in order to maximize the efficiency. The collector was constructed using aluminum sheets, ply-wood board, rigifoam, glass and metal sheet. The corrugated absorber plate was painted to obtain a blackish surface to absorb maximum solar heat radiation and to minimize reflection of solar radiation and thus to improve the efficiency of solar collector.

Furnace was designed to have a rectangular shape and was made with iron bars & metal sheet, bricks, clay and cement. The heat exchanger inside the furnace was designed with 5 cm GI metal pipe with several bends which facilitate to hold air longer times and increase contact area for efficient heat transferring process. Rice husk was burned to obtain heat energy. The heated air through solar collector was moving through furnace making it being further heated. Then heated air was dragged by blower and introduced into the drying bin. Blower (8.5 m^3/min, 2850 rpm and 440 W) was connected to bottom of the drying chamber. Blower was selected according to static pressure theory [5].

The drying chamber was designed to have a rectangular shape and was divided into three longitudinal parts to improve the drying operation. It was constructed using aluminum sheets, ply-wood, mc-foil, iron bars, nail and mesh. The dimension of the dryer was 0.9 m x 0.6 m x 1.2 m. The capacity of drier was 200 kg of paddy per batch. The perforated wire mesh used at the bottom of the paddy bed and side walls of the longitudinal parts are used to facilitate the flow of heat across the paddy bed. The dryer was installed along the north-south direction. The schematic diagram of the newly designed dryer is given in figure 1.

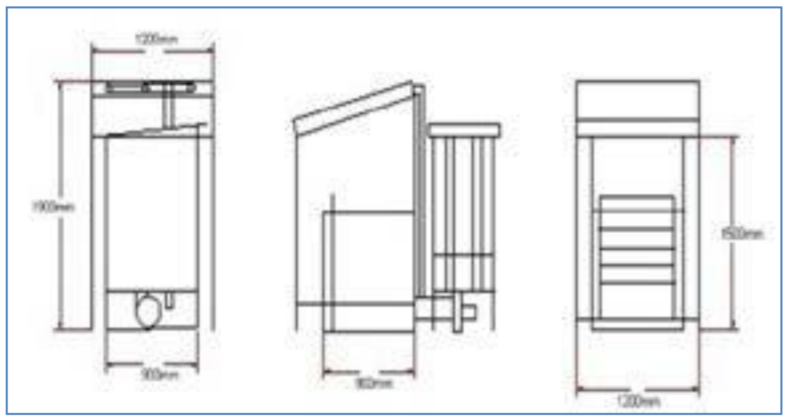


Figure 1: Schematic diagram of the newly designed drier

Thermo regulator was used to maintain constant temperature inside the chamber. Thermocouples were used to observe temperature fluctuations in different parts of the dryer throughout the drying process and these were located at the centre of the drying chamber, plenum chamber and at the centre of the solar collector. Air temperature, relative humidity, solar radiation and wind velocity were recorded and monitored continuously as parameters of ambient condition in every hour during the drying period. Temperature, relative humidity, solar radiation and wind velocity were measured using dry bulb thermometer, wet bulb thermometer, pyranometer and anemoneter respectively.

Paddy dryer was tested using solar energy and biomass energy under loading and unloading condition. The temperature and moisture content of the drying bin was measured in the places given in the following figure 2.

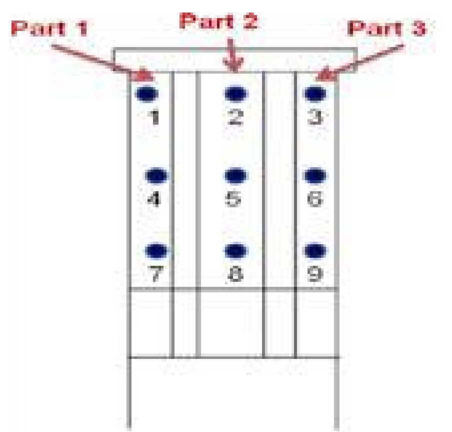


Figure 2: (a) Positions of moisture determination,

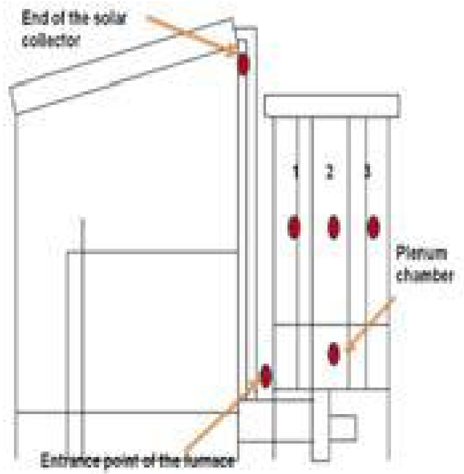


Figure 2: (b) Positions of temperature determination

Rice husk feeding rate was determined by measuring total amount of rice husk needed to obtain desired temperature in the drying chamber.

Drying efficiency was calculated using equation 1 [6].

$$Drying\ Efficiency = \frac{T1-T2}{T1-Ta} \qquad \text{Eq.1}$$

Where,

T1 = Inlet air temperature in to the dryer

T2 = Outlet air temperature from the dryer

Ta = Ambient air temperature

Thermal efficiency was calculated using equation 2 [7].

$$Thermal\ Efficiency = \frac{\varphi\times\lambda\times(M_0-M_f)\times100}{W\times C(100-M_0)} \qquad \text{Eq.2}$$

Where,

M_f = Initial moisture content (%, wet basis)

M_0 = Final moisture content (%, wet basis)

ϕ = Quantity of the final dried product at M_f moisture content (kg)

λ = Latent heat of vaporization of water (kCal/kg)

W = Quantity of fuel used (kg)

C = Calorific value of fuel used (kCal/kg)

The data were analyzed to determine the performance of the dryer. Moisture content of dried grain and temperature variation during drying process were determined using the drying curve. Statistical software (SAS) was used for data analysis.

Results and Discussion

The Unloading test of the dryer was done using solar energy and biomass energy. The temperature variation in drying chamber, solar collector and plenum chamber during the testing periods was given in figure 3. There is not much difference among the temperature variation pattern of the three parts of the drying chamber with unload conditions. There is a profound effect of solar energy for increasing the temperature inside the dryer. The average ambient temperature and solar irradiation were recorded as 30-35°C and 0.633 kW/m^2 respectively and temperature at outlet of solar collector was recorded as 65^{o}C at 12.30 p.m.

Temperature variation during load test and unload test are given in figure 4 (a) and (b).

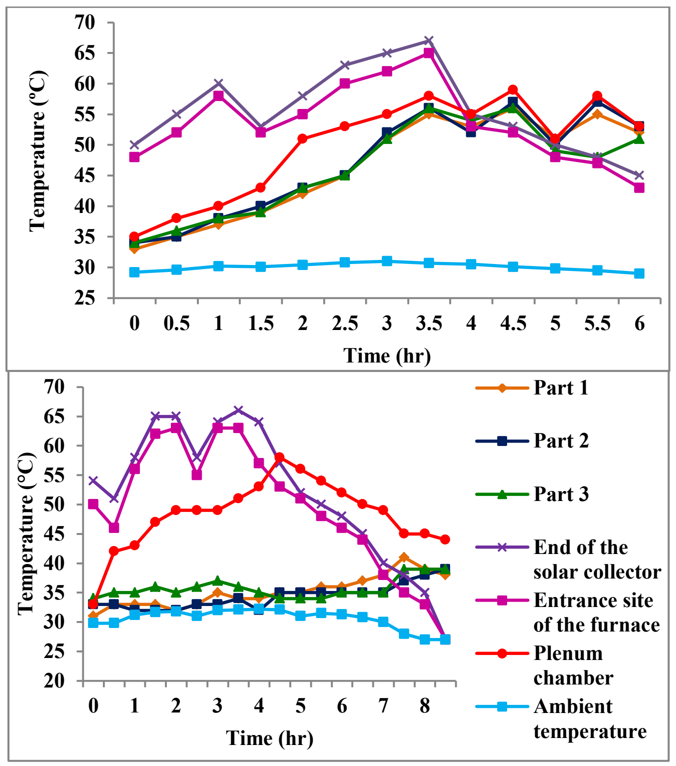
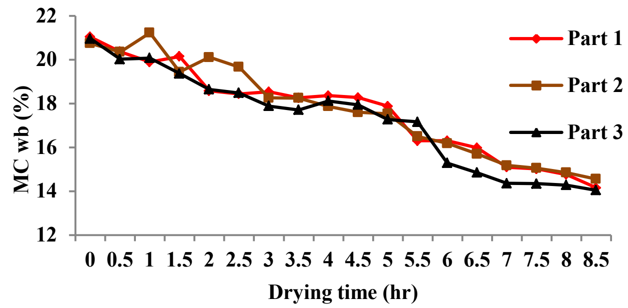
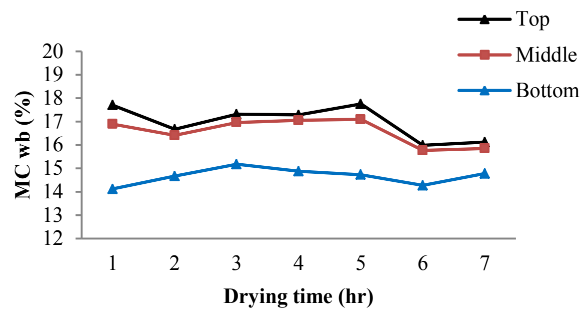


Figure 3: Temperature variation using solar energy and biomass energy (a) with unload test condition (b) with load test condition



(a)



(b)

Figure 5: Moisture variation during drying periods (a) among different bins (b) with depth of the bin

The temperature of the air heated through solar collector was observed around 60 - 65 °C during the morning session and it was decreased during afternoon session. The drying air was heated with the biomass energy during evening session and drying process was continuing until 6.00 pm. The drying air temperature can be maintained about 45 °C though the ambient air temperature was about 28 °C. Thus the newly designed dryer can be used for drying the grain under bad weather condition.

Temperature inside the grain bin was observed as 39 ^{o}C. It was lower than the expected value as adjusted temperature was 50 ^{o}C for drying the grain. Though temperature of plenum chamber was higher and it was not properly moving through the grain bin due to high resistant of grain bin for air moving. Husk feeding rate of the designed dryer was observed as 2.35 kg/hr.

The moisture variations of the different parts of the dryer and depth of the dryer were shown in figure 5. There is no remarkable difference among the different parts of the drying bin and moisture content of the Paddy reached to safe level during 8.5 h time duration.

It was indicated that heated air circulation among the parts of bin had better pattern. Moisture content of the dried grain varied significantly (p=0.05) with depth of the grain bin & bottom layers were dried quickly than the top layers. The heated air was not properly distributed horizontally through the vertical mesh. Pressure in the blower was not sufficient to distribute the air. Therefore, it needs to contain the sufficient pressure to distribute air throughout the drying process.

The drying efficiency and the thermal efficiency of the dryer were observed as 83.3% and 12.1% respectively. According to the experiment conducted by the Ayyappan and Mayilsamy (2010) the thermal efficiency of the solar tunnel drier was calculated with an average efficiency of 18% [8].

Conclusion

The average temperature inside the grain bin during the unload and load test with paddy were observed as 56 ^oC and 39 ^oC respectively. Drying air temperature can be increased up to 65 ^oC by designed solar collector and temperature inside the drying bin can be increased up to 39 ^oC. The hybrid dryer spent about 8.5 h time interval to reach safe moisture level up to 14 %. Drying air temperature can be maintained around 45°C with utilization of biomass energy under lower irradiation values. As thermal efficiency of the dryer is lower than the reported literature, the air circulation pattern of the drier should be improved.

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Use of Simulation for Optimizing Energy Performance and Indoor Environment Quality of New Buildings

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Abstract

Building energy performance and its indoor environmental quality incorporated with visual and thermal comfort have become critical issues from both indoor environmental and financial points of view. Building performance simulations are useful to understand and move towards optimized building performance during the design phase. These become important tools in the hands of experienced designers/engineers to derive better performance through optimization.

This paper describes how simulations have been used to improve performance, benefitting building owners through energy efficiency and occupants through better visual and thermal comfort, supporting the work of architects and designers. In this instance, the developers of a commercial real estate project in Colombo required guidance regarding glass used for cladding and HVAC system options to understand impacts related to design alternatives.

Simulations were used to determine the best performing glass cladding to be used for the building. Due to high exposure to direct solar radiation in a multi-storey building, using glass cladding could have high thermal impact as well as visual and thermal discomfort. Simulation results identified the glare generated within the building at different times of the day for different glass options. A whole building energy simulation was used to determine the variation of building cooling load, its energy consumption with the said glass options including benefit from daylighting. Glass selection for the building was determined based on the simulation results.

Three types of HVAC systems - water cooled screw chiller, water cooled VSD chiller and a water cooled VRV were considered for the building. The whole building modeling software was again used to model building envelop, equipment load and occupancy patterns and climatic variations for a typical meteorological year and carry our corresponding simulations. Performance characteristics of the different system types were also modeled to obtain annual energy consumption for the building for the three different options. The system type selection was made based on the predicted energy consumption based on simulation.

Keywords : Energy performance simulation, Lighting simulation, Glass Comparison, eQuest, Dialux

Introduction

Use of building modeling tools and simulations have proliferated in the last decade as critical means of understanding and analyzing behavior and energy performance of a building. Numerous software are available in the market that forecast energy performance of a building to a high degree of accuracy under typical operating patterns and climate conditions. These software provide opportunities to do accurate lifecycle cost calculations. Other software simulation models are available for various aspects related to building performance including lighting and daylighting, thermal performance, acoustic performance, etc. to assist building designers.

The building discussed in this paper is an eight storey office building located in Colombo. More than 60% of the outer shell is glass, with a significant impact on the thermal load of the building. The client was interested in selection of the glass type and the HVAC system with optimal energy performance for the building. Visual comfort for the occupants was also a consideration for the selection of glass.
Two software tools were used for the evaluation process.

1. eQUEST is a freeware designed by James J Hirsch Associates in collaboration with Lawrence Berkeley National Laboratories in the USA and is one of the most widely used software for energy saving assessments. It provides with easier to use front end for the designers with a powerful simulation engine that provide to allow detailed analysis of projected building performance and energy consumption. [1]
2. DIALux is a freeware developed by Dial GMBH, for professional light planning in buildings. [2]

Modeling the Building

eQUEST simulations based on the whole building model were used to determine the energy consumption of different options of glass and HVAC systems. The DIALux simulations were used to understand the daylight penetration within the building and glare for different glass options.

a. Daylight Simulation

Daylight on a building is based upon its geographical location, elevation, time, orientation & daylight penetrative materials (glass) which are used. The daylight penetration varies throughout the year and also throughout the day due to solar orientation. To understand the impact variation, analysis used the 1st equinox of the year and the two solstices for the DIALux simulation. The building was modeled using the software including the properties of glass options proposed. Daylight outputs for different days/times were obtained to determine the impact.
For the eQUEST simulation, daylight controls were introduced to assess the energy savings potential due to daylighting.

b. Construction Materials

Thermal properties of construction materials can have a significant impact on a building performance with impact on thermal loads of the building, especially when higher amount of glass is used. In the building under consideration, three sides of the building are directly exposed to solar radiation.

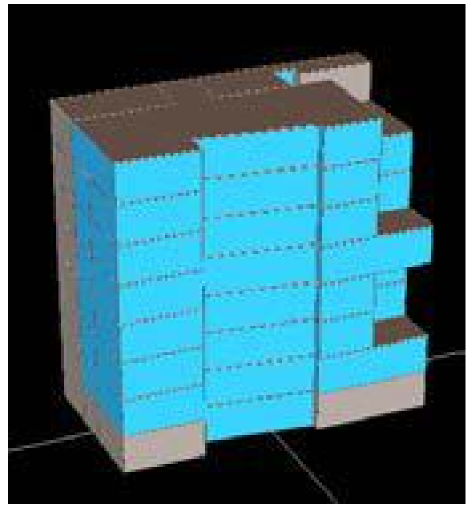

Figure 1 : Building geometry in eQuest (Source – Co-Energi)

Table 1 shows the parameters of the glass which were used for comparison.

Table 1 Glass Parameters (Source – Co-Energi)

Glass	Visual Transm--ittance (%)	Solar Heat Gain Coefficient (%)	U Value (W/m²K)
Glass A	42	51	1.65
Glass B	15	22	1.62

c. Weather Data

Geographical location and the climate around the facility is a crucial factor determining the cooling load. Geographical location determines the solar impact while the climate characteristics determine the heat gain from the environment. Climate condition of a Typical Meteorological Year (TMY) for Colombo was used for the simulation.

d. Zoning of the building

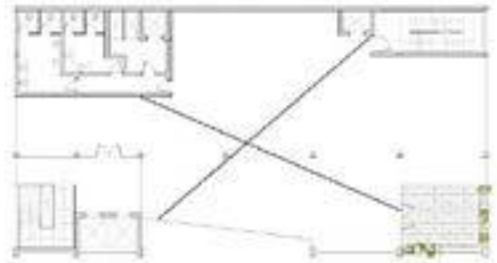

Figure 2 Office Area of a typical floor of the building under study (Source – Co-Energi)

The area crossed out in Figure 2 is the typical office area of a floor which was considered as a single zone. This area is conditioned while rest of the areas were considered as unconditioned. Typical occupancies, light power densities and equipment loads were used for modelling.

e. HVAC Systems Used

Three HVAC systems were considered and simulated to determine the energy performance of the building. Water cooled screw chiller, water cooled screw chiller with a VSD compressor and a water cooled VRV system were the systems considered for simulations.
Simulation difference in HVAC systems are mainly due to their behavior in part load curves, heat rejection method & AHU functionality. Part load curves under typical operating conditions for Colombo was obtained from manufacturers and

incorporated using curve-fit method of eQUEST. Where product specific part load curves were available for HVAC equipment with the supplier, these curves were used. Optimisation options were also considered including variable speed pumps for chill-water and multi-stage fan control for cooling towers. Fresh air input to meet ASHRAE 62.1 requirements were also incorporated in the design.

Simulation Results

Daylight Simulation for Glass Comparison with DIALux

Simulation results shown in figure 3 & 4 are done for the 4th floor on March 21st at 9.30am with the different glass types.

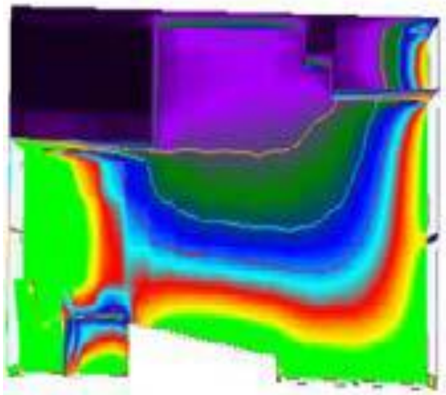

Figure 3 : Daylight effect with Glass A at 9.30 a.m. with clear sky (Source – Co-Energi)

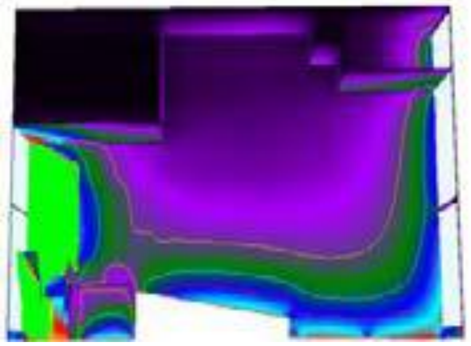

Figure 4 Daylight effect with Glass B at 9.30 a.m. with clear sky (Source – Co-Energi)

Glass comparison through eQuest

Following simulation results have been obtained by using Glass A & Glass B for the same building and for the same HVAC system.

Table 2 Cooling load requirement for Zones (Source - Co-Energi)

Area Name	FCU Sizes			
	Glass B		Glass A	
	TR	BTU/h	TR	BTU/h
Zone 1	12	144000	12	144000
Zone 2	5	60000	5	60000
Zone 3	13	156000	14	168000
Zone 4	11	132000	14	168000
Zone 5	11	132000	14	168000
Zone 6	13	156000	15	180000
Zone 7	10	120000	14	168000
Zone 8	10	120000	13	156000
Zone 9	11	132000	15	180000
Total	96	1152000	116	1392000

Total annual energy consumption was also considered for the two glass options. Energy usage is separately shown in order to determine the energy category which impacts when the type of glass is altered.

Table 3 Electricity Consumption Comparison (Source - Co-Energi)

	Annual Electricity Use (kWh x000)	
	Glass A	Glass B
Space Cool	79.48	61.04
Heat Reject.	1.45	1.01
Vent. Fans	6.52	5.07
Pumps & Aux.	21.67	21.26
AC Total	**109.12**	**88.38**
Misc. Equip.	104.9	104.9
Area Lights	17.03	18.79
Elevators	12.461	12.461
Total	**243.511**	**224.531**

Daylight Controls

Switching controls of the artificial lighting system also effects the total energy consumption of the building when it is aligned with daylighting. Three simulations were carried out to determine the overall energy deviation for 3 switching systems, and also to determine whether varying the switching system has a considerable effect on the total energy usage.

Table 4 Electric energy comparison for switching (Source - Co-Energi)

	Annual Electricity Use (kWh x 000)		
	On/Off	2 Level + Off	3 Level + Off
Space Cool	80.19	80.19	80.19
Heat Reject.	1.46	1.46	1.46
Vent. Fans	13.48	13.48	13.48
Pumps & Aux.	21.77	21.77	21.77
AC Total	116.9	116.9	116.9
Misc. Equip.	104.9	104.9	104.9
Area Lights	17.03	16.95	16.9
Total	238.83	238.75	238.7

HVAC System Comparison

HVAC System selection was done based upon the energy numbers which was provided by eQuest. The final comparison was done between a Variable Refrigerant Flow (VRF) system and a water cooled screw chiller with VSD compressor.

Table 5 Electric energy comparison between VRF & Chiller (Source - Co-Energi)

	Annual Electricity Use (kWh x000)	
	VRF	Chiller
Space Cool	78.26	80.2
Heat Reject.	18.42	1.46
Vent. Fans	11.25	13.48
Pumps & Aux.	26.38	21.77
AC Total	134.31	116.91
Misc. Equip.	104.9	104.9
Area Lights	17.12	17.12
Elevators	12.46	12.46
Total	268.79	251.31

Observations

The daylight simulation results indicate significant glare and high daylight penetration with significantly high lux levels with the glass A. This will contribute to significant visual discomfort for the occupants which would require opaque shading which would negate any potential savings on lighting with daylight and blocking external views. The shading would also negate the architectural intent.

eQUEST simulation results shows that in terms of energy conservation options Glass B is a more suitable selection where there is an 18980 kWh annual energy saving and also a significant reduction in the building cooling requirements. By comparing the glass technical data which has been provided, it can be concluded that a glass with lower visual transmittance and a lower shading coefficient value can be considered as a high performing glass in the energy sense. Also in terms of reducing radiant heat which is entered into the building space, Glass B is recommended because radiant heat is proportional to the interior illuminance levels represented by lux levels inside the building. It can also be concluded that varying the switching system is not having a significant effect on the overall energy consumption of the building in this particular case and reflected as a total annual reduction was 130 kWh only.

The chiller system is better performing than the VRV system under the given circumstances for the building which gives a 17481 kWh annual energy saving. This is because the building load values vary predominantly within the range where the particular chiller has the highest efficiency with respect to its part load performance compared to that of the VRF system. The particular VRF system considered also came with a double loop cooling tower which increased the energy consumption of the overall solution.

Conclusion

Based on the above observations, the building energy performance was significantly improved with Glass B & and the proposed chiller system. Using glass B option resulted in an overall annual energy saving of 18980 kWh compared to the glass A. The chiller system provides a 17481 kWh annual energy saving. Combined, the two results contributed to an overall annual energy saving of 36481 kWh compared to the worst case scenario of the building.

The simulation process used and analysis aided the decision process of the building owner, enabling reduction of visual discomfort and reaching higher levels of energy efficiency with the design. Similar approaches can aid building developers and designers to make better decisions by providing accurate information to aid analysis and decision making.

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Distribution System Loss Reduction by Effective Phase Balancing

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Abstract

Load unbalance is one of the major causes for the power losses in three-phase distribution lines. In Sri Lanka, the unbalanced distribution system is balanced by dividing the consumers equally among the three phases. However, this procedure is less effective as far as daily total energy consumption patterns are concerned. This paper proposes a load balancing method by using Mixed Integer Programming to select the phase for a load connection effectively. Here, optimal load assignments were obtained by minimizing the maximum difference of current flows between phases at the branches. This applied research was done in three steps. They are (i) field measurements to collect data, (ii) simulation to analyze its operations and (iii) Laboratory prototype to validate the proposed technique. The selected feeder network was modeled using EMTDC/PSCAD software. The feeder loads were modeled by considering daily load pattern and consumers' monthly energy consumption. Loads' connecting points, which were obtained from the program, were implemented in the simulations and laboratory scale-down models. The test results of simulation as well as laboratory models verify the effectiveness of the proposed method.

Keywords: Unbalanced distribution system, Phase balancing, Mixed Integer Programming, Phase swapping, Unbalanced flow, Node reduction

Introduction

Load unbalance is one of the major causes for the power losses in three-phase distribution lines. It is due to the line loss in the neutral, which is proportional to the square of the neutral current, i.e. I^2R. In addition, there are many other problems caused by unbalanced load such as, poor voltage regulation in the heavily loaded phase, equipment over loading due to creation no unbalance voltage, and malfunction of protective relays [1] etc.. With the collaboration of Ceylon Electricity Board's (CEB) energy management branch, Central Province, the University of Peradeniya has initiated this study to investigate the load unbalancing problem. The CEB has the usual practice of balancing the distribution systems by connecting equal number of customers in each phase. However, no consideration was made based on the consumers energy consumptions. Also the feeder power consumption which varies during 24 hours has not been taken into account. It was also understood that each consumers' load varies inconsistently. As a result the present balancing procedure may not be effective. By balancing the system with an effective method, above mentioned problems can be reduced to some level and also reduction of power loss leads to a real gain in energy thus reduces capital-intensive investments. This paper proposes an enhanced method to balance such systems.

It may also benefit the country's economy by numerous ways such as (i) reduction of unit electricity cost,(ii) improvement in financial performance of electrical utilities, (iii) improvement in the quality of supply and service offered to customers,(iv) optimize the investments by saving energy loss and (v) improvement of the environment.

Existing phase balancing techniques

In practice it is impossible to keep the distribution system always at balanced operation. However, it has to be noted that the unbalanced loads contribute to the system losses unnecessarily. Since the current flow in each phase does not equal during the unbalanced operation, there is a current flow exists in the neutral and causes line losses, extra system losses, and line equipment over loading, etc. Also it often causes feeder service tripping because of neutral over current. Two common options are possible in phase balancing.

1. Phase Swapping :- Rearranging the loads among the phases such as balancing the phase currents
2. Feeder Reconfiguration :- Transferring loads among the feeders when the unbalance operation occurs

Since feeder reconfiguration is primarily designed for load balancing among the feeders, it cannot effectively solve phase balancing problem [1]. Therefore phase swapping is a direct and effective way to balance a feeder in terms of its phases, which consists of change the connection of the loads or lateral branches among the phases of the line. Carrying out the study and do appropriate swapping can reduce the unbalanced level of the network, since the main cause of unbalances in an electric network is mostly the single-phase loads connected to a three-phase network.

Various methods using the optimization problems have been employed for phase swapping to balance the phases. Those problems are solved using Immune algorithm [2]. Mostly, the multi objective functions of those analyses are formulated by considering the unbalances of phasing currents, the customer service interruption cost and labour cost. The objective function is formulated by including the number of customers affected, the total load demand interruption and the time duration to complete the re-phasing works.

Heuristic Search Approach [3] is used to minimize the unbalance flow. The phase unbalance index of distribution feeders is calculated based on the phase current magnitude of each line segment and it has been solved by a 3-phase load flow study. *Further above* mentioned method is enhanced [5] by including the reduction of neutral current, cost of the feeder power losses, the customer interruption cost, and the labour cost in the expert system.

The phase swapping is solved with the use of a Heuristic Search Approach in Taiwan [3]. The objective function is formulated by considering the power loss cost over one year, the customer service interruption cost and the labour cost to perform the re-phasing of laterals and distribution transformers. Therefore, this method will determine the re-phasing strategy based on the heuristic rules and system data, to achieve the reduction of neutral current and system power loss. This will be used to justify the customer service interruption cost and labour cost for the re-phasing strategy.

These methods have complexities in their approaches, which require continuous phase swapping operations with the time; therefore it cannot be applied in Sri Lanka, due to the lack of equipment.

This paper presents a simple method to resolve the phase balancing problem effectively by using Mixed Integer Programming. This gives the optimum load arrangements to achieve a radial feeder network with minimised unbalance operations.

Mixed Integer Linear Programming

In the proposed phase balancing formulation, the voltage drop is not considered to simplify the problem. The assumption on ignoring voltage drop is reasonable because the unbalance current component due to imbalance in voltage drop is very negligble. It is usually assumed that all the loads have the average power factor, which was measured at the distribution transformer. Thus all the loads can be modelled by their current magnitudes.

Here, the r.m.s. value of the current is considered for the phase swapping. Also, harmonics and the frequency changes are ignored. It was taken that each single phase load is only connected to a specific phase line. The unbalanced flow is defined as the maximum difference of current flows at a branch. The lower the unbalanced current flow is the more balanced operation of the branch. The phase balancing problem is solved with the use of LINGO optimization software. Here phase swapping can be treated as load assignment to lines. The decision variables are used to indicate whether the load is connected to a phase or not; which can be represented as 1 or 0.

Since voltage drops are ignored, the objective function becomes as a linear function, then the problem can be modelled as a mixed-integer linear programming [1]. The objective is to minimize the unbalanced flows on branches. The results show the load tapping scheme to balance a radial feeder system.

Field Investigation

A semi-urban 400 V, LV feeder was selected at Kiulpana in Mawanella area for this study. This area has limited number of consumers (single phase loads) and the location has been observed as a heavy unbalance network by the Energy Management Branch of CEB in Kandy city. The data logger and energy meter were fixed in the test feeder at the substation. The daily load pattern of the feeder was obtained by measuring the power consumption by a data logger over a 24 hour period at every 30seconds intervals. Consumer account numbers of the feeder and the energy consumption of consumers during last 12 months were obtained. Figure1 and Figure2 show the distribution feeder network and the measuring setup.

Figure 1: Measuring setup at the feeder

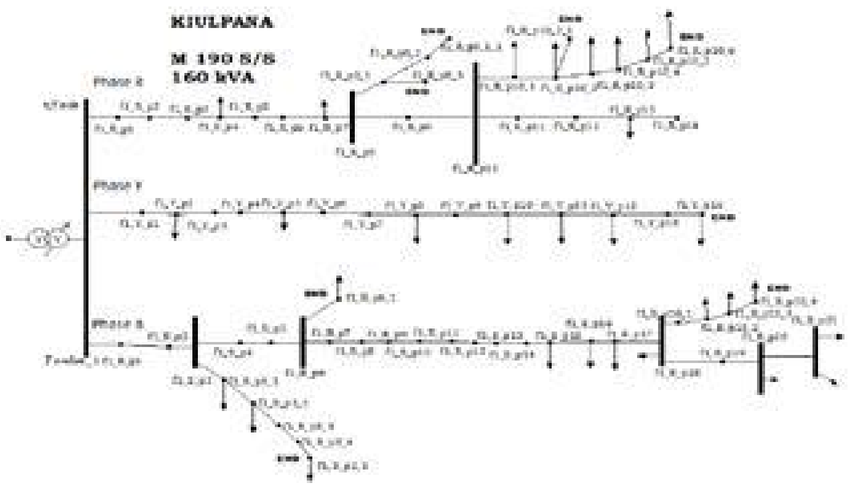

Figure 2: 400 V distribution system network at Kiulpana,Mawanella

Simulation

The selected feeder was developed in PSCAD software with the collected data, to obtain phase current loading of each branch. A distribution system component can be categorized as either branch or node. Each branch is an arc connected to two nodes while each node is a connecting point of branches attached to it. A branch can be any device with two terminals such as line sections, switches, transformers, etc., while a node is an electricity point that connects different branch devices together. The network was reduced such that there were three line segments to make the approach easier. For that it was assumed that the line losses are negligible when comparing with the power delivered by the loads.

Since the load current varies with time, first the load pattern of 24 hours, which was taken from the data logger, was divided into four regions such as (i) Night time (12.00 midnight-3.00a.m.), (ii) Morning peak (4.30a.m.-7.30a.m.), (iii) Day (10.30a.m.-1.30p.m.), (iv) Night peak (6.00p.m.-9.00p.m.).The same methodology, mentioned below, was applied to study system performance in each region.

The power delivered to each loads for the specific region was calculated using the consumer monthly bill data and the data logger readings. Also, the average power factor for each region was taken from the data logger readings.

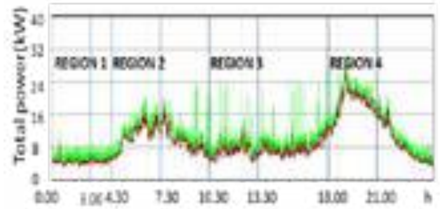

Figure 3: Power plot of four regions

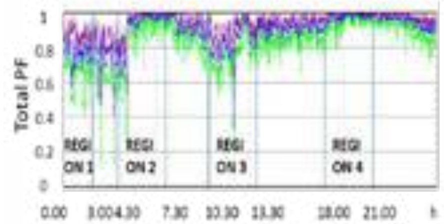

Figure 4: Power factor readings of four regions

Components selection for simulation

Load values

The power consumption ratio of each consumer was calculated, using the consumers' monthly energy consumption data. Based on that, the transformer output power of the particular region was distributed among the customers as shown below.

$$P = \left(\frac{P_1}{P_T}\right) \times P_D \qquad \text{Eq. 1}$$

Where,

P =Real power delivered to the load

P_1 =Power delivered to that load, according to monthly energy consumption bill

P_T =Total power delivered to the feeder, according to monthly energy consumption bill

P_d =Transformer output power to the feeder, from the data logger reading

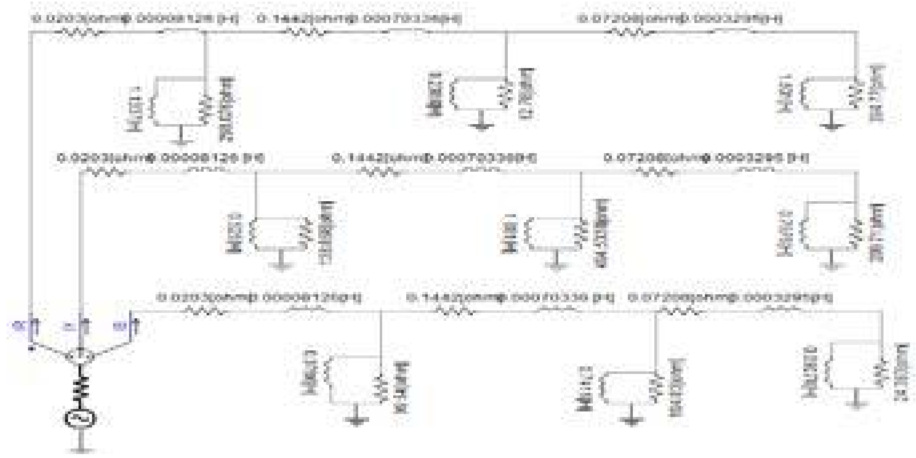

Figure5 :Software model for region 1

The components values were calculated as follows,

$$R = \frac{V^2}{PR} \qquad \text{Eq.2}$$

$$X = \frac{V^2}{P\tan\theta} \qquad \text{Eq.3}$$

Where,

V =Base voltage of real system

R =Load resistance

X =Load inductance

Θ =Average power factor angle (from the data logger readings)

Line values

Kelani cable company book was used to get the line impedance. For the AAC-Fly conductor the DC resistance is 0.4505Ω/km

$$\text{DC resistance} = \text{r} \times \text{l} \qquad \text{Eq. 4}$$

Where,

R = resistance of the line/km

L =length of the conductor

Observations and results

The current flow obtained in the software model (PSCAD) for the actual system is shown in the Figure 6.

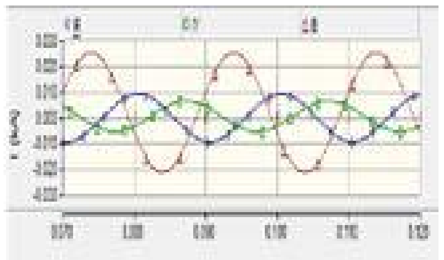

Figure 6 : Before phase balancing

The re arrangement of load tapping is same in all four regions. The current flow obtained in the software model (PSCAD) for the re arranged system is shown in the Figure 7.

The inductance value of the conductor was calculated using the following equation [7]

$$L = \frac{\mu_\circ l}{2\pi}\left(\ln\left(\frac{2l}{R}\right) - \frac{3}{4}\right) \qquad \text{Eq.5}$$

Where,

L =Inductance

$\mu_\circ$ =Permeability of air ($4\pi\times10^{-7}$H/m)

l =Length of the conductor

R =Radius of the conductor

The system was modeled in PSCAD software using the calculated values which is shown in Figure 5.

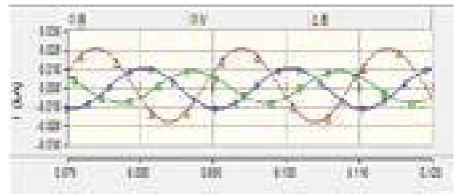

Figure 7: After phase balancing

The results show (in table 01) that the unbalanced current is reduced by a significant amount. This is very useful during the peak time periods, since the unbalanced flow is reduced by a large amount. The accuracy of the results can be improved by considering more nodes for tapping the loads.

Table01: The unbalanced current flow of all regions, before and after applying the proposed balancing methods

Period	U1/A	U1new /A	U2/A	U2new /A
Night time	11.492	8.108	12.42	10.394
Morning peak	27.076	16.505	20.24	21.067
Day time	19.343	11.558	14.60	14.814
Night peak	30.118	18.683	28.10	23.598

Laboratory model

Before applying the phase balancing method in the real system, a scaled down hardware model of the system was designed to ensure the application. By considering the hardware component values, the night time period of the system was scaled down. The criteria for scaling down were defined as follows:

- The average power factor of each load is kept constant in both networks
- Percentage of voltage drop is kept constant for both networks

Base voltage was selected for the new system as 20V considering safety and to get the components values practically.

New system impedance can be written as

$$Z_{new} = Z_{old} \times \left({V_{new}}/{V_{old}}\right) \times \left({I_{old}}/{I_{new}}\right) \qquad \text{Eq. 6}$$

Where,

V_{old} =400V

V_{new} =20 × √3 V

I_{factor} =3

Average power factor =0.767

Hardware Components

Line resistance

For the line segment,both the resistance and inductance were represented using copper coil. Based on the DC resistance value, required length of the conductor was calculated.

$$R = \frac{\rho l}{a} \qquad \text{Eq.7}$$

Where,

R=Resistance of the conductor

ρ=Conductivity of the conductor material ($1.68\times10^{8}\Omega$m)

l=Length of the conductor

a=Cross sectional area of the conductor

Load resistance

Load resistances requires high power ratings, since the load current is high. Therefore appropriate rheostats were used to represent the loads.

Line inductance

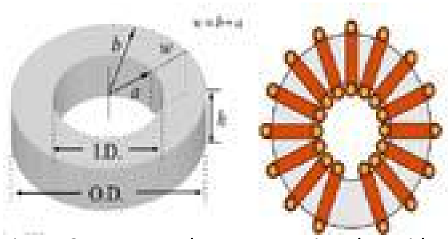

Figure 8 : Rectangular cross sectional toroid

The line inductance was modeled using rectangular cross sectional torroids,with the calculated length of line. The number of turns were calculated using the following equation.

$$L = \left(\frac{\mu N^2 h \ln(b/a)}{2\pi}\right) \quad \text{Eq.8}$$

Where,

μ =Permiability of the core medium

N =Number of turns

H =Height

A =Inner radius

B =Outer radius

Load inductance

The calculated load inductance was designed using the E-I core such as shown in Figure 9.

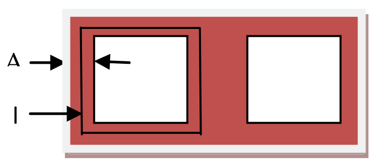

Figure 9 : Simple structure of the E-I core

The inductance for the E-I plate core is given by

$$L = \frac{\mu A N^2}{2l} \quad \text{Eq.9}$$

Where,

μ =Permeability of the core medium

N =Number of turns

A =Cross sectional area

l =Circumference of the one side core

All the loads were built up using copper coils with proper gauge to withstand the current flow.

Table 02: Component values calculated for laboratory model

Phase	Resistance (Ω)	Inductance (H)
	79.290	0.3020
R	16.699	0.0635
	105.01	0.3990
	131.55	0.5000
Y	36.726	0.1397
	55.783	0.2122
	26.478	0.1010
B	51.825	0.1970
	6.489	0.0247

Figure 10: Laboratory model

Conclusions

The three-phase balancing of distribution feeders has been enhanced by lateral re-phasing with Mixed Integer Programming. To demonstrate the effectiveness of the proposed methodology, a distribution feeder was selected and modelled for four different time periods using PSCAD simulation software. The data were collected from consumer monthly bills and data logger. Proposed method was verified with simulation and the scaled down hardware model for one of the time periods. This method can give a better solution for phase re-phasing than the currently used method.

Acknowledgement

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Utilization of Biomass Byproducts to Prepare Specific Industrial Bio Fuels and Chemicals

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Abstract

The purpose of the research reported here was to investigate the possibilities of converting biomass byproducts of industrial wastes into useful fuels and/or chemicals as alternative energy sources using more efficient and novel techniques.

In achieving this target, acid and alkali pretreatment processes were carried out to swallow the cellulosic materials of the selected industrial biomass byproducts and the chemical components of the pretreated waste were extracted into suitable solvents under reflux. The functional groups present in the chemicals extracted were characterized. Attempts were made to isolate crystalline products whenever possible. UV-Visible, XRD and FTIR techniques were used for the characterization of the species isolated. Distillation was performed for the separation of the components.

The results revealed that bio based waste could be used to produce some useful starting materials such as cellulose nanocrystals for the production of bio-fuels.

Key Words: Bio-mass, Energy, Bio-fuels, Bio-chemicals, Bagasse.

Introduction

In order to save the planet and its available natural energy resources, bio-fuel has been recognized as an alternate energy source. At the same time, industrial revolution has created unbearable environmental pollution to the global environment. Therefore, it is extremely essential to search on the possibilities of minimizing environmental pollution and maximizing the alternative energy sources to achieve sustainable development.

In recent years, the quest for sustainable development has motivated efforts toward maximizing the efficiency of the use of raw materials and minimizing the creation of waste. In this context, the use of biomass residues as feedstock for the production of energy and materials has been the objective of intensive academic and industrial research. The reuse of these residues allows a significant reduction both in the volume of waste accumulated in the environment and in the extraction of raw materials. Thus, an efficient reuse of these wastes is of great importance, not only for minimizing the environmental impact, but also for obtaining a higher profit [5].

With the high demand of present global interest in cellulosic biomass as a feedstock for intermediate chemicals and bio-fuels, the characterization of different feedstock is a critical component of many current researches. The biomass and their byproducts can be converted into non-hazardous fuels and chemicals that can reduce loading of greenhouse gas emissions unlike fuels derived from fossil sources.

Bagasse obtained as a byproduct of sugarcane processing, is composed of fiber, pith, non-soluble solids and water; fiber represents about half of all components, and includes cellulose, hemicellulose and lignin of low molecular weight. Its morphological structure is not strong in comparison with other fibers such as those of wood; its advantages are shown during chemical and mechanical treatments, since it does not have to be submitted to severe processes. Another important advantage is that it is directly obtained and concentrated in the sugar factory as a process byproduct, thus simplifying handling and transport operations.

Pulp and paper, boards, furfural and animal feeds are among the main products obtained from bagasse as non energy products. The most widespread use of bagasse around the world is in the production of pulp and paper. There are about 90 factories in all, of which three-quarters are established in Asia, Oceania and the Middle East, delivering up to 2.5 % of the total world production. Most chemical firms have based mainly on petro-chemistry, while other alternatives such as those offered by sugar cane, have received much less attention. The economical causes for this situation are expected to change in the future. Therefore, the use of sugarcane bagasse as the primary source for producing cellulose fibers and nanocrystals is promising. It has been reported that cellulose nanocrystals could be easily extrapolated to bioethanol production.

The aim of this study was to extract cellulose fibers from the sugarcane bagasse using alkali and acid treatments. The preparation of cellulose nanocrystals from these natural fibers was also investigated.

Methodology

Materials and Reagents

Bagasse was collected from Pelawatta Sugar Factory, washed several times with distilled water and air dried. Sodium Hydroxide (NaOH, extra pure pellets) were from Loba Chemie Pvt. Ltd. while Sulfuric Acid (H_2SO_4 , 97-99% wt), Hydrochloric Acid (HCl, 35.4% wt) were from Sigma-Aldrich Chemicals Pvt. Ltd. Extra pure Pottasium Bromide (KBr) solid was purchased from Loba Chemie Pvt. Ltd.

Instrumentation

Shimadzu IR Prestige-21 Infrared spectrophotometer was used to obtain FTIR spectra. The KBr disk (ultra-thin pellets) method was used in taking the IR spectra. Samples were ground and mixed with KBr (sample/KBr ratio, 1/100) to prepare ultra-thin KBr pellets. The experiments were carried out in the range of (400-4000) cm^{-1} with a resolution of 16 cm^{-1} and a total of 15 scans for each sample.

Shimadzu LabX XRD-6000, operating at a power of 40 kV with a current of 30 mA and Cu Kα radiation (1.5406˚ A) was used to obtain the spectra. The X-ray diffractograms of suspensions were obtained at room temperature within a 2θ range from 5° to 40° and a scan rate of 2 min^{-1}.

UV – Visible spectra were recorded with a Shimadzu UV-1800 double beam ultra violet spectrophotometer and UV-Probe software were in the wave length range of (190-700) cm^{-1}.

A Centurion centrifuger was used whenever necessary to centrifuge the mixtures.

A drying oven (DHG-9140A, 2050 W, Temperature range of RT+10 ^{0}C – 250 ^{0}C) was used to dry the samples.

Preparation of cellulose nanocrystals from Sugarecane bagasse

Alkali treatment

The alkali treatment was performed to purify the cellulose by removing lignin and hemicellulose from sugarcane baggase fibers. The ground bagasse (10 g) was mixed with a 4 % (w/w) NaOH solution (20 ml of the alkali solution per each gram of the cellulose sample). The mixture was refluxed at 100 ^{0}C for 2 h with continuous mechanical stirring. The solid was then filtered, washed several times using distilled water and dried at 50 ^{0}C for 12 h in a drying oven. The solid isolated was characterized by FTIR and XRD techniques.

Acid treatment

After the alkali treatment, the acid hydrolysis treatment was performed for

the fibers for 30 min with 64% (w/w) H_2SO_4 at (45-50) ^{0}C with continuous stirring (20 ml of the acid solution was used per each gram of the cellulose sample). Immediately following the hydrolysis, the suspension was diluted 10-fold with cold distilled water to stop the hydrolysis reaction and centrifuged two times for 10 min at 4000 rpm to remove the excess acid. The suspension was then treated with NaOH pellets (~5 g) until the neutral pH (~7.00) was reached. Subsequently, the resulting suspension was centrifuged four times for 10 min at 4000 rpm to remove all the soluble salts. Finally, the suspension was ultrasonicated for 10 min and stored in a refrigerator at 4 ^{0}C. Few drops of chloroform were added to the suspension to avoid any bacterial growth. The solvent was evaporated and the solid remained was characterized by FTIR, XRD techniques.

Distillation and determination of acid base reactivity of extracted Sugarcane bagasse

Only acid treated, neutralized (as in 2.3) sugarcane bagasse filtrate was distilled and the distillates were collected at different temperatures. UV and FTIR spectra were taken for each distillate. UV visible spectroscopic behavior was separately checked for another part of the filtrate upon adding acid and base. For acid base reactivity, 0.1 M HCl (5 μl aliquot) followed by 0.1 M NaOH (5 μl aliquot) was added into a separate portion (3.5 ml) of the solution. Then 0.1 M NaOH followed by 0.1 M HCl was added into another portion (3.5 ml) of the solution.

Results and Discussion

Preparation of cellulose nanocrystals from Sugarcane bagasse

The formation of nanocrystals was studied by comparing the FTIR data with the reported data [2], [3].

Figure 1: Photographs of (a) Sugarcane, (b) Raw, (c) Alkali treated, (d) Acid treated sugarcane bagasse

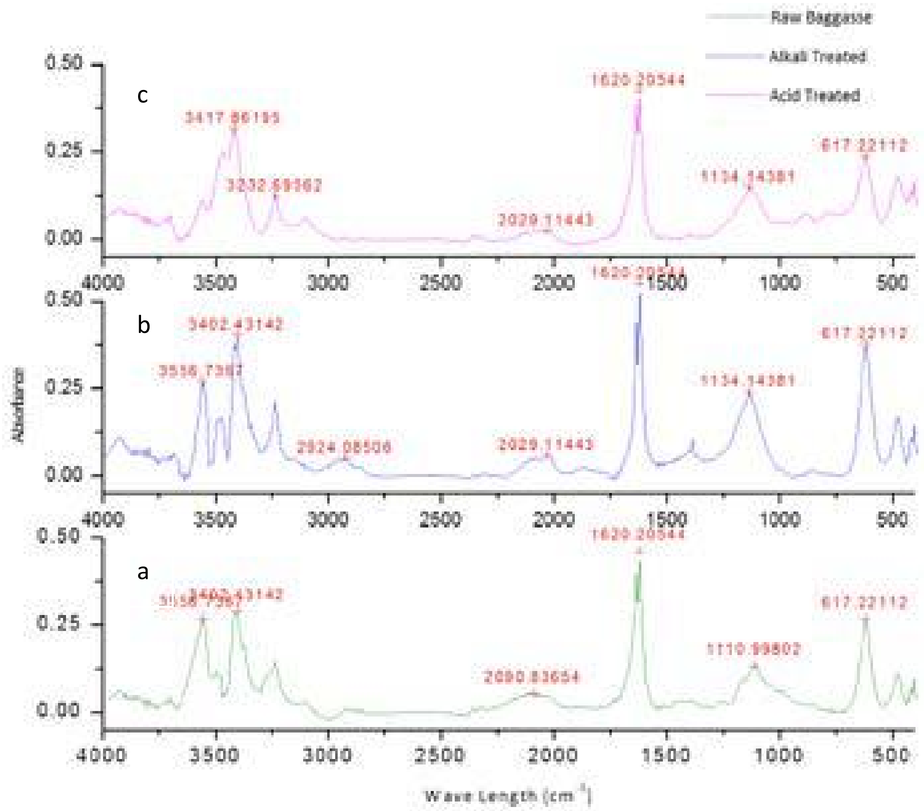

Figure 2: FTIR spectra of (a)Raw, (b)Alkali treated, (c)Acid treated sugarcane bagasse

The formation of nanocrystals was studied by comparing the FTIR data with the reported data [2],[3]. Figure 2 shows the FTIR spectra of raw, alkali treated and acid treated sugarcane bagasse. The prominent peak at 1620 cm^{-1} in the spectrum may be attributed to –C=C- groups present in all the samples. Comparing the FTIR data of treated and untreated samples it could be noted that the original band present at ~ 2800 – 2900 cm^{-1} corresponding to –C-H (stretching), is not seen in the treated sample. This may be due to the removal of hemicellulose and lignin. The prominent peaks (due to C-H and OH groups) between 3200 and 3700 cm^{-1} could be seen in all three spectra as reported, but they are sharper than those reported [4], [5]. The sharpness of the bands may be due to the presence of non H-bonded OH groups (i.e. lack of water absorption). However, after the acid treatment, these bands become broaden as more H- bonds are formed due to the absorption of water in the suspension. All these peaks are ascribed to the stretching of hydrogen bonds and bending of hydroxyl (OH) groups bound to the cellulose structure. These results indicate that the cellulose component was not removed during the chemical treatment carried out on bagasse and is the common material found in all samples. The peaks in between 2090 – 2000 cm^{-1} imply the presence of C=O functional groups in all the samples. The lower frequency (2029 cm^{-1}) in treated

samples may be due to the H-bonded C=O groups. The peak located around 1134 cm^{-1} in the spectrum of the treated bagasse sample refers to the bending frequency of C H, OH, or CH_2 [5]. The absorption at 617 cm^{-1} observed in the spectra refers to the C-H stretching vibration of the structure of the cellulose component. No significant differences were observed between the spectra corresponding to alkali and acid hydrolyzed fibers except the slight changes seen in frequencies higher than 2000 cm^{-1}. The results indicate that the cellulose molecular structure remains unchanged following acid and alkali treatments (Table 1).

Table 1. Peak absorption of bagasse at different treatment stages

Untreated (cm^{-1})	Alkali Treated (cm^{-1})	Acid Treated after the alkali treatment (cm^{-1})	Involved Groups
3556	3356	-	Alcohol/Phenol O-H Stretch
3402	3402	3417	Alcohol/Phenol O-H Stretch
3240	3240	3032	Alcohol/Phenol O-H Stretch
2893	2924	-	Alkyl C-H Stretching
2090	2029	2029	C=O stretching
1620	1620	1620	Aromatic C=C Bending
1110	1134	1134	bending frequency of C H, OH, or CH_2,
617	617	617	C-O stretching and C H vibration

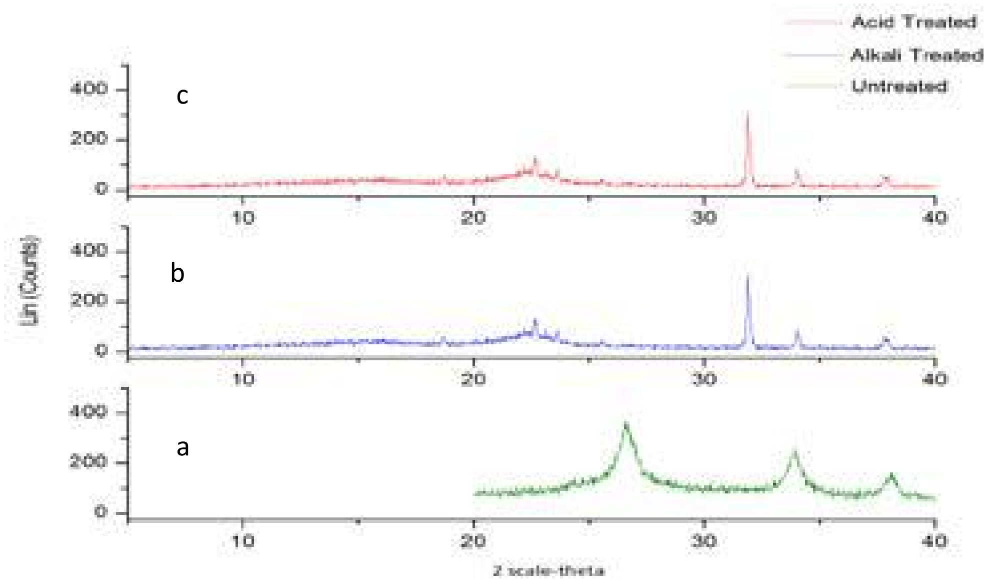

Figure 3: XRD spectra of (a) Raw, (b) Alkali treated, (c) Acid treated sugarcane bagasse

Figure 3 shows the diffraction patterns obtained for (a) raw, (b) alkali treated and (c) acid hydrolyzed bagasse. Chemical treatment performed on bagasse can affect the crystallinity of cellulose. Therefore the crystallinity of chemically treated bagasse can be determined and compared to untreated bagasse to access the effectiveness of the chemical treatment. Three well-defined amorphous peaks appear around 2θ = 27, 34, and 38 for untreated bagasse. These peaks become more defined, narrow and shifted to lower 2θ values upon chemical treatment. This narrowing of the diffractive peaks may be due to the formation of monocrystals in the process of forming cellulose nanocrystals [7].

Distillation of extracted Sugarcane bagasse

Samples were distilled at the different temperatures (Table 2). The color intensity was increased with temperature.

Table 2. Different distillation temperatures

Symbol	Temperature (^{0}C)
Temp1	95
Temp2	96
Temp3	98
Temp4	102
Temp5	110
Temp6	114

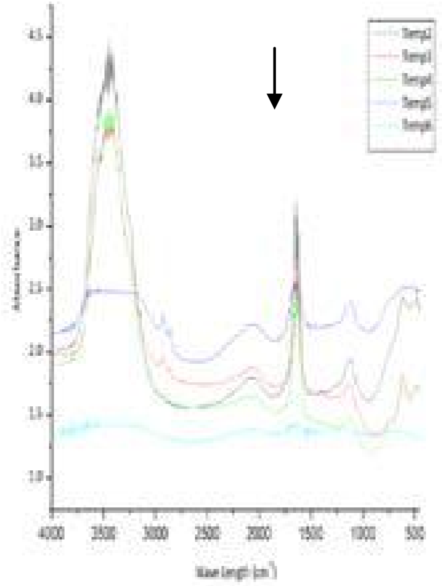

Figure 4: FTIR spectra of distillates at different temperatures

FTIR spectra of the distillates isolated at different temperatures are shown in figure 4. In the IR spectra absorption at ~ 3500 cm^{-1} is smaller at higher temperatures. The intensity of the band corresponded to C=C (~ 1600 cm^{-1}) also decreases on increasing the temperature. At the higher temperatures (> 100 ^{0}C) the structure of the compound isolated shows no similarities to cellulose according to the huge difference in their UV-Visible spectra. The expected absorptions for cellulose can be seen only in the distillates isolated at temperatures below 100 °C. Therefore, it can be concluded that the optimum temperature to isolate cellulose should be <100 ^{0}C.

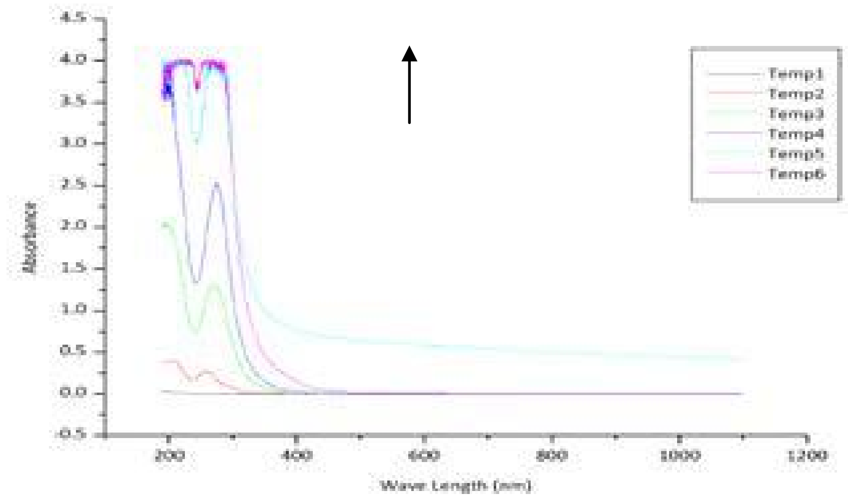

Figure 5: UV spectra of distillates at different temperatures

UV-Visible spectra of the distillates isolated at different temperatures are shown in figure 5. According to the UV spectra a new band appears in between 200 and 270 nm upon increasing temperature. A compound with higher charge transfer transition (at 250 nm) could be isolated at higher temperatures.

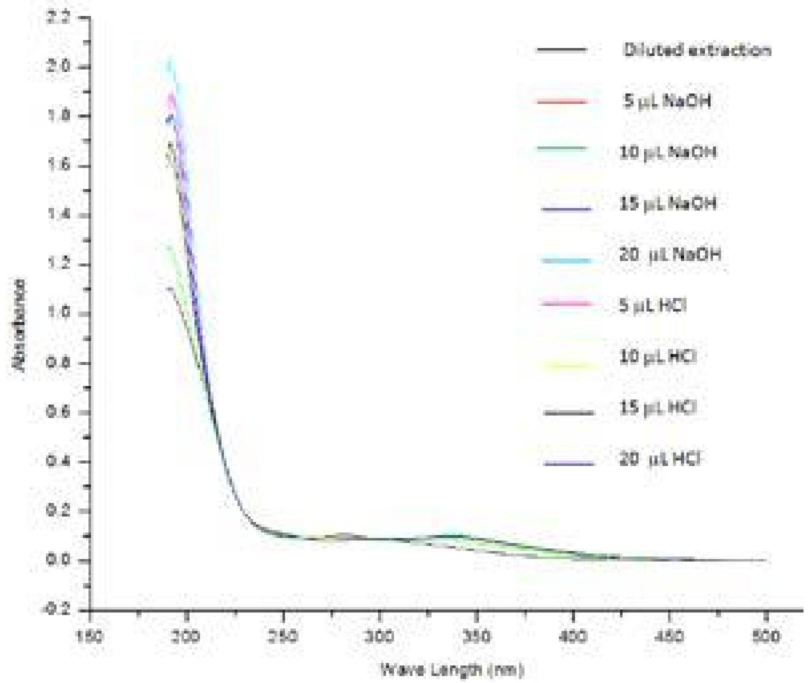

Figure 6: UV spectra of adding NaOH (0.1 M, 5 μL aliquot) followed by HCl (0.1 M, 5 μL aliquot) to the chemicals extracted from bagasse

Determination of acid base reactivity of the chemicals extracted from Sugarcane bagasse

UV-Visible Spectra of chemicals extracted from bagasse upon adding HCl and NaOH are shown in Figures 6 and 7. Upon adding a base the intensity at the band ~200 nm gradually increases and upon adding an acid to the same solution the peak intensity gradually drops down. The reverse can be seen upon adding a base to the solution that is treated with acid first.

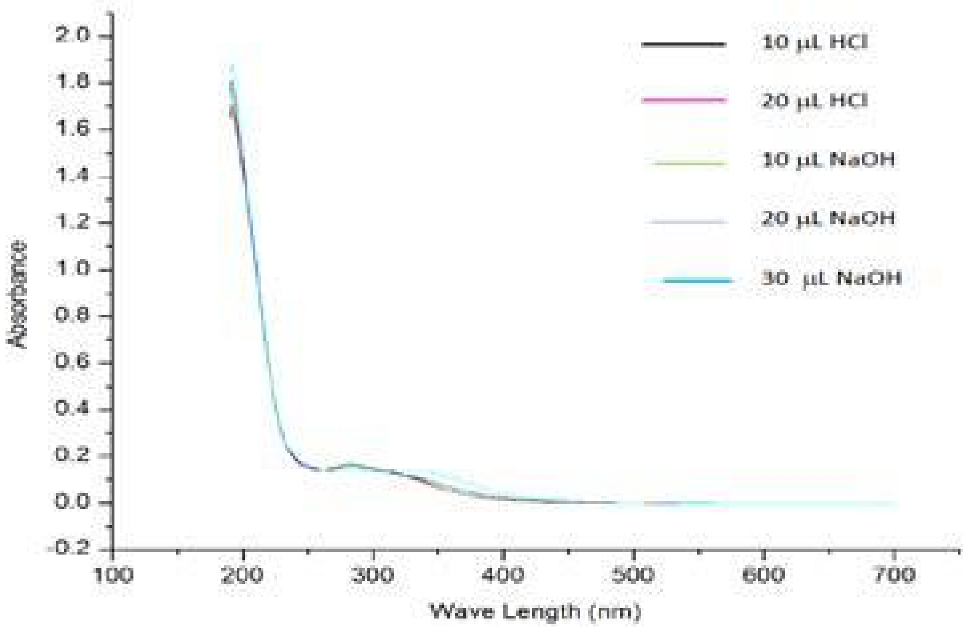

Figure 7: UV spectra of adding HCl (0.1 M, 5 µL aliquot) followed by NaOH (0.1 M, 5 µL aliquot) to the chemicals extracted from bagasse

Conclusions

The present work shows that bagasse from sugar production process is an interesting source of raw material for the production of cellulose nanocrystals. Chemical treatment performed with NaOH and HCl removes the hemicelluloses resulting fibers with higher crystallinity, most probably cellulose nano or monocrystals. The production of cellulose crystals from this underutilized bagasse has potential application that can add value to the sugar industry. In addition, the reuse of these waste materials such as bagasse allows a significant reduction both in the volume of waste accumulated in the environment and in the extraction of important chemical components such as cellulose. The results revealed that the chemical species extracted at different temperatures are different. The results indicate that the cellulose molecular structure remains unchanged following acid and alkali treatments. Further studies are underway to identify the composition of the chemicals extracted at higher temperatures >100 °C.

Acknowledgement

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Energy Security for Tea Industry in Sri Lanka: A Review of Present Status & Opportunities for Self Sufficiency

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Abstract

Continued stability and growth of the tea industry is paramount to the Sri Lankan economy. However, the tea industry is faced with many challenges of which the cost of energy and security of supplies are becoming grave concerns for all tea producers. Two main forms of energy used in tea factories are electrical and thermal. While electricity needs have been subsidized by the Ceylon Electricity Board (CEB) over many years, this situation may change due to financial constraints faced by the CEB and thus the rising cost of electricity may become a major problem for the tea industry.

Decades ago thermal energy needs were met by imported liquid fuels. With relative Dollar price of oil increasing in comparison to FOB (freight on board) price of tea, where for example, quantity of tea to buy a barrel of oil has increased from 10 kg to 19 kg over the last decade, use of fuel oils in meeting thermal energy needs in tea processing is now completely replaced by Firewood. Though cheaper, there is very little sustainable management of firewood in tea industry where most factories rely on purchases from whatever available source. This mostly involves ad hoc felling of trees in jungles and other homesteads. This situation cannot continue in the future.

The tea industry however holds key advantages of access to lands, labour and expertise in large scale plantations to convert this risk to an opportunity and to become a net energy exporter going beyond just self sufficiency for its own needs. Thus it can regain its position as a major contributor to the export earnings not only by the export of tea alone but by the reduction of the import of fossil fuels. This paper reviews the energy demand and supply situation at present, immediate and long term problems of reliability & sustainability of supplies and environmental issues, strategies to enhance the energy security of the tea industry and recommendations to implement these much needed strategies.

Key words: Tea, Energy security, fuel wood

Introduction

The importance of the tea industry in the Sri Lankan economy requires no elaboration. In addition to the growing contribution the tea industry has made to the GDP and for generation of export income, considering the special significance of "Ceylon Tea" as the most recognized icon of the Sri Lankan identity in the world scene, the continued stability and growth of the tea industry, is paramount. However, the tea industry is faced with many challenges which threaten its ability to maintain and enhance this role. Amongst these the security of supply of the energy resources, at an affordable cost, is becoming a grave concern for all tea producers.

The process of manufacture of tea requires two forms of energy, i.e. electrical and thermal energy. The electricity is required for driving machineries and lighting while thermal energy needs are for withering and drying operations. Average electrical energy demand in tea factories varies in the range of 0.63-0.75 kWh/kg made tea while that of thermal energy is in the range of 1.5-1.7 kg of firewood per kg of made tea [1] [2]. In the estate sector, there is also a great energy demand for domestic cooking and lighting of resident plantation workers.

Nearly all 695 tea factories in operation in Sri Lanka are grid connected. Sri Lanka in general enjoys a stable and reliable electricity supply from the National Grid. The tea industry consumes only about 2.5 % of the electricity generated [3]. Although, the electricity supply from the national grid is a reliable source, there may be issues of cost of electricity in the coming years with the rising fossil fuel prices and the tea industry may have to look for alternatives for electricity in the future. Nevertheless, presently, the greater issues are with the availability of fuel wood for tea processing and hence, proper evaluation of demand, availability, supply and efficiency of use of fuel wood in tea factories is the need of hour.

Fuelwood demand for tea processing and domestic use in estates

In the past, even after the first and second oil shocks in 1973 and 1978, the price of oil in Sri Lanka market was low enough not to be a significant contributor to the cost of production of tea. However, over the past decade or two the international price of oil has continued on an upward trend and coupled with the depreciation of the rupee against the US dollar, the cost of oil has become significant and many factories have modified their equipment for the use of fuel wood for this purpose. With the introduction of Hot Water Generators most operation and maintenance issues associated with firewood fired furnaces have been removed, which allowed even the most discerning quality producers to shift from high cost oil firing to much lower cost firewood firing without risking on possible smoke taint in Tea. Therefore, well over 90% of the factories use fuel wood and only exceptions are few factories using low cost materials such as saw dust and paddy husk. When national tea production in 2012 (326 million kg), [4] is considered, the thermal energy need of the tea factories could have been about 6,608 $x10^3$ GJ/year [1] [2]. Assuming a specific fuel wood consumption of 1.5 kg of fuel wood per kg of made tea, the estimated consumption of fuel wood by the tea industry is about 489,000 tons per year (approximately 1.7 million m^3) and that for domestic use in the corporate sector estates is approximately 1.3 million m^3. Of the total fuel wood demand for processing, about 60% (293,000 tons per year) is accounted for by bought leaf factories.

Present Sources of Supply

With the conversion of the energy supply to fuel wood in many factories the primary source of supply targeted was the rubber wood. With a program of replanting of rubber as well as the conversion of rubber plantations to other crops when the margins of profit from natural rubber were at a very low level, this was an abundant source. Further, rubber wood was then not considered as a source of timber and hence, trees were commonly sold as firewood logs. As a result, it was a cost effective source of energy as well. However, the situation has now changed and presently, the value of rubber wood as timber is markedly high. Several other circumstances too have changed the rubber wood supply scenario adversely, in the past few years. These include reduction of rubber extent being uprooted for replanting due to high prices of natural rubber, use of rubber wood as a source of valuable timber for making furniture, floor boards and MDF boards, fuel switching by other industries from fossil fuel to fuel wood due to high cost of the former, government regulations restricting felling of fuel wood tree planted by estates and selling of fuel wood trees as timber for higher prices.

To be self sufficient in supply of wood fuels, tea estates were expected to devote a certain extent of lands for growing of fuel wood. In high yielding estates in Kenya the norm is 30%, whereas that for an average yielding tea estate in Sri Lanka is about 10-15% of the tea extent [2] [5]. Very low productive/abandoned tea fields, scrub lands and ravines of tea plantations can be effectively used for planting fuel wood to meet this requirement. Some plantation companies commenced establishment of wood lots since 1980s. The total extent of the wood lots planted by the industry is reported to be about 19,000 ha [6]. It is to be noted that the species selected for the wood lots were mainly *Eucalyptus spp, Acacia spp and Albizzia spp* which require a minimum of 10 years to grow up to the required girth for fuel wood. In addition, it is reported

that some plantations have cultivated small extent of short rotation coppicing (SRC) trees such as *Calliandra* and *Gliricidia* as fuel wood lots in the recent past.

It is important to note that all biomass or fuel wood irrespective of the species have a calorific value of about 4,500 kcal/kg (18.83 MJ/kg) measured on dry ash free basis. This is an important point often misunderstood by many.

Shade trees

The estates have ready source of fuel wood by way of the shade trees grown at specified spacing. Of the two types of shade trees *viz*: High and Medium Shade, the medium shade of short rotation coppicing tress such as *Gliricidia Sepium* and *Caliandra calothrysus* are viable sources of fuel wood, being pruned periodically to maintain the optimum levels of shade. *Gliricidia* shade trees in tea can provide around 20 tons/ha (wet basis) of lopping annually [7] of which around 3/4 could be considered for fuel wood. However, till recently there was not much interest by the factories to use these coppices as fuel wood.

Establishment and management of shade trees in tea lands are also not up the recommended levels that deprive estate of harnessing their full benefits as a source of fuel wood for their factories. Often shade trees are grown with the sole aim of supplying necessary shade and green manure supplied by leaf fall without much focus on value of firewood that could be obtained.

Rubber Wood Supplies

In spite of the demands by other sectors a significant amount of fuel wood supplied to the tea factories is still rubber wood. However, the quality of supplies has deteriorated with the short supply and factories being forced to accept roots and other sections, which they would have rejected in the past. The price levels have also risen to the level of Rs 1,250-2,200 per Cubic meter from levels of Rs 500 per Cubic meter prevailing prior to year 2000. The market is now entirely supplier driven with the suppliers laying down the conditions to the factories desperate to obtain the requirements practically on a hand to mouth basis. Once converted to cost per ton with a moisture content of about 50% at point of receipt, the cost at present would be in excess of Rs 6.50 per kg. However, some corporate sector plantations with rubber cultivations have the privilege of using rubber firewood at a cheaper cost covering part of their requirements.

Mixed Fire Wood

The factories also receive increasing quantities of other species of fuel wood vaguely called mixed fuel wood of approved species. In case of some bought leaf factories such firewood constitutes the majority of supplies exceeding 80% [8].

The supply of mixed firewood has to be viewed with concern as there is a grave danger of un-controlled felling of jungle wood with absolutely no regeneration. Hence, this source is not reliable and it is a fast diminishing supply. Further, environmental concerns can also surface sooner than later thus restricting the supply of mixed firewood in the near future. Tea industry also has to take cognizance of these facts and should not be seen as being a party to environmental degradation in the country. At present mixed fuel wood fetches a slightly lower price than rubber wood and is in the range of Rs. 1,000-1,500 per Cubic meter.

Firewood from Wood Lots and shade trees

Although, some estate based factories have a potential to obtain substantial quantities of firewood from their wood lots, it is currently hindered by the regulatory problems preventing harvesting at optimum time. In view of this constraint there is lack of interest for efficient cultivation and management of woodlots by Plantation Companies.

A very small percentage (<3%) of SRC wood species mainly *Gliricidia*, is delivered to bought leaf factories, by regular fuel wood suppliers or by tea smallholders. However the potential for developing this supply chain is substantial. Additionally, lopping of the shade trees are also being used by estate based tea factories. However it is learnt that the establishment and management of shade trees are much below the recommended levels.

Strategies for Reducing Fuelwood Demand and Sustaining Supply

In order to ensure thermal energy security of the tea industry, it is important to reduce fuel wood demand and ensure sustainable supply at a reasonable cost. In order to achieve these goals, following strategies can be recommended.

1. Demand Side Management
   a. Improvement of Operating Practices
   b. Efficiency improvement of factory machineries
2. Diversification of suppliers and species
3. Self generation of fuel wood

Demand Side Management

It has been noted that the consumption of fuel wood in the tea factories has been sub optimal due to low quality of firewood and poor operating practices [2]. Therefore strategies have to be developed to promote and facilitate proper operational practices, which could contribute to substantial savings. In this context, some areas in need of greater attention are as follows.

1. Prevention of use of fuel wood with high moisture content
2. Prevention of use of large logs
3. Potential for recovery of waste heat from the stack, for drying of fuel wood.

It is an axiom of the combustion technology that the fuel should be fed at the smallest possible size and with lowest possible moisture content to ensure high combustion efficiency.

Therefore a radical departure from the current practices of feeding large logs with a high moisture content (>20%) is necessary. Feeding small sized or chipped fuel wood pre-dried to acceptable moisture content (<20%) will result in immediate savings in the fuel wood consumption. In this regard, reducing the size of traditional fuel wood logs to a typical size of 25 mm- 50 mm in diameter may be considered impractical and costly. However, the additional cost of labour and energy used in this operation would be more than compensated by the increased efficiency of combustion.

Diversification of suppliers and species

Green leaf suppliers as energy suppliers

It is eminently feasible to create a culture of the green leaf suppliers graduating to be suppliers of both the raw material and the energy for the bought leaf factories. The small holders being the backbone of the supply chain for these factories currently cultivate more than 118,000 ha of tea lands [9]. They have the potential to generate more than 531,000 tons of fuel wood per year by planting *Gliricidia* as medium shade trees at an initial density of about 900 trees per ha giving an average fuel wood yield of about 5 kg per tree per year [7] [10]. This is far in excess of the all the fuel wood requirements of the bought leaf factories estimated to be about 293,000 tons per year.

Since this practice is not prevalent at the moment a concerted awareness campaign will be required to generate the necessary enthusiasm amongst the small holders, highlighting both the additional monetary gain by the sale of the fuel wood to an assured market with the bought leaf factories as well as the value of the foliage as fertilizer. Since the bought leaf factories will be the greatest beneficiaries of such a change they would need to evolve the necessary strategies to entice the small holders. The potential additional income of Rs 600 million annually that could flow into the hands of the small holders, only by the sale of the wood (@ Rs 2,000.00 per ton) could be highlighted in this exercise.

Short Rotation Coppicing (SRC) species as fuel wood

The tea industry has traditionally used rubber wood supplied in log form as the main supply mode. While all factories have invested in wood splitters, the feed to the furnace is in the form of relatively large chunks of wood mostly with high moisture content. Both these practices lead to inefficiencies of combustion. SRC species of wood does not require splitting using wood splitters. As the branches are 25-50 mm diameter, just cutting to necessary length is adequate as far as preparing the fuel is concerned. Additionally such small size fuel wood is ideal for automated feeding systems. Further, efficiency of use of such fuel wood (0.85 kg/kg of made tea; [11] is considerably better than what is achieved at present. The commonest SRC species that could be considered for fuel wood are *Gliricidia sepium* and *Caliandra calothyrsus.* These species are known to be well adapted to the soil and climatic conditions in tea growing regions. Moreover, they are familiar to tea growers and are available in substantial quantities as shade trees and fencing and wind barriers. These species are also having the environmental advantage of being nitrogen fixing and/or generation of nitrogen rich foliage and more importantly being tolerant for continued coppicing at short time intervals. This quality makes them a truly renewable resource of fuel wood. Further, obtaining planting material is also not a problem.

Self Generation of fuel wood

The foregoing analysis amply demonstrates the feasibility of generating fuel wood more than the requirement of the tea industry by the estates and the small holders themselves through diversification of fuel wood species without fully depending on rubber and mixed firewood. Any surplus can generate an additional income to both the plantation companies and the small holders, given that the demand for fuel wood is growing in the other sectors as well. In the long term, this would be a boon to the country at large providing a means of limiting the import of fossil fuels and expanding the power generation from renewable resources.

Availability of land for fuel wood plantations

As per the available records, there are substantial extents of lands within corporate sector plantations, which can be utilized for generation of fuel wood that ensures reliability of the supply. Survey conducted by the Tea Research Institute has shown that there are about 14,287 ha of uncultivated lands in the corporate sector tea estates of which 7789 ha are at low elevations. In addition, there are about 12,569 ha of forest/scrub lands. It is also a well known fact that large extents of marginal tea lands with an uneconomical productivity exist in the sector. It may be prudent to progressively convert such lands to fuel wood lots. The estimated extent of such marginal lands yielding less than 1000kg/ha/yr is more than 19000 ha [6].

Economic viability of fuel wood cultivation

Detailed financial analysis [12] given below (Table 1a-c) indicates that the establishment fuel wood plantations is an economically viable venture giving attractive returns. Moreover, such plantations are of great environmental importance by way of fixing carbon dioxide and controlling soil erosion in poorly managed tea lands.

Table 1a: Economics of energy plantations (per ha): Gliricidia Plantations [12]

Criteria	@15% discount rate		@20% discount rate	
	Wood value	Wood + leaves	Wood value	Wood + leaves
B/C	1.38	1.66	1.14	1.38
NPV Rs.	108,735	191,239	Rs. 34,039	Rs.91,373
IRR	24%	30%	24%	29%
Payback Period	6 yrs	5 yrs	6 yrs	5 yrs

Table 1b: Economics of energy plantations (per ha): Albizzia Plantations [12]

Criteria	@15% discount rate	@20% discount rate
B/C	2.53	1.19
NPV (Rs.)	462,156	51,589
IRR (%)	21	21
Payback period	12 yrs	12 yrs

Table 1c: Economics of energy plantations (per ha): Eucalyptus Plantations [12]

Criteria	@15% discount rate	@20% discount rate
B/C	4.32	2.06
NPV (Rs.)	1,024,118	299,068
IRR (%)	26	26
Payback period	12	12

Potential for net energy export

While the primary focus is on achieving self sufficiency of fuel wood to meet the thermal energy needs of the tea industry, the potential for generation of a significant surplus of fuel wood from within the tea sector has been demonstrated in the evaluations done above.

Thus it is possible to examine the more ambitious prospects of generation of electrical energy as well within the tea sector. This need not be limited to the internal needs and the variability of the demand over the 24 hour period can be explored to permit the export of excess power to the national grid at least during part of the day, thus generating an extra income.

The distinct possibility of the consumer tariff even for industries escalating in the future such that the cost of self generation may become more economical in the coming years is a reality. The most attractive feed in tariff for biomass based power generation is a further incentive to explore this potential.

To garner the best advantage, any power generation system should be designed on the combined heat and power model since the process of manufacture of tea requires both these modes of energy. The relative demands were described earlier and the variability of the hours and levels of demand of the two forms of energy can be leveraged to optimize the system, coupled with the means of export of the excess power to the national grid.

While the capacity of the individual systems and the final model selected will vary from factory to factory, primarily governed by the availability of fuel wood, the following schematic diagrams (Figure 1) illustrate the different possibilities.

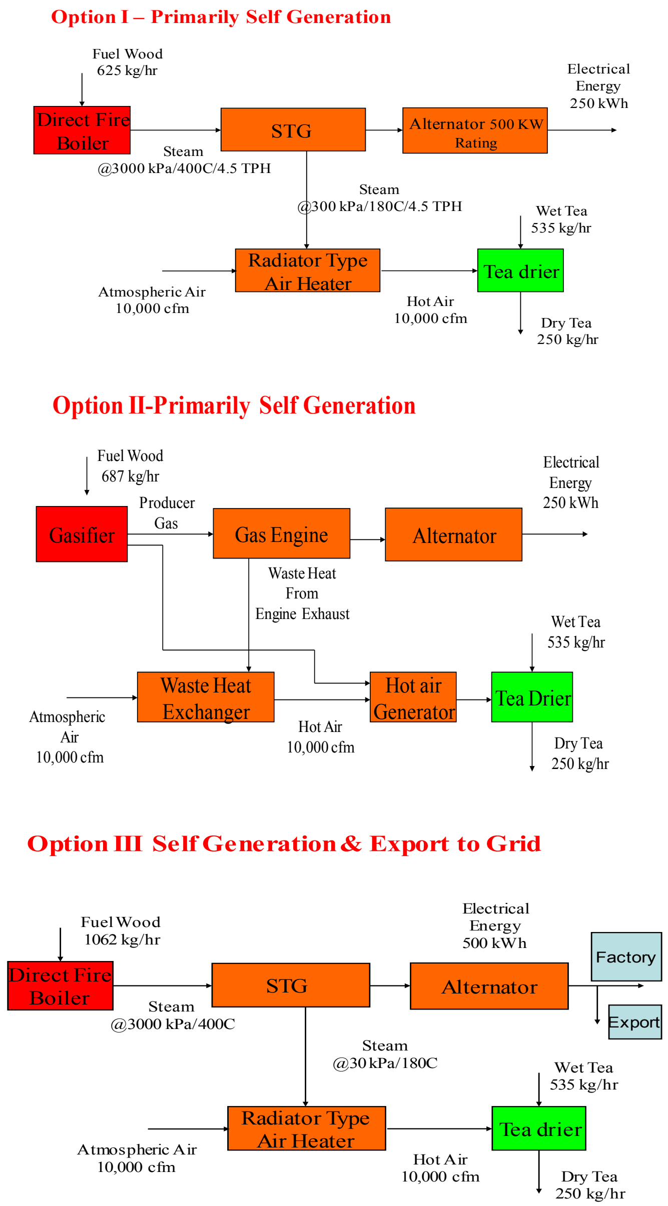

Figure 1: Options available for self generation of energy (quantities of fuel wood at 20% moisture content)

While the systems above would require considerable initial capital expenditure, with the total control over the supply and cost of the primary input of fuel wood, a life cycle cost analysis would prove the financial viability.

The Additional fertility benefits of leaves of SRC species

It is well known that the recommendation for growing SRC species such as *Gliricidia* and *Calliandra* etc. in the tea plantations has been done to achieve a dual advantage. One is for providing the required shade for the tea plant. The other is for improving soil fertility in recognition of the fertility value of the leaves and small twigs left on the field after loping of the branches. Due to long term cultivation, soil erosion and rising temperatures the fertility level of tea plantations are reported to be declining. The organic carbon status of tea lands that largely determine the fertilizer use efficiency is remarkably reduced. Relying only on chemical fertilizers and lack of application of green manure to tea lands have also made tea lands more acidic than optimal levels. Planting and proper management of shade trees and green manure crops will provide large amount of organic manure to tea lands thus improve soil health. Therefore, shade trees not only provide shade and energy but also supply much needed soil organic matter to tea lands. The SRC species commonly planted as medium shade trees are rich in nitrogen (4 - 4.5%) and potassium (1.5 - 2%) [13].

Under the present circumstances when the cost of imported fertilizer is on the increase and the burden on the state coffers to maintain the current levels of subsidies, the above option may prove to be a great boon, particularly for the small holder tea growers. Moreover this would prove to be great incentive to promote planting of SRC species in tea lands which will also help solving the problem of energy self sufficiency.

Recommendations and Barriers to Overcome

From the foregoing it is evident that the self generation of total fuel wood requirements is feasible within the industry itself with substantial surplus. In addition such an approach would create additional sources of income for both the estates and the small holders. The most important spin off benefit would be the prevention of the environmental degradation caused by the unchecked extraction of so called Mixed Wood from non renewable sources.

However, since it appears that such potential is not appreciated either by the estates or by the small holders, several measures would need to be taken to create the necessary awareness as well as to overcome potential barriers.

The following measures are therefore, recommended to ensure energy security of the tea sector in Sri Lanka.

1. Promote the adoption of fuel wood saving technologies discussed above to reduce the consumption of fuel wood.

2. Create suitable avenues of concessionary credit for the plantation companies to embark on an urgent and time targeted program for the establishment of fuel wood plantations.
3. Evolve a program with the bought leaf factories to encourage the small holders to grow fuel wood at least as the shade trees in tea smallholdings.
4. Obtain the commitment of the relevant state agencies under to facilitate the planting of SRC species and regulate the sale in lines similar to that of bought leaf.
5. Relax or remove the undesirable regulations on harvesting and transport of cultivated firewood lots and provide guidelines for the proper methods of periodic harvesting of the various species to maintain the growth and renewability.

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Biogas Production Using Market Garbage

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Abstract

The paper presents lesson learnt from implementing a medium scale biogas project in Sri Lanka. The first attempt of this project was to introduce medium scale PVC type plug flow unit having a capacity of 50 m^3 to our country. Specialty of this type was the low initial cost, low retention time and easy installations. The results of the project indicate that the feeding of 100-250 kg of market garbage enough to produce equalant to half domestic LP gas (12.5 kg) cylinder per day. It can be predicted that, biogas production potential from market garbage is 40-50 liters per 1kg of wet market garbage per day.

Introduction

Disposal of solid waste is a priority environmental issue in Sri Lanka and at present it has become a national concern. The most commonly used method of municipal solid waste (MSW) disposal still remains to be open dumping. Per capita waste generation in the country is ranging in 0.4-0.85kg and total waste collection is around 3700 tons per day from total generation of around 6400 tons per day. The Western Province shares more than 59% of the country's daily collection of waste, amounting to 1840 MT. This creates many hazards to environment due to open dumping. The most popular dump site in the country was Blemendal which had 200-300 feet height of garbage collected. In response to numerous public protests, the superintend court of Sri Lanka banned dumping garbage in to this site in 2009.

Fruit and vegetable wastes are generated in large quantities in the greater Colombo city area from vegetable markets collectively adding higher MSW to above total waste generation. Due to its high biodegradability, it creates problems for both environment and the society. Jathikapola in Narahenpita, Colombo is a busy market area in the commercial capital of the country. It faced a typical problem of market waste management. It generates about one tone of fruit and vegetable waste per day. Main fruit wastes are papaya, banana, mango and pineapple. Vegetable waste includes most leaf wastes, tomato, cabbage, beans, carrot, ect. Presently, dumping is the only solution for this problem. It is noted that biodegradability of this waste is around 70-80 %. Therefore it has a good potential to produce biogas from this resources, to generate energy and organic fertilizer, which also act as a soil conditioner. Sri Lanka Sustainable Energy Authority, in collaboration with the National Engineering Research and Development Centre (NERD) and the Colombo Municipal Council (CMC) formulated a biogas project to demonstrate the feasibility in managing biodegradable waste through the employment of the biogas technology.

Project objective

a) Demonstration of biogas generation in finding a solution for the market garbage problem at 'Jathikapola', Narahenpita using PVC plug flow digester as a research

b) Demonstrate the ability of biogas to generate electricity

c) To exhibit organic fertilizer as a byproduct which can be sold to farmers visiting 'Jathikapola'

Project location

Jathikapola waste dumping site was also seriously damaged by dumping the market garbage since in 1980. The project site 'JathikaPola' has assumed serious proportions in this problem as depicted in figure 1. According to 2009 data it generates about one tonne of fruit and vegetable waste per day.

Figure 1: Project Site (Jathikapola)

Project implementation mechanism

The project was outsourced to achieve the above objectives. The main project objective was to demonstration of biogas generation in finding a solution for the market garbage problem at 'Jathikapola', Narahenpita using PVC plug flow digester as a research. Reason for the selection of PVC bag type plug flow system is due to law cost and best efficiency in anaerobic digestion process and low retention time. The contractor was selected based on cost based selection (QCBS) and the project offered to Ever Green Biogas Ltd.

Technology

Fluid going through in a plug flow reactor (PFR) may be modeled as flowing through the reactor as a series of infinitely thin coherent "plugs", each with a uniform composition, traveling in the axial direction of the reactor, with each plug having a different composition from the ones before and after it. The key assumption is that as a plug flows through a PFR, the fluid is perfectly mixed in the radial direction but not in the axial direction. Each plug of differential volume is considered as a separate entity. As it flows down the tubular PFR, the residence time (τ) of the plug is a function of its position in the reactor. Usually length of the reactor is four times than the width of the reactor. Due the low retention time, higher efficiency, easy maintenance and low cost the above plug flow system was selected for this study.

Plant Design

Plant consists of raw material collection bed, copping machine room, feeding tank, plug flow digester, outlet tank, gas storage tank as shown in attached annex 01. Fig. 02 below shows the plug flow digester schematic diagram. The rectangular digester tank with the capacity of $48m^3$was constructed with bricks. The length of the digester was three time the width of the digester including effective digester volume 10x3x1.6 ($48\ m^3$).

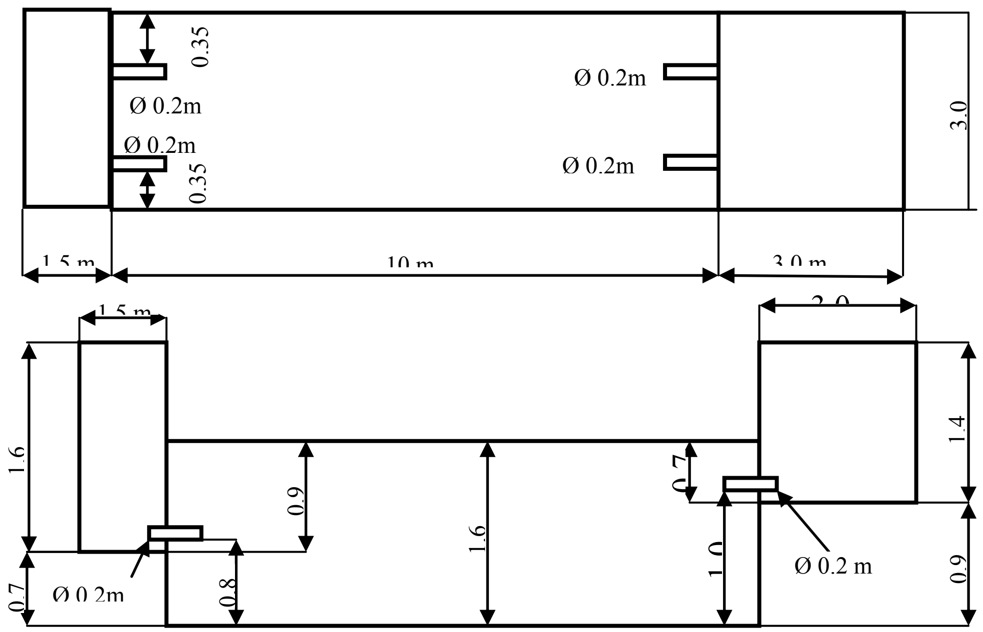

Figure 2: Schematic diagram for 50 tones of Plug flow type Continues digester

Project Implementation

The project commenced on Thursday, 25th of February 2010. The plant was constructed with bricks, plastered and hanged the PVC bag type material on the wall. The total feed material would collect to this PVC bag and let produce biogas to be collected in the gas holder with capacity of four m^3 and weight of the gas holder was around one tone kg.

With that starting Plant construction and feeding has been done by the contractor within one year period, the space used for the project was 80 m^2.

Project Cost

Initially estimated budget for the project 1.25 million and total actual budget was around 1.5 million, while the digester construction cost LKR 0.69million. It was experienced that equipment maintenance cost of the project was extremely low representing 0.23% from the total expenditure during last four years. Typically rectification cost of the project was very high representing 28% of the total expenditure.

Materials and Method

Initially, the physiochemical parameters of market garbage were tested and the results were given in table 02. The digester construction finished at the mid of year 2010 and after the leakage tests, the digester was fed with 5 tons of Fresh cow dung on 16th June 2010. The cow dung was mixed with water (i.e. to a ratio of 1:1).

Table 1: physiochemical parameters of market garbage at jathikapola

Sample	Total Organic Carbon(%)	Total Nitrogen (%)	C/N ratio	Total Phosphorous (%)	Total Solids (%)	Volatile Solids (%)
Carrot	8.46	0.011	769	0.041	9.47	74.48
Leaks	9.97	0.04	249	0.046	6.87	80.26
lettuce	8.77	0.19	46	0.044	7.91	66.97
Bringal	9.83	0.036	273	0.048	8.39	91.37
Radish leaves	8.07	0.21	38	0.052	9.98	71.82
Jack wastes	10.7	0.091	118	0.017	19.86	95.4
Mixed:	8.43	0.206	41	0.037	13.68	84.39

After observing the blue flame two weeks later, the digester was sealed after one day and it was taken two weeks to initiate the biogas production. The digester was fed with market garbage starting 50 kg and gradually increasing by 25 kg up to 220 kg of market as shown in fig. 03

Figure 3: The digester feeding point

Raw materials were chopped into about 30cm pieces. Specialty of this chopper machine was low energy consumption. With the two horse power motor, it has capacity to chopped one ton of garbage within one hour period. The biogas produced continually about one month period and it was able to cooked 50 people and lighted bulb as shown in figure 08.

The operation failed about one year due to technical issue, until the NERD Center attempt was success in second time. The NERD center followed the following procedure made the digester performance success.

Testing for air and water tightness

The air and water tightness was confirmed by conducting a test for air tightness of the digester before feeding to the digester. The digester was pressurized up to fourteen Inches of water gauge by filling water and observed and monitor pressure drop for a period of one hr. It was observed that no change of pressure inside the digester conforming that the digester was water and air seal. Generally eighteen mm of pressure change was allowed for a period of one hour for a properly sealed biogas digester.

Feeding of substrate

The digester was fed with five tons of fresh cow dung second time on 22nd November 2012 and added water until the digester fill up to top most layer of the inlet so that to trap the produce biogas in the digester. Then let the digester unsealed for two days to increase the growth of anaerobic bacteria. Feeding of market garbage started on 29th November 2012 with 5 Kg of papaw, 4.4 Kg of Leaks, 1.4 Kg banana fruit, 10. kg of Glirisidia 10.8 totally 20 kgs. Then the adding market garbage was gradually increased by 20 kg until reaching the maximum 220 kg of market garbage.

Issues met and how they were overcome

After initial feeding it was generated biogas continually only about one month period. The top cover concrete slabs of the digester were raised up by the generated biogas in the digester on 12th July 2010 as shown in fig. 4.This may be due to over production of biogas gas or not enough space availability in the digester cavity space. After this unexpected incident, the PVC bag was damaged in several places. Even though the bag re-plastered several times, the biogas continually leaked. Therefore, it was appointed an advisory committee headed with Prof. Ajith De Alwis, chairman of the biogas association to undertake this technical problem. However, the committee decided to rectify the digester tank from NERD center mature plug flow technology to avoid frequent leakages by replacing the damaged bag with new bag. Further, on that time the project was one year lagging behind the time schedule.

Figure 4: Top cover concrete slabs of the digester were raised up by the generated biogas

Figure 5: measuring water leakages

Figure 6: Obtaining instructions from Prof. Ajith De Alwis

Even though, the contractor under had taken the NERD center plastering method, the water leakage test was failed twice as shown in the fig. 5. The digester was tested for leak by pressurizing it up to -14 inch in water gauge and two inch waster leakage observed within one hour period.

Finally, the committee decided to offer the contract to NERD center and to compensate the payment by the contractor to NERD center. Accordingly, this Authority entered into an agreement with the NERD Centre to rectify the shortcomings of the project, on 27th September 2011.

As shown in fig.6 Prof. Ajith De Alwis frequently observed the rectification works of the digester and instructed for many corrections. NERD Center completed re-plastered to stop gas & water leakage, initial feeding, plant operation several modifications to inlet and outlet of the digester and chopper machine modification.

Major obstacle faced by the project was the reluctant of the market people to initiate this project with their negative mind for the biogas sector. Further, the author had to reduce the project cost with the limiting budget for this project. Finally, by showing the benefit of biogas it was able to collect the project surrounding people and CMC laboures to made ‘ Saramadane’ to make the aesthetic appearance good in the project site and to reduce the project cost (fig. 7).

Figure 7: made a ‘Shramadane’ to make the aesthetic appearance good in the project site

Fig. 8 The appearance project site after landscaping

Data Collection

The rates of bio gas production, pH, pressure variation, daily feeding were measured daily.

Results and Discussions

Figure 09 shows the daily market garbage feed to the digester. Even though, the market garbage production was one ton per day when, the project started in 2009, the biodegradable material has been reduced to about half of that in year 2012 when the digester operation starts. As per the agreement with CMC, the CMC labourer was engaged for the plant operation. It was unable to engage the laourer full time, due to reduction in labour forces in the Jathikapola market. Any how the maximum feeding was 220 kg on 10th December 2012 as shown in the fig. 9. The best digester performance recorded when plant operated by the NERD Center during January to March 2013 . Totally the digester was fed about two tones of market garbage during November 2012 to march 2013 except five tons of initial feeding of cow dung. It can be predicted from the results of this project biogas production potential from market garbage is 40-50 liters kg of market garbage per day.

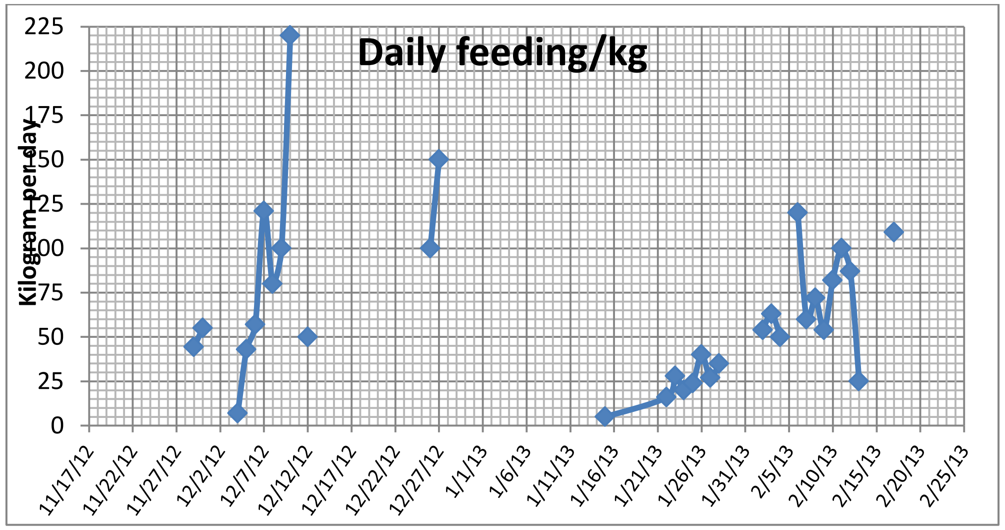

Figure 9: Daily market garbage feeding

Figure 10 shows the daily biogas usage with time. Gas production was started within one week's time after feeding and sealing of the digester whereas usually taken about 1-2 days for observing the gas formation. The initial gas production was mainly in the form of CO_2 since mixing with cow dung effectively and readily exposed the organic substrates to a high population of mixed syntrophic microbes. Thus hydrolysis and acidogenesis occurred rapidly, as the time taken for bacterial acclimatization to the substrates was comparatively short. During this period the pH of the substrate were rang in 5.4-6.5. Indicating

the growth of methonegens bacteria, and having the composition of biogas 36% CH_4 and CO_2 64%, the slightly blue colour flame was observed after two weeks time of the feeding to the digester in the presence of pH range in 6.5-7.

The daily biogas produced were used as thermal application by the nearby canteen which is usually cooked for about 200-500 people. The produce biogas distributed to the canteen via a gas meter which recoded the accumulated gas passing through the meter. The meter and gas distribution are shown in the annex 03.

Total biogas generation within three months period was 261 m^3 giving average gas production 6.8m^3. This much of biogas was enough to cooked 7 – 8 curries for 100 – 150 people per day which was equivalent to 1/2 (half) Cylinder of domestic LPG (13.5 kg). The recorded highest gas production was 19.8 m^3. This might be due to feeding of higher papaya during those days.

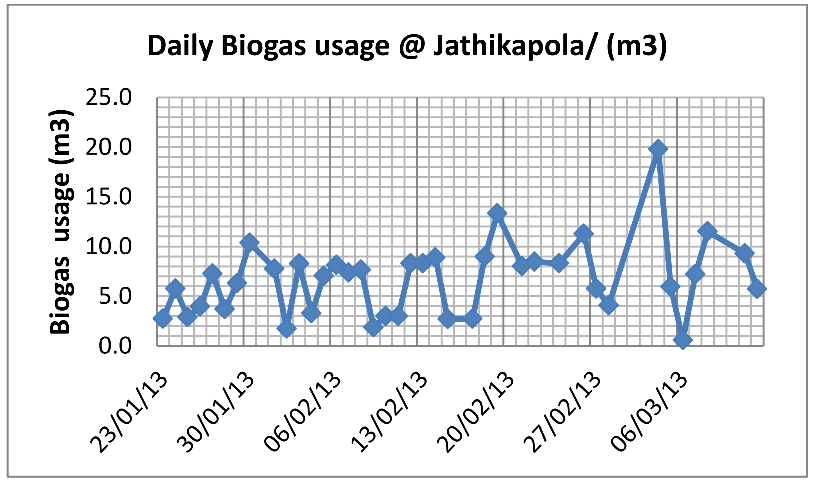

Figure: 10 Daily biogas production usage

Quality of Biogas

Gas production increase very slowly in the digester and pressure increased from 1 inch to maximum 32 water inches by 15th February 2013. As a consequence, the quality of biogas produced during the initial stages of the study was poor due to lack of CH_4. In other words there was hardly any blue flame produced when the collected gas was ignited. The composition of gas recorded on 12/2/2013 was CH_4-65.30%, CO_2-34.07%., at the pressure of 3 Inches WG. Biogas was burnt giving blue flame. The digester produces quality biogas rang in 50 -68

Table 3: Biogas composition and fig. biogas analysis meter

	CH_4 (%V)	CO_2 (%V)
27/01/2013	49.30	43.40
5/2/2013	57.7	42.3
7/2/2013	61.9	33.1
8/2/2013	63.5	36.4
11/2/2013	64.8	35.2
12/02/2013	65.3	34.7
13/02/2013	64.1	35.6
18/02/2013	56.3	43.5

There is a marked variation in quantity of marked garbage feed daily. On average during these selected time period garbage had been fed at a rate of 62.5kg per day.

Economical benefits from the project

The project benefits the economy in several ways. It is estimated that the digester will generate 10 – 20 m^3 of biogas, depending on the quantity of feeding material, 200 – 300 litters of liquid fertilizer per day. This fertilizer is 40% more nutrient-rich than normal composting. The biogas can be used for cooking at the site canteen, while the liquid fertilizer can be sold at the market as a nutrient rich organic fertilizer. The avoided costs due to the project are given in
Table 04.

Table 4– Income Generation of the Project

	Unit	
Usage of LPG gas at the Canteen	12.5 kg	1 cylinder for 2 days
Cost of Cylinder	LKR	2,300.00

The gas generated from the biogas plant is sufficient for all cooking needs of the canteen. The avoided costs of the project are indicated in the table 5.

Table 5 – Direct Benefits of the Project

	Unit	Amount
Avoided cost per day	LKR/day	1,150.00
No. of curries cooked	Nos./ day	7 - 8
No. of people served	Nos./ day	100
Liquid fertilizer	l/day	250 - 300
Income from liquid fertilizer	LKR (if LKR 5/litre)	1,250.00

*This output is achieved by feeding 100 – 150 kg of market garbage per day.

When the project reaches maturity, it is recommended to the CMC to trade biogas to the canteen, at a reasonable cost. This would add more value to the product and would also encourage similar endeavors in other areas.

Lessons learnt and Recommendations

This section explores the lessons learnt in the project, with a view that it would provide insights for future endeavors.

Technical

- Initially, this project aimed at introducing the medium scale PVC Bag Type Plug Flow Unit as a low cost method in biogas generation. This project served as a research; however, results indicated that the medium scale PVC Plug Flow Unit is not suited to Sri Lanka, Therefore the project shifted to the dome type plug flow system, which is the proven technology in Sri Lanka.

Social

- Many previous projects in biogas generation from waste management done by various institutes have failed. Therefore, the community was reluctant to accept this project, citing that it would be yet another failure.
- Even though the project was sanctioned amidst many difficulties, a certain faction of the community continues to resist the project and even vandalize it in minor scale. Therefore, it is necessary to strongly mobilize the community in the market place and vest the project in their custody, emphasizing on the direct and indirect benefits of the project.
- Initially there was a considerable stigma involved in the project, since it was dealing with garbage. Hence, the community and other stakeholders were off and on reluctant to support the project and their enthusiasm gradually reduced with time.
- A community based mechanism to maintain the project is desired to achieve long term sustainability of the project.

Environmental

- Prior to the project, the site was infested with garbage and scavenging animals like crows, mice and insects. The garbage dump emanated a stench and was an eyesore in the area. The project directly contributed to managing the garbage and converting waste into resource, by generating biogas.

Conclusion

- It can be predicted from the results of this project biogas production potential from market garbage is 40-50 liters from 1kg of market garbage per day. And daily feeding of average 67 kg of market garbage could produce enough biogas to cooked 7 – 8 curries for 100 – 150 people per day.

Recommendations

- It is need to give extreme attention when selecting the contractor, location, and project beneficiaries when doing community project like this. Risk management is essential element that should consider when planning the project. For example the raw material quantity may reduce instead increasing. It is must to have a dedicated plant operator for sustainability of the project.

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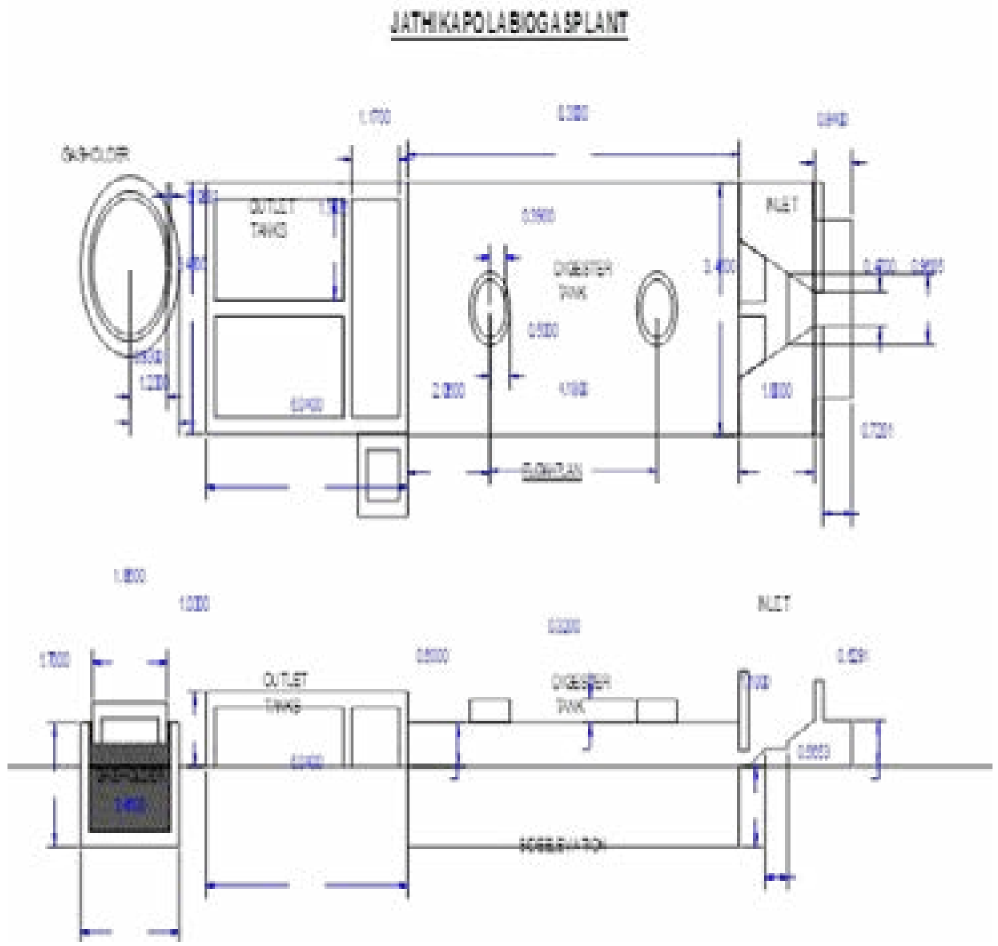

Twenty Four Indicators to Assess Environmental Sustainability of Bioenergy Systems: A Literature Review and Future Research Agenda

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Abstract

There are pressing reasons for developing a better understanding group of indicators to assess social, economic and environmental sustainability of bioenergy systems. Therefore an important current research need is to develop a better accepting of group of indicators for environmental sustainability. Effective indicators can help to identify and quantify the sustainability attributes of bioenergy options. Therefore, the aim of this paper is to critically review the indicators that assess the environment sustainability of bioenergy systems. A comprehensive literature review and a desk study of 20 key research papers written on bioenergy are analyzed in this research study. This research identified a set of indicators influencing sustainability criteria for bioenergy under environment sustainability. Twenty four environment indicators are identified for green house gases, water quality and quantity, soil quality, air quality, biodiversity, energy efficiency, waste, productivity and land use and land use change from literature review. Twenty four indicators identified under nine categories from literature review will be used to identify critical indicators affecting the sustainability criteria for bioenergy during the next phase of the study. These critical indicators are hypothesized to be practical toolset for capturing key environmental effects of bioenergy across a range of bioenergy system, including different pathways, locations, and management practices. To evaluate the hypothesis that the toolset meet this goal, and also to help measure variability and establish appropriate targets, the toolset should be field tested in systems spanning a wide variety of conditions. If the hypothesis is confirmed, the toolset can be implemented more broadly, modified as necessary for particular situation.

Key Words: Bioenergy Sustainability, Environment Indicators, Food security, Biodiversity and Land use change

Introduction and background

The production and use of bioenergy have potential roles in mitigating climate change, promoting energy security and fostering economic and social development. Various types of biomass are used for the production of bioenergy through many types and sizes of economic operations. Virtually every country in the world produces and consumes some form of bioenergy. The characteristics of bioenergy production therefore are very heterogeneous, and their production processes depend on several factors, such as geographic location, climatic conditions, level of development, institutional frameworks and technological issues.

In fact still if you ask a direct question how sustainability looks and feels answering can be quite difficult. Big countries and big powers will think quite different to small and less develop countries and those who are about to be submerge due to climate change. For the latter the criteria should be applied to others on how they work and play as they are going under no fault of theirs but more due to excessive consumption and selfishness of some others. Sustainability is often considered to be the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the socioeconomic, environmental and other requirements of present and future generations. A less work has focused on the development of environment indicators for sustainable bioenergy system in Sri Lanka. In international Standardization of sustainability criteria for bioenergy system, no consensus has yet emerged regarding which indicator should be assessed and which indicator should be given the highest priority. Therefore a need arise to identify whole set of indicators to assess the sustainability of different types of bioenergy systems. To fulfil above requirement, Set of environmental sustainability indicators are identified from this literature review study.

This set of indicators may be useful for policy makers, Agronomists, Producers, business people, and other stakeholders in all stages of the supply chain from an albeasia (vatamara) grower or waste suppliers to those involved in logistics, conversion facilities such as biomass power plant owners and end users. Now the sustainability criteria should consider all different aspects of these operators and their physical locations and operations. A biomass plant owner can influence across a wider group as they would be influencing long distance farming including where and by whom. How well and comprehensive you address social, environmental linkages and performances will mean the accuracy of your work and the honesty of your purpose. It is important to understand that if we are to grow our food, live our lives and grow our energy too from the same land mass, competition has to come in some day.

The fact is that as yet bioenergy is not mainstream energy in countries. This is true with many developing economies as bioenergies do not operate in the domain of commercial energy. With globalization and with increased demand for reducing GHG emissions one can grow your energy elsewhere and proceed to source or have carbon accounting and offsetting. Where the energy is grown, if the offer is attractive, one may witness the shift of land for more opportunistic bioenergy than for food or other use.

Indicators provide information about potential or realized effects of human activities on phenomena of concern. Indicators can be used to assess the social, economic and environmental conditions of a system, to monitor trends in conditions over time, or to provide an early warning signal of change. While this review made to be broad enough to apply to bioenergy, generally, the indicators were selected based on biomass production pathways. The review was done to address few objectives. The first objective is to identify a full set of environmental indicators that can effectively support policy makers, decision makers and planners. The second objective is to identify indicators that apply across the supply chain, including feedstock production and logistics, conversion to biomass, biomass logistics and biomass end uses, as defined by the group of actors at each stage. For example, growers and suppliers are the major players in the feedstock production stage; the conversion stage involves biomass plant and other biomass application; and fuels users (including the public) are at the end-user stage. It is important to consider the components of the supply chain both individually and collectively. The third objective is to identify a full set of indicators of environment aspects of sustainable bioenergy systems based on literature review. The lack of consistent application of selection criteria can weaken attempts to promote sustainability indicators by generating well-intended but bulky aspiration lists. Too many indicators and data requirements upset effective adoption because of unacceptable technical, administrative or economic burdens. The fourth objective is to help in the implementation of certification programme (ISO Bioenergy standard is under development) that can be applied to either the whole supply chain, parts of a supply chain, or a single process in the supply chain. The fifth objective is to facilitate comparison between various bioenergy process and product. This full set of indicators can also be used to facilitate comparison between bioenergy processes or products and other energy options.

Aim and scope

This paper performs a review of a large portion of the existing scientific literature on effective indicators that is used to identify and quantify the sustainability attributes of bioenergy options. Author of this paper assume that the reader already has a basic knowledge of environmental effect of the full supply chain for bioenergy, including feedstock production and logistics, conversion to bioenergy, bioenergy logistics and bioenergy end uses, so that general information on these aspect is not provided here. The main purpose of this work is to discuss the key direct and indirect indicators of environment and striking features emerged from a review process of the wide scientific literature available and analyzing the approaches used by the different authors to face these issues, thus reporting the current state of the art. In addition, only papers written in English and with good and reliable supporting data and references were selected. Selection of indicators was based on research in the disciplines related to each category of indicators. The diversity of indicators needed to broadly assess environmental sustainability may not allow for a uniform, well defined indicator selection process. Therefore, expert judgment is an important part of the selection process.

Table 1: List of recommended environment indicators for Bioenergy sustainability - Different studies, Authors and the indicator identified by them,

Studies' Authors / Indicators	Michael Wang 2002	Amarathunga AAD 2013	Bremner & Mulvaney 1982	Doran & Jones 1996	Eaton AD 2005	Buchanan & Somers 1969	Appel et al 2007	Prakash & Krish 2010	Clark et al 2001	David SL & Kathleen 2008	Tad WP 2009	Turlure et al 2010	ISO / TS 14067 CFP	Stefan F 2013	Christopher K W 2012	Ellen M F 2013	Matthias F 2013	Mehlich A 1984	Charles P 2010	Gaffney & Marley 2009
Greenhouse gasses (GHG)																				
Life cycle GHG emissions	■												■				■			
Water quality & quantity																				
Consumptive water use*																				
Peak storm flow						■														
Sedimentation		■			■															
Increase in water temperature		■																		
Minimum base flow						■														
Phosphorous removal		■			■															
Pesticide herbicide concentration					■															
Nitrate concentration in streams		■			■															
Quantity of effluents																■				
Soil quality																				
Total organic carbon				■																
Total soil nitrogen			■																	
Change in soil bulk density				■																
Extractable Phosphorus																		■		
Air quality																				
Carbon monoxide							■													
Total particulate matter less than 2.5µm (PM2.5)								■												
Total particulate matter less than 10µm (PM10)																				■
Biodiversity																				
Ecosystem Services										■		■			■			■	■	
habitat area of taxa of special concern												■			■			■	■	
Energy resources																				
Energy efficiency											■									
Waste																				
Bio-waste																■				
Productivity																				
Above ground net primary Productivity									■											
Land use and land use change																				
Total area for bioenergy compared to national surface														■	■		■			
Direct effect on food security resulting from land use change														■	■		■			

Consumptive water use can be calculated from flow measurement of feedstock production.*

Categories of Indicators

Indicators of greenhouse gas

Estimated net carbon equivalent (C_{eq}) flux to the atmosphere is recommended to measure the effect of bioenergy systems on atmospheric concentration of greenhouse gases that contribute to climate change [13] [Table 1].The direct and indirect environmental effects of elevated atmospheric C_{eq} concentrations differ regionally, but, because the atmosphere is well-mixed, those effects do not depend on the locations of C_{eq} release or sequestration. Therefore, C_{eq} release and sequestration throughout the bioenergy supply chain can be summed, and the marginal environmental effects of those fluxes can be estimated using standard global climate models. Review learned the expected effects of increasing greenhouse gas concentrations on climate, environment, and human health, such as increases in temperature, sea level, extreme weather events, species loss, and disease.

To estimate net C_{eq} flux associated with bioenergy, we recommend that nitrous oxide (N_2O) flux and carbon dioxide (CO_2) flux be considered. N_2O is emitted directly from soil during both nitrification and denitrification, as well as indirectly when volatilized nitric oxide and nitrogen dioxide (NOx) and ammonia (NH_3) are deposited offsite and converted to N_2O or when leached nitrate is denitrified in waterways. In agricultural systems, N_2O emissions are strongly dependent on the amount of N fertilizer applied to the soil. In addition to application-related emissions, N_2O is also released, typically in smaller amounts, during the production of nitrate fertilizers, specifically during the intermediate step of nitric acid production [1].

The bioenergy supply chain also contains several sources and sinks for CO_2 that must be considered in estimating net greenhouse gas flux. Where feedstock are produced, these sources and sinks include changes in carbon stocks in biomass and soil, dissolution of agricultural lime, and fossil fuel used in sowing, tilling, harvest, and application of soil inputs. Offsite sources upstream from feed stock production include fossil fuel used in the manufacture and transport of agricultural inputs such as fertilizer, pesticide, seed, and agricultural lime. Offsite sources downstream from feedstock production include fossil fuel used in processing and in the transportation of feedstock and fuel. In addition, electricity must be generated off-site for use in all stages of the supply chain. This list of sources and sinks is an extension of that used for agriculture. The exclusion from this list of carbon fixed in photosynthesis or released through the oxidation of biomass is consistent with the assumption of other researchers that any difference between these two quantities is represented by changes in soil or standing biomass carbon stocks.

Indicators of water quality and quantity

Indicators based on water properties can be used to assess whether the agricultural aspects of bioenergy production allow for the maintenance of soil quality, aquatic ecosystems, and clean and plentiful water for human use. Water indicators are affected by some of the same pressures that influence soil indicator (e.g., fertilizer application and vegetative cover). In contrast to soil indicators, water indicators can change more rapidly and integrate changes over an entire watershed, thereby allowing for finer temporal resolution and broader spatial integration of relevant effects. In this sense water quality and quantity reflect the diversity of environmental conditions and land practices that occur upstream and upslope as well as in the past. For example, runoff attributes are influenced by current and past land cover, chemical applications, and soil conditions.

Nine indicators of water quality and quantity are recommended: consumptive water use, peak storm flow, sedimentation, and increase in water temperature, minimum base flow, phosphorus removal, pesticide herbicide concentrations, and nitrate concentration in streams and quantity of effluent [Table 1]. These indicators were selected based on their ability to reveal changes in several environmental properties that might occur as a result of bioenergy crop management: water availability, Groundwater level, water potability, change in water flow or levels considering periodicity, water depletion, reduced availability of irrigation water for existing downstream users, aquatic biodiversity, change in eutrophication, loss of habitat for identified existing species, dissolved oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, soil erosion, sediment loading, reduced assimilative capacity, soil leaching potential, Other relevant contaminant concentration, soil porosity, restrict water taking during low flow conditions and soil water holding capacity. In selecting these indicators, we assume that in most cases, water from feedstock production sites will drain into streams (some of which may be only ephemeral) before reaching lakes and waters.

Water withdrawn from public sources is recommended as an indicator reflecting consumptive water use in biorefineries. Most consumptive water use in biorefineries consists of evaporation from cooling towers and dryers/evaporators during distillation. Total water withdrawal is typically metered and easily reported by biorefinery managers. Not all water withdrawn represents consumptive use; however, the extent to which water withdrawal overestimates consumptive use is decreasing as water recycling in biorefineries increases.

Two flow properties, peak storm flow and base flow, are indicators of environmental effects of changes in soil and crop hydrologic processes. Base flow is related both to availability and quality of aquatic habitat and to the availability of water for human use. These two issues are considered separately. Interpreting flow measurements requires also measuring rainfall on similar timescales in order to separate the effects of rainfall from those resulting from changes in soil and crop hydrologic properties [6].

Increased peak flow during storm events can be caused by decreased infiltration and water holding capacity in soil. High peak flows during storms can increase erosion and sediment loading. In addition, high peak flows can reduce benthic organism biomass and habitat as a result of streambed scouring and can contribute to potential flood damage downstream [6].

As an indicator of water quality, base flow should be considered at its minimum, often occurring in summer or early fall, because lotic habitat quality can be limited by minimum base flow. During periods of low base flow, dissolved oxygen levels in streams are usually at their lowest due to lower rates of oxygen diffusion into water from the atmosphere and greater depletion of available oxygen supplies in water from respiration by aquatic organisms. Very low dissolved oxygen levels can lead to stress or death of some aquatic organisms, particularly fish [6].

In addition to its utility as an indicator of lotic habitat quality, base flow also serves as one of two measures of consumptive water use. Consumptive water use in bioenergy systems, mostly during feedstock production and in biorefineries, may affect the amount of water available for other human uses. Changes in base flow can reflect consumptive water use in feedstock production. For this purpose, base flow should be considered throughout the growing season. It should also be measured sufficiently downstream to capture both irrigation return flow and the surface discharge of groundwater sources drawn upon by deep-rooted crops [6].

Suspended sediment concentration is an indicator of stream habitat quality. Siltation diminishes interstitial space in stream substrata, impairs fish spawning grounds, and reduces the ability of sessile benthic organisms to attach to streambeds. Increased turbidity reduces the ability of benthic plants and attached algae to photosynthesize. Reduced benthic productivity and biodiversity can reduce available food for grazing organisms. Suspended sediment also clogs the gills of fish and hinders nutrient uptake by filter feeders. In addition to its adverse effects on aquatic habitat, suspended sediment also serves as an indicator of soil erosion, which can be used to assess the sustainability of bioenergy systems [2, 5].

In addition to concentrations of nitrate, total P, herbicides, and sediments, export levels per unit watershed area of these substances are also important. Whereas concentrations are indicators of the effects these substances may have on the streams in which they are measured, export levels are related to the effects of these substances on downstream bodies of water. Area specific export levels can be calculated by multiplying stream concentrations of each substance by flow measurements and dividing by total watershed area. Because estimating watershed area is straightforward and flow measurements are recommended as indicators in the following paragraph, we do not treat these area specific export levels as separate indicators [2, 5].

Concentrations of nitrate and total phosphorus (P) in streams are indicators of potential eutrophication. Whereas aquatic systems respond to nitrogen (N) in other forms, nitrate is usually the most abundant form, relatively inexpensive to measure, highly mobile, and expected to be sensitive to the management of bioenergy feedstock systems. Furthermore, nitrate in drinking water is also associated with health risks such as methemoglobinemia. In streams, total P includes dissolved phosphate, organic phosphorus, and phosphate sorbed to suspended sediment. Measurement of total P in streams is especially important during storm events, because P export during storm events tends to dominate watershed P export and is sensitive to crop management practices [2].

Concentration of pesticide, herbicides in streams measures exposure of aquatic life to these chemicals and their potentially toxic effects, the last recommended water related indicator. Most pesticide use in the U.S. consists of herbicides. In 2000 and 2001 combined, 62% of conventional pesticides used (by mass of active ingredient) consisted of herbicides [21] found that various pesticides, including herbicides, were detrimental to stream macro invertebrate community structure and ecosystem function when they occur at concentrations lower than those previously known to have such effects.

Measuring herbicide concentrations is expensive, and therefore we recommend that only herbicides known to be used or of concern in a given area should be measured [5] [Table1].

Indicators of soil quality

Among the environmental systems for which indicators have been chosen, soils are especially important because soil quality affects the broader ecosystem, the immediate productivity of bioenergy crops, and the maintenance of productive capacity for future generations. Selection of soil indicators was influenced by prior research on soil indicators in general.

Four indicators of soil quality are recommended: change in soil organic carbon, total soil nitrogen, changes in soil bulk density and extractable phosphorus [Table 1]. These indicators were selected based on their ability to reveal changes in soil properties as a function of bioenergy crop management; including carbon balance, nutrient availability and mineralization, cation exchange capacity (CEC), change in salinization, change in compaction, change in soil contamination, change in nutrient availability, change in soil organic matter, changing field management practices and timing, Rainfall, Runoff, Wind, adjusting residue removal rates, altering crop sequence within a rotation, Buffer strips along riparian zones, humification, microbial community dynamics, erosion, leaching potential, soil porosity, and soil water holding capacity.

Total organic carbon (TOC) is often seen as the most important indicator of soil quality. TOC integrates a wide range of important soil properties and functions and also is a direct cause of several positive soil responses. First, it serves as the primary source of energy for soil microbial communities, which, in turn, promote crop growth by supporting nitrogen mineralization. Second, high TOC suggests high humus levels, which promote water holding capacity, infiltration, and CEC. Third, compounds in soil organic matter, which correlates with TOC, help bind soil aggregates in non-calcareous soils, contributing to porosity and further enhancing water holding capacity and infiltration [4].

Total soil nitrogen (N) and extractable phosphorus (P) measure the two most important soil nutrients in typical productive land management systems. Most N in soil is bound in organic compounds and is not available to plants. However, total N is considered a valid indicator because N mineralization is driven by the availability of organic N in the soil, so that plant available N (ammonium and nitrate) is closely related to total N. Excessive soil N and P can result in nutrient runoff and leaching, leading to down-stream eutrophication. In addition, excess soil nitrate may increase N volatilization as the potent greenhouse gas nitrous oxide. Conversely, depletion of soil N and P threatens the future productivity of soil [3, 18].

Finally, bulk density is found as a physical indicator of soil quality. Bulk density can rapidly be affected by human agronomic practices. Bulk density is especially of concern in forestry, because tree harvesting activities can cause soil compaction. Increases in bulk density are usually considered harmful, but in some crops, such as switch grass, it is desirable to have light surface soil compaction before sowing in order to improve seed soil contact [4].

Indicators of air quality

Along the supply chain most of the air pollutants can be found. Carbon monoxide, troposphere ozone, and two fractions of suspended particulate matter (PM 10 and PM 2.5) are found from the review as indicators to measure the effects of bioenergy on air quality [Table 1] [8].

The entire CO related to bioenergy released due to combustion. Combustion throughout the bioenergy supply chain includes combustion of biofuels for vehicles, heat, and electricity, as well as the combustion of fossil fuels used in the production of bioenergy. CO is a minor contributor to climate change, but it is of environmental concern primarily for two reasons. First, it has severe effects on human health in high concentrations and may also be harmful at low, chronic concentrations. Second, it is a precursor to ozone production, as discussed below. The emission of CO in biofuel combustion varies widely based on fuel type and combustion method [7].

In some cases, an increase in the overall efficiency of a combustion process can have a counterintuitive inverse relationship with CO emissions. Because present-day liquid biofuels are oxygen containing compounds, burning biofuel either as an additive to petroleum products or as a primary fuel can result in lower CO emissions than burning pure gasoline or petroleum diesel fuel.

PM 2.5 measures mass per unit volume of all airborne particles less than 2.5µm in diameter, also known as the fine particle fraction. Fine particles can be emitted directly from point sources; such particles (soot, for example) are called "primary". Fine particles such as ammonium nitrate, ammonium sulfate, and secondary organic aerosols (SOA) are formed in the atmosphere from gaseous emissions and are known as "secondary". Bioenergy systems can contribute to fine particulate pollution through solid biomass combustion or through the emission of various secondary particulate precursors through biofuel combustion, through burning of fossil fuels during feedstock production or processing [i.e., oxides of sulfur (SOx), NOx], or from soil biochemical processes during feedstock production (i.e., ammonia) [8].

PM 10 measures mass per unit volume of all airborne particles less than 10µm in diameter and thus includes those particles measured by PM 2.5. In addition to fine particles, PM 10 includes coarse particles, those between 2.5µm and 10µm in diameter. Agricultural systems can affect this coarse fraction through tilling and solid biomass combustion. As with the fine fraction, the coarse fraction can affect human respiratory health, though health effects may be restricted to the short term.

Coarse particles also impair visibility, though also to a lesser extent than fine particles. The lesser environmental concerns relating to coarse particles, as well as the confounding inclusion of both fine and coarse particles in PM 10, are drawbacks to using PM 10 as an indicator of environmental aspects of bioenergy sustainability. Nonetheless, we recommend its use for two reasons. First, the coarse fraction may have greater influence on health and visibility issues where it dominates the fine fraction in abundance, such as on feedstock production sites and where solid biomass is burned. Second, because of historical Environmental Protection Agency (EPA) regulations in the U.S., more infrastructures exists to measure PM 10 than to measure PM 2.5; therefore, even where the fine fraction is of primary concern, PM 10 may serve as a rough but affordable proxy measure of the fine fraction [20].

Indicators of biodiversity

Measures of biodiversity are valuable indicators of sustainability in agro ecosystems. Biodiversity can relate to any type of organism, including plants, animals, fungi, and microbes. Biodiversity is affected by other environmental changes such as erosion, nutrient loss, and land-use change. Bioenergy systems are likely to affect biodiversity in several ways. For example, feedstock cultivation in extensive monocultures or pollution from biorefineries may cause loss of species, changes in abundance of species, and habitat degradation or loss.

The presence and habitat area of taxa of special concern are recommended as indicators to measure the effects of bioenergy systems on biodiversity [Table 1]. The actual taxa that are of special concern vary in identity and number by site and region. Examples include rare native species, biodiversity-related keystone species, and taxa that are part of bioindicators. These three examples are defined and discussed below. Other taxa of special concern include species of commercial value, cultural importance, or recreational value.

Native species that are locally or globally rare (whether naturally or through human activity) or that could become rare due to bioenergy system implementation are examples of taxa of special concern. Rare or potentially rare species may be at greater risk of extinction (local or global) than common species; therefore, monitoring their presence may lead to a relatively larger probability of capturing a decrease in biodiversity due to their extirpation.

Other taxa of special concern are those that comprise what are commonly termed "bioindicators," which are taxa frequently used to monitor the condition of an environment or ecosystem. Bioindicators often consist of aquatic taxa and are used to assess the impacts of anthropogenic stresses on water quality. The presence of some taxa in aquatic systems downstream from bioenergy feed- stock production may indicate positive effects of bioenergy systems (e.g., if bioenergy land management results in less chemical or sediment loading than prior land use). The presence of other taxa may indicate negative effects of bioenergy (e.g., if crops require more fertilizers, herbicides or pesticides than prior land use).

In addition to aquatic organisms, other generalizations can be made about types of taxa likely to be affected by bioenergy systems, even though the selection of particular indicator taxa is inherently site- or region-specific. Organisms likely to be affected include aquatic animals, arthropods, birds, small mammals, and ground flora.

For many species of special concern, it is more feasible to measure the extent of suitable habitat than to measure the presence or abundance of a taxon directly. For example, [12] demonstrated the validity of using habitat area as a proxy for population size for two vulnerable peat bog butterflies. By showing that habitat area worked best as a proxy when defined according to functional resources rather than host plants, their study emphasized the importance of carefully defining suitable habitat. Because species of special concern in different systems differ widely in habit, methods for measuring presence and habitat area of those taxa also differ [12].

Indicator of energy efficiency

One indicator of energy efficiency is recommended. The use of technologies in bioenergy operations shall seek to maximize production efficiency and social and environmental performance, and minimize the risk of damages to the environment and people. Information on the use of technologies in bioenergy operations shall be fully available, unless limited by national law or international agreements on intellectual property. Use of energy, both fossil and renewable, shall be monitored and declared. Good practices shall be implemented for the storage, handling, use, and disposal of biofuels and chemicals. The technologies used in bioenergy operations including genetically modified: plants, micro-organisms, and algae, shall minimize the risk of damages to environment and people, and improve environmental and/or social performance over the long term. Micro-organisms used in bioenergy operations which may represent a risk to the environment or people shall be adequately contained to prevent release into the environment. The calculation of GHG in the life cycle is mostly good enough measurement of the efficiency the energy consumption and energy conversion. Especially since the standard has focus on biomass/bioenergy and the outputs will be fuel (solid and liquid), electricity, heat... But if energy efficiency is consider to be reported as well as GHG it is necessary to tell what methods that have been used when the calculation have been made. Open and transparent report of used energy resources and information on used method of calculation. Efficiency needs to be addressed along the whole supply chain and not only in bioenergy production [11].

Indicator of waste

One indicator of waste is recommended and biodegradable fraction of waste is called bio-waste. Along the supply chain most of the waste can be found. It is important to promote responsible management of waste. The economic operator provides information on how wastes are addressed. It is important to describe procedures taken to identify potential impacts of generated wastes on human health and the environment. It is also important to list potential impacts of waste generated under this indicator. Describe the measures taken to address potential impacts listed above including handling, storing, recycling, reusing, recovering and disposing. Report the value of key parameters or metrics used to quantify the effect of measures taken above. List the wastes that are the subject of measures above, and report the annual quantities of each waste generated in units of mass or volume per unit of production. The “unit of production” can be the functional unit for the GHG calculation, or a different measure of production described by the economic operator as more directly related to the waste. Report the percentage of each waste identified above that is recycled, reused, or recovered, separately [16].

If waste is used as a feedstock, the GHGs associated with its handling and processing shall be included, and any exclusion of up-stream emissions shall be documented and justified. If a waste is used as a feedstock for bioenergy production, the alternative fate of that material shall be documented (e. g. fodder, used in animal raising, building materials, land fill, waste incineration, or decomposition on a field). The alternative fate should be included in the system boundaries of the reference case. The GHG emissions and GHG removals associated with the fate of waste in the reference case should be counted because the GHG emissions and GHG removals from this system do not occur in the bioenergy case. This procedure constitutes system expansion and should be the preferred approach when waste is utilized. Alternatively, allocation may be used to estimate the GHG intensity of the waste being used as feedstock. The treatment of waste in the GHG analysis shall be documented and justified [16].

Indicator of productivity

One indicator, aboveground net primary productivity (ANPP), is recommended to assess the ecosystem productivity of bioenergy associated land use (Table 1). The selection of this indicator is motivated by the importance of net primary productivity (NPP), which is denned as the net flux of carbon from the atmosphere into green plants per unit time and measures the rate of production of useful net energy by all plants in an ecosystem. NPP is a measure of the condition of both the land (e.g., soil fertility, topography, vegetation type, and prevailing weather conditions) and several ecological processes (including photosynthesis and autotrophic respiration as affected by local hydrology and temperature) [9].

NPP manifests physically as total new plant biomass generated by photosynthesis per unit time (typically measured per year). Even so, the continual death and decay of plant tissue, especially below ground, as well as the import and export of organic compounds to and from the environment, make direct measurement of NPP difficult. Because of these and other challenges in directly measuring NPP, ANPP is often used as a substitute for NPP. Even measuring ANPP accurately is not trivial; however, certain difficult to measure components of ANPP (e.g., biomass consumed by herbivores or that dies and decomposes during the growing season) are often assumed to be small enough to ignore [9].

In agricultural systems, producers routinely measure yield, which in the case of biomass crops can serve as a proxy for ANPP. For some bioenergy systems in which not all aboveground biomass is harvested, such as corn starch ethanol, harvest indices are available for specific sites and systems. A harvest index is the ratio of dry grain mass to total dry aboveground biomass for a given crop, and it varies somewhat with local varieties, conditions and management practices.

Because ANPP can be roughly approximated for both managed and unmanaged ecosystems, it provides a simple way to compare ecosystems that may differ dramatically in many respects. In cases where bioenergy feedstock crops replace less intensively managed ecosystems, the yield or estimated annual aboveground biomass of the feedstock crop can be compared to the ANPP of the prior ecosystem, measured either before bioenergy system implementation or on similar nearby proxy sites. Coupled with harvest indices to estimate NPP based on ANPP, such comparisons can also serve as one component for calculating the effects of land-use change on carbon dioxide flux.

Indicator of land use and land use change

For a smaller country when the competition rises one has to understand that the land has to surrender from one to another. It is the process that will be arrested with defined criteria as much more consensus would be sought rather than proceeding only through economic leverage. A presence of defined criteria may indicate the sustainability, when a plan is mooted for two million hectares of farmland in an African country to grow jatropha for biofuel by another country. Here the land is used for an energy crop. The European Union has set ambitious renewable energy targets with the Renewable Energy Directive (RED). As of 2020, 20% of the energy consumption and 10% of the total transport fuel demand should be based on renewable sources, it is expected that the bioenergy sector (biofuel and biomass) will contribute substantially [22]. This is unlikely to be yielded utilizing land within EU and one can see examples of EU using land in Sub-Saharan Africa, Madagascar etc. There can also be the possibility of a grower switching supplying soybean from a food commodity market to an energy commodity market though the person will essentially continue growing the same crop. These two scenarios can be multiplied across and the cumulative effect should be visible after a certain level of operations. It is not right to say that there is no effect - there may not be an immediate observable effect - as a result of different land use. The effect as with food may not be in the immediate neighbourhood as the switching may actually increase the prosperity of a local area as the switching is primarily because of an economic benefit. EU biofuel demand could be satisfied "Sustainably" according to RED despite its negative environmental effects. This is because the majority of global crop production is produced "Sustainably" in the sense of RED and can provide more than 10 times the total European biofuel demand in 2020 if reallocated from sectors without sustainability criteria. This finding points to a potential policy failure of applying sustainability regulation to a single sector in a single region. To be effective this policy needs to be more complete in targeting a wider scope of agricultural commodities and more comprehensive in its membership of countries [14].

It may be true that there is no absolute connection identified between food security and bioenergy as yet with the commercial bioenergy movement being somewhat in its infancy, however the real truth is that it is not at all possible to state positively that there is no link. There is significant knowledge deficit and that needs to be addressed quite fast to prevent adverse decisions being made citing ignorance or due to ignorance. Today land is becoming a lucrative investment opportunity and the evidence points to a new gold rush. Once a high yielding resource is identified, there are always many interested parties who will move in as the society is not full of sustainability practitioners but more with speculators.

A global land rush is on with far more complexity with significant global security implications and it is important that we do understand the dynamics. In land we put our faith and trust for our living. The issue is when the same plot has to serve the need of many from afar as well. One policy question under debate is whether calculations of the greenhouse gas implications of biofuel should count emissions from so-called "indirect land use change" or "ILUC." These are the emissions that occur when biofuel divert crops from existing cropland and farmers elsewhere plow up forests or grasslands to replace the crops, which releases the carbon stored in plants and soils. Some people argue that these emissions should not be counted either because their quantity is too uncertain or because farmers and biofuel producers should not be held responsible for the harmful behavior of others [15].

This whole discussion assumes that biofuel start by reducing greenhouse gas emissions, and then ILUC cancels out some or all of those gains. Lifecycle greenhouse gas accounting for biofuel prior to 2008 generally worked this way because those analyses ignored the carbon dioxide released by burning the biofuel. Ignoring this carbon dioxide is what leads to the finding that biofuel often reduce greenhouse gas emissions. Burning ethanol and biodiesel releases carbon just like burning gasoline and diesel. So the question should be: what justifies ignoring that carbon.

The reason usually offered is that the production of a biofuel starts with plant growth, which absorbs carbon, and that carbon balances and therefore offsets the carbon released by burning the fuel. In fact, if a farmer takes otherwise fallow land and grows a crop for biofuels, that offset is real. The additional plant growth absorbs additional carbon, which offsets the carbon released by burning the biofuel. But what happens when biofuel producers use crops that farmers were growing anyway. In that event, there is no direct additional plant growth. Because there is no additional carbon absorbed, there is no direct offset for the carbon released by burning the biofuel [17].

Any greenhouse gas reductions have to follow a different path in the reactions to the diversion of crops away from food and feed and into fuel: One possibility is that the crops are not replaced. In that event, people or livestock consume fewer crops and they therefore emit less carbon through their breathing and through their waste. That generates a greenhouse gas reduction although it is obviously not desirable. A second possibility is that farmers replace the crops by producing more crops on the same land. That absorbs more carbon and generates a greenhouse gas reduction in a desirable way. The third possibility is that farmers plough up more forest or grassland. In that event, they grow crops that absorb more carbon, but they also emit carbon by ploughing up of forest or grassland releases carbon.

All these responses occur because the diversion of crops increases prices and spurs further reactions. The only possible way to generate greenhouse gas benefits by diverting crops to biofuel is if the reactions that reduce greenhouse gases exceed the reactions that increase greenhouse gases. In some way, a proper greenhouse gas accounting cannot simply ignore the carbon released by burning biofuel as if the carbon did not exist. It should count that carbon and then examine all of these indirect effects to determine the extent to which that carbon is offset by net carbon absorption by plants or reduced consumption of plants by people and livestock [17].

When lifecycle calculations count ILUC they in effect assume that the carbon in plants is free by ignoring the carbon released by vehicles but then estimate and count the degree of emissions from land use change. That gets the calculation correct mathematically but it does so backwards. One of the consequences of doing the calculation backward is that it obscures the role of reduced food consumption. ILUC models do in effect estimate that, but it is hidden in the inside of the models. In effect reduced food consumption results in greenhouse gas reductions.

The next key challenge facing LCAs is how to factor in land-use changes. A common method to estimate land-use change is to use remote-sensing images, especially for monitoring deforestation. On the basis of spatial patterns, different techniques are then used to identify the agents involved in the land-use change. Further, the use of primary and secondary data on areas planted and harvested in the past can help predict future land-use patterns – even at the local level, if such data readings can be matched with other crops. There is a distinction between direct and indirect land-use change. When newly demanded products – such as biofuel feedstock – are grown on converted land, this is described as direct land-use change (DLUC) and is typically included in the carbon accounting procedure in most life cycle analyses. Indirect land-use change refers to second, third and higher degrees of land substitutions. This is harder to measure and remains unresolved. There is currently a debate about measurement of GHG emissions resulting from indirect land use change that may occur when increased demand for biofuel crops displaces other crops to new areas. The indirect land-use change impacts (ILUCs) of biofuel describe the unintended consequences of releasing more carbon emissions because of land-use changes induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuel.

As farmers worldwide respond to higher crop prices in order to maintain the balance between global food supply and demand, pristine lands are cleared and converted to new cropland to replace the crops for feed and food that were diverted elsewhere to biofuel production. Because natural lands, such as rainforests and grasslands, store and sequester carbon in their soil and biomass as plants grow each year, clearance of wilderness for new farms in other regions or countries translates into a net increase in GHG emissions. Because of this change in the carbon stock of the soil and the biomass, ILUCs have consequences in the GHG balance of a biofuel. Other authors have also argued that indirect land-use changes not only release sequestered carbon, but also produce other significant social and environmental impacts, putting pressure on biodiversity, soil, water quality, food prices and supply, concentration of land tenure, displacement of workers and local communities and cultural disruption.

Discussion: recent trends and future challenges

These 24 indicators collectively represent how bioenergy systems may affect environmental sustainability with respect to soil quality, water quality and quantity, waste, energy efficiency, greenhouse gas concentrations, biodiversity and eco system, air quality, and productivity, ecosystem and land use change. Transitions from fossil-fuel based energy systems to bioenergy systems can affect environmental sustainability because of increases or decreases in various anthropogenic stresses, including resource exploitation; changes in land use, water use, and disturbance regime; and emissions of waste, pollutants, and greenhouse gases. Measured over time, this group of indicators should reveal many of the effects of changes in these stressors not only pertaining to the current state of ecosystems but also relating to their resilience.

In the recent years, numerous studies using a life-cycle approach to estimate socioeconomics and environmental performances of bioenergy systems have been undertaken. An increasing number of papers dealing with lignocelluloses' biomass, sugarcane or palm oil and located in developing countries was observed, especially in South-Eastern Asia. By contrast, few studies are currently available on promising feedstock like algae and jatropha oil as well as papers based on advanced biomass processing. In Sri Lanka "Gliricidia Sepium" is used extensively. The various names include Makulatha, Albizzia, Sevana, Kola Pohora, Nanchi, Wetahiriya, Ladappa, Wetamara and Giniciria. This tree has been named as fourth plantation crop by the government of Sri Lanka.

In particular, different approaches are used to deal with the indirect effects which have a large influence on final figures, and the way by which they should be estimated is still under discussion. The inclusion of these indirect effects in ISO standard represents the next research challenges for Bioenergy practitioners. In fact, even though valuable improvements were achieved in determining the direct GHG emissions of bioenergy, a standard methodology for the indirect effects is still at a preliminary phase, and further research is needed. It is therefore predictable that future LCA studies will focus on reducing the uncertainties of these current key open issues, e.g.: inclusion in the assessment of indirect LUC effects and their amortization over time, estimation of bioenergy impacts on biodiversity, better determination of fertilizer induced N emissions, and others.

However, standardization in GHG balance accounting (either called carbon footprint [13]) of products is particularly perceived as urgent by policy makers, and the methodological standards provided by consultants and stakeholders try to address this need. A variety of policy objectives have motivated governments around the world to promote bioenergy, on condition that a certain amount of GHG emission savings is achieved. This means that legislation requires a standardized GHG accounting procedure, encompassing the inclusion of indirect emissions in the life cycle of bioenergy, even if this topic is still in its scientific infancy. In order to cover this gap, several methodological standards have been proposed, as previously mentioned. In most of the cases, these guidelines tend to simplify or overlook concepts and issues of paramount importance, like indirect LUC effects and

carbon storage in products. In addition, methodological standards usually limit the assessment to a very limited number of indices and indicators.

On one hand, these simplifications can make the overall assessment and interpretation of final results easier, but on the other hand approximation and fixed approaches may have the drawback of misleading and inaccurate conclusions. Therefore, the formulation of regulatory standards in the presence of scientific uncertainty may lead to inefficient or counterproductive methodologies. Finding a compromise is challenging, because a certain degree of simplicity and standardization in sustainability assessment of bioenergy systems is highly desirable nowadays, especially at a governmental and political level, where the best strategies for climate change mitigation should be put into practice as soon as possible.

Conclusions

These aspects do not make possible to provide once for ever an exact quantification of the social, economic environmental impacts of bioenergy, because too many variables are involved. Some of the key parameters (such as indirect effects) are not well known and strongly depend on local and climate conditions. Although policy makers are claiming for methodological standards, scientific research for estimating indirect effects is still at a preliminary stage.

However, with bioenergy policies influencing changing patterns of land tenure, social inequity may increase. The worlds poorest may become even poorer, losing their (informal) access to land resources. Mitigation of negative indirect effects of bioenergy is going to be huge challenge, particularly where land tenure is not formalized. Governments, NGOs, private sector and academia should join forces in facing these challenges.

This review identifies a group of 24 indicators in nine categories to measure the environmental sustainability of bioenergy systems. The group of indicator is intended to be a handy toolset for capturing key environmental effects of bioenergy across a range of bioenergy systems, including different pathways, locations, and management practices. To evaluate the hypothesis that the group meets this goal, and also to help measure variability and establish appropriate targets, the group should be field tested in systems spanning a wide variety of conditions. If the hypothesis is confirmed, the group can be implemented more broadly, modified as necessary for particular contexts. This broader implementation will have further two goals. First, it will help stakeholders judge the relative environmental sustainability of different bioenergy systems, including the question of which feedstock, management practices, and post-production processes are appropriate for different locations as well as the question of how bioenergy systems compare with alternative energy systems. Second, it will help provide an empirical foundation for indicators designed to assess environmental sustainability based on the predicted effects of management practices, such as many of the indicators proposed for use in certifying sustainable bioenergy systems.

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