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Timber drying by solar kilns: a performance comparison

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Abstract

The predictive wood drying for the two different greenhouse-type solar-kiln designs (Oxford and Boral kilns) has been described in this paper. The dimensions of the original Boral kiln have been scaled down in order to describe the relative kilns performances on the basis of same load capacity. Climatic boundary conditions for the summer season, 2013 (January and February) of Brisbane in Australia were used for this comparative study. The performance between the two designs was compared over a typical drying period of 50 days. The performance for the Oxford design was generally predicted to be superior to that for the Boral kiln throughout the selected season.

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Keywords: Timber drying; solar kiln; predictive performance.

1. Introduction

For hardwood lumber producers, kiln drying has been an important stage in the overall value chain of the final wood products for use as furniture and construction materials. With reference to the possession of attractive characteristics, such as its low embodied energy, its low carbon impact, its sustainability, and being a renewable resource, [1] mentioned that wood is expected to uphold its demand for future building industries. Obtaining the highest yield from the hardwood resources, while maintaining the desired quality, has thereby been an important objective especially for the lumber production companies. There has been extensive evidence, including [2] that the kiln drying of wood improves both the productivity and quality of the end-use timber. However, understanding the wood drying behavior only by using experimental approach involves practical difficulties due to the extremely large

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number of variables that must be considered, in addition to the large time involved and the cost, as reported by [3] and [4]. Several workers, such as, [5] and [6], explored the properties of wood during the drying process. Because of the low operating and construction costs, solar kilns for the purpose of wood drying have received special attention in developing countries, such as, Bangladesh, India, Uganda, Philippines, and Fiji. With few exceptions, a number of research/experimental solar kilns have been documented in the literature over the last few decades and a summary of them has been given by [7]. Most of the solar kilns reported have been of a greenhouse-type, or a modification of a greenhouse-type structure, but they have varied significantly both in size and design. Previously the authors have applied numerical schemes in [8], in order to predict the solar kiln behavior for the Oxford design with the geographical and climatic conditions of three representative cities (Sydney, Melbourne, and Brisbane) in Australia. Their simulation results indicated that Brisbane was likely to give the most favorable drying conditions for the Oxford design. This paper describes the predicted timber drying behavior for two different greenhouse-type solar kilns (Oxford and Boral) by using the weather conditions of summer season (January and February), 2013 while the geographical location was Brisbane (27.46°S) in Australia.

Nomenclature

Symbol	Description	Units
T_b	temperature of wood board	K
T_a	temperature of internal air	K
T_w	temperature of walls	K
T_{na}	temperature of north absorber	K
T_{sa}	temperature of south absorber	K
T_{nr}	temperature of north roof	K
T_{sr}	temperature of south roof	K
T_{ra}	temperature of roof absorber	K
T_r	temperature of roof	K

2. General description of the two solar kilns used in this study

Figure 1 shows the overall dimensions, used in this simulation, for the original Oxford design. The Oxford kiln consists of a wooden frame on which polythene glazing material used to cover the timber stack is rested. Figure 1 shows that the size of wood stack is 4.88 m long, 2 m wide, and 1.83 m high, which leads to an overall kiln capacity of about 10 m³ of timber. Two painted matt black corrugated iron solar absorbers are rested on wooden frames and used to capture solar energy in order to provide heat for the wood in the stack to dry up. The north panel is placed parallel to the inclined north roof while the south panel is horizontal. Two axial fans driven by 0.25 hp electric motors are used to circulate air over the absorber surfaces and through the wood stack. Figure 2 shows dimensions of the scaled-down Boral kiln, as used in this study. The original Boral kiln was manufactured in Western Australia by Advanced Environmental Structures Pty Ltd. and was supplied by Australian Design Hardwood s Pty Ltd. The original Boral kiln has been scaled down in order to give the same stack capacity as the Oxford kiln. The resultant dimensions, which were used in this study, are shown in Figure 2. It is shown in Figure 2 that the size of the scaled-down Boral kiln is 5.6 m long, 5.6 m wide, and 3.25 m high which can ultimately give a net kiln capacity of approximately 10 m³. This kiln is also a greenhouse type solar kiln which has a rectangular stack chamber within a tunnel-like greenhouse structure. The glazing plastic materials used to cover the wood stack are rested on a large, curved aluminium frame and are always kept inflated by a small fan. Likewise Oxford kiln, two axial fans were assumed to be installed in the scaled-down Boral kiln in order to circulate air over the absorbing surfaces and through the stack of timber.

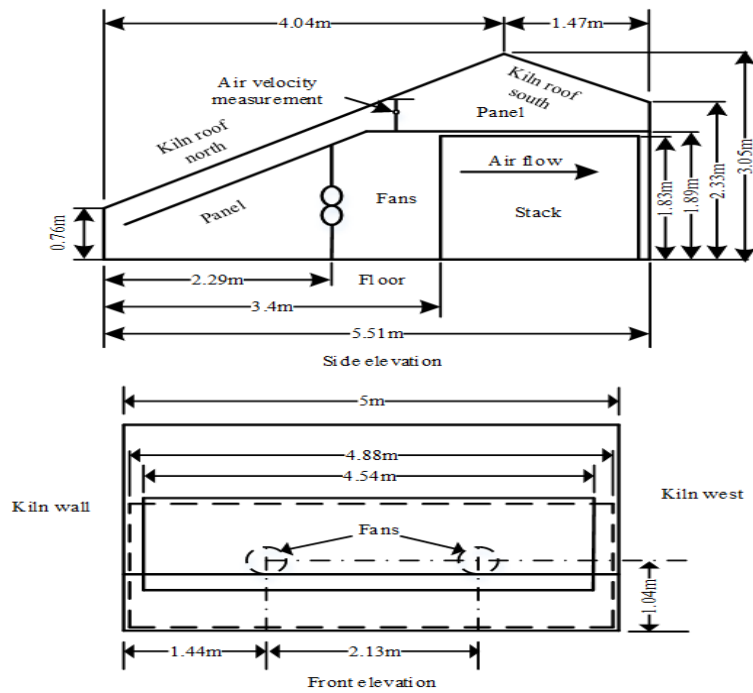


Figure 1. The dimensions of the Oxford solar kiln [9].

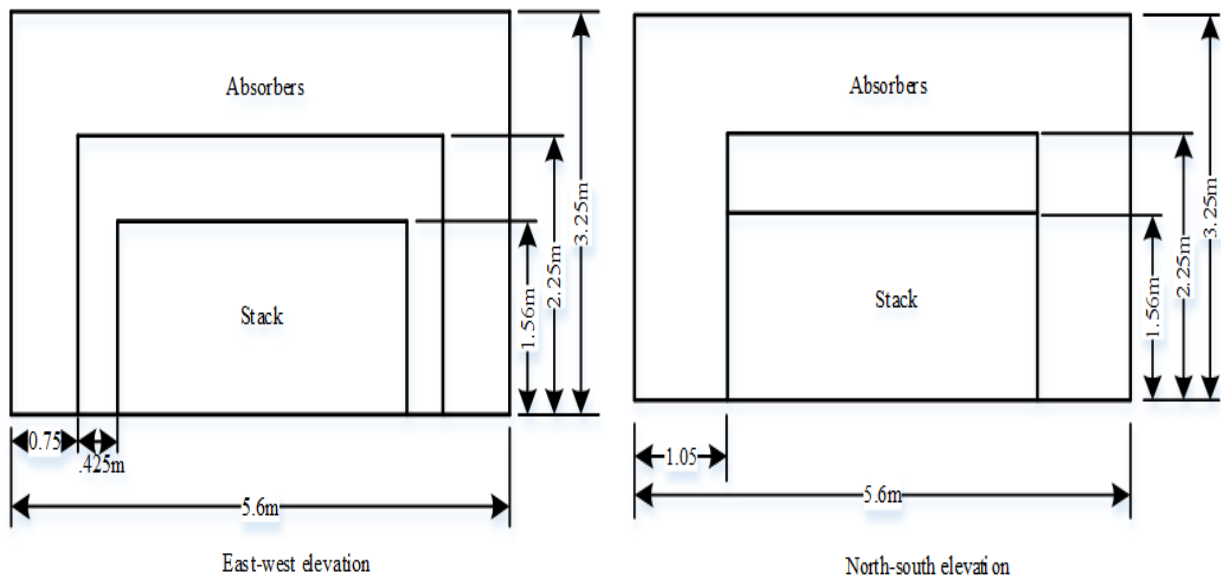


Figure 2. The scaled-down dimensions of the Boral kiln.

3. Materials and method

The simulated drying behaviour of hardwood timber for the two typical solar kilns over a typical drying period of 50 days has been described by using the climatic data of Brisbane in Australia. These data were collected from Australian Bureau of Meteorology [10]. This location was chosen for the current study because the authors previously found in [8] that Brisbane was the most favourable for solar wood drying out of the three representative locations (Sydney, Melbourne, and Brisbane) in Australia. The simulation was done by solving a solar kiln model developed by [7], which was later validated by [11]. In this study the model was solved by numerical techniques adopted in “Matlab” software. The dimensions of the original Boral kiln have been scaled down in order to give the same load capacity for both the kilns. The thickness of the timber boards and the stickers were assumed to be 25 mm and 20 mm, respectively, for both the kilns. It was also assumed that the timber properties (and/or species) used in this study were also the same for the kilns being studied here. The operating variables and their control strategies, such as, stack velocity, heat transfer coefficient during active and natural drying periods, venting, and humidity have been described in the authors’ previous study [8], and have been maintained in this study.

4. Results and discussion

The results and discussion are given in the following sections.

4.1. Solar gain and drying time

The predicted solar gains during the summer and the corresponding timber drying rates over a 50-day drying period for the Oxford and Boral kiln designs are shown in Figures 3 and 4, respectively.

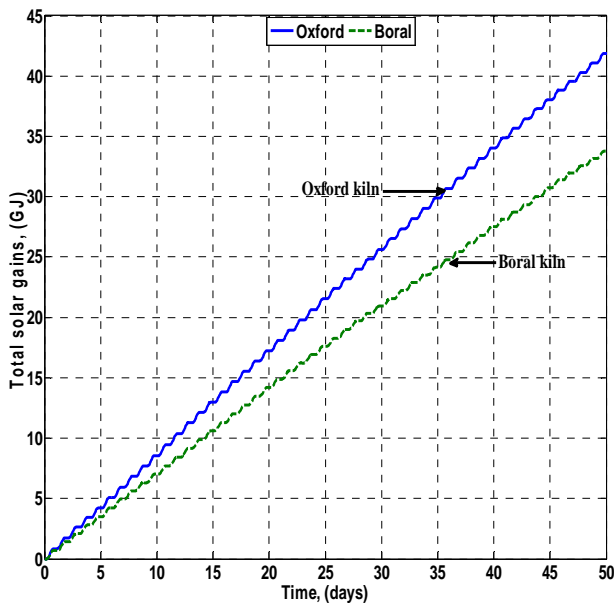


Figure 3. The predicted solar gain, as function of time, during the summer, 2013 in Brisbane climate.

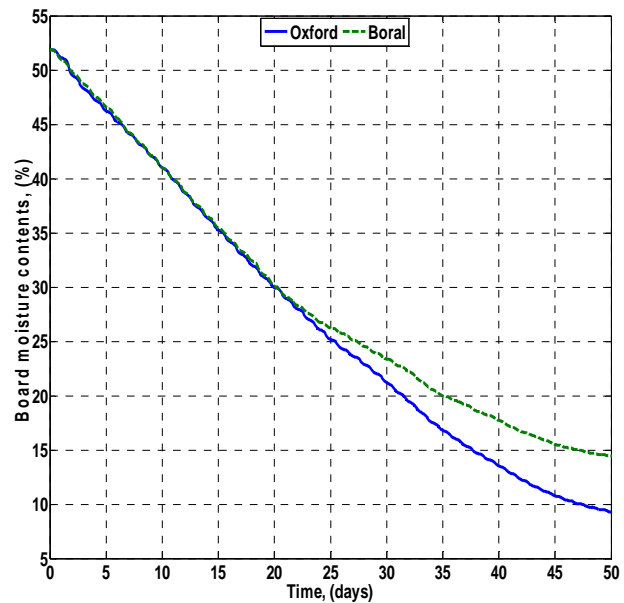


Figure 4. The predicted drying rates, as function of time, during the summer, 2013 in Brisbane climate.

Figure 3 shows that, the predicted solar gain, when calculated over a certain period of drying time (50 days) is higher for the Oxford kiln than that predicted for the Boral kiln. A probable reason for this discrepancy in the solar gains between the kilns is due to the differences in the solar collector areas and their orientations with respect to the sun. The scaled Boral kiln has 17 m² of absorber (horizontal) facing the sky and a combined area of 10 m² of

absorbers (perpendicular) facing to the north and south. By contrast, the Oxford kiln has 25.7 m² of absorbers facing the sky (either horizontal or slightly inclined). Due to the vertical orientation of the north and south absorbers in the Boral kiln, the absorbers’ areas seem to be used less effectively to collect the solar radiation. Correspondingly, the lower final moisture content (MC) was predicted for the Oxford kiln (9.2%, dry weight basis) than that predicted for the Boral kiln (14.5%, dry weight basis) over the same drying period (50 days), as shown in Figure 4. Part of the reason of this faster drying rate for the Oxford kiln may be that the total volume of the scaled Boral kiln (101 m³) was greater than that of the Oxford kiln (58 m³). The larger dimensions of the Boral kiln appeared to result in larger thermal masses of both the internal air (for the same load capacity) and the kiln structures in the Boral kiln, which further means that more energy would be required to raise the temperature of the kiln internal conditions by 1K. This condition is likely to lower the kiln air temperature “and/or” the board temperature in Boral kiln, as also can be seen from Table 1.

Table 1. The predicted average temperatures for the kiln components during the summer, 2013 of Brisbane in Australia.

Design	T _b (K)	T _a (K)	T _w (K)	T _{na} (K)	T _{sa} (K)	T _{nr} (K)	T _{sr} (K)	T _r (K)	T _{ra} (K)
Oxford	300	299	297	301	309	300	304	-	-
Boral	299	298	296	298	296	-	-	298	305

This lower kiln air temperature in Boral kiln would decrease the diffusion coefficient for the moisture transport within the boards. This situation in the Boral kiln (lower diffusion coefficient within the boards) might lead to slower drying rates in this Boral design.

4.2. Predicted timber quality

The predicted timber quality during drying over a 50-day period for the two solar kilns (Oxford and Boral) is shown in Figures 5.

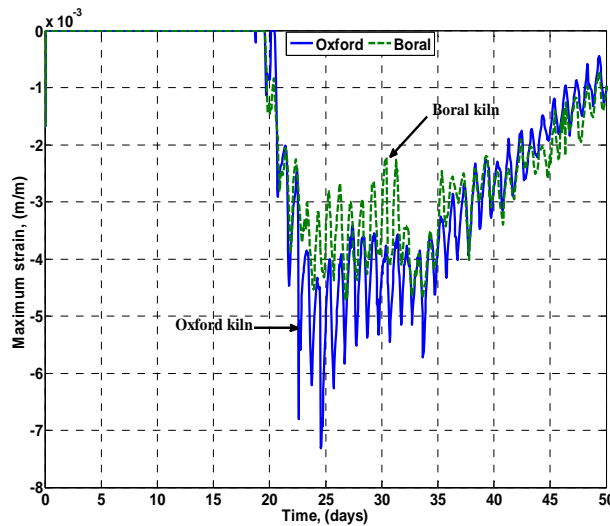


Figure 5. The predicted maximum strains developed within the timber boards, as function of time, when drying timber during the summer, 2013 in Brisbane climate.

Figure 5 shows the predicted timber quality for the two kilns being studied here. In both cases, no strains experienced by the boards were predicted on or before 20 days of drying, as can be seen from Figure 5. This was the case mainly because, before 20 days, the MCs within the boards were above the fibre saturation point (approximately 30% MC, dry basis) during which only free water was removed from the wood cell cavities. Generally, no significant

difference has been predicted in terms of the developed strains during the drying of hardwood timber between these two different designs, as shown in Figure 5. However, during the drying period of 25 to 37 days, timber boards were predicted to experience relatively higher level of strains for the Oxford kiln than those for the Boral kiln. This is not unusual because faster drying rates in Oxford kiln may lead to higher strains or cracks to occur within the boards. However, the maximum predicted strain was approximately 0.0072 m/m for the Oxford kiln, which is well below the maximum allowable strain level (0.02 m/m), as suggested by [12]. Thus, the predicted quality of the dried timber for both the kilns is likely to be acceptable. It is also apparent from Figure 5 that, for both the kilns the strain levels decrease towards the end of the drying period. This situation means that both kilns are capable of producing timber of acceptable quality with different production rates.

5. Conclusions

A comparative description of the predicted performance for the Oxford and scaled-down Boral kilns has been given, when the summer season, 2013 of Brisbane in Australia was chosen for the ambient boundary conditions. The results have shown that the Oxford design is capable of capturing more solar energy and thereby indicated higher production rate potentiality for the Oxford kiln. There were no significant differences predicted in the timber quality between the two designs. However, in order to compare their life cycle benefits, including environmental performance for the purpose of drying operations, it would be worth to carry out a detailed life cycle assessment for both the solar kilns discussed in this paper.

Acknowledgements

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Prospect of Moringa seed oil as a sustainable biodiesel fuel in Australia: A review

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Abstract

Moringa oleifera is one of the most widely cultivated crops in tropical and sub-tropical areas in the world. The common name is drumstick which contains 6 to 10 seeds. The matured seeds yield 38 - 40% of colourless and odorless vegetable oil. The oil contains concentrated oleic acid which has the potential to be used as a biodiesel. The study reviewed the prospect of *moringa oleifera* seed oil as a source of alternative transport fuel in Australia. The distributions, habitat, growth, production, oil extraction and biodiesel conversion techniques are briefly discussed. The literatures available on engine performance test and emission studies are also summarized for better understanding of the prospect of the *moringa oleifera* as a sustainable and alternative source of transport fuel. A review of the literatures indicates that *moringa oleifera* oil could be one of the prospective sources of biodiesel in Australia. Further studies are recommended on issues such as engine combustion characteristics, emission parameters, environmental impact and economic analysis of the species before it can be considered for commercial application.

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Keywords: Biodiesel; Moringa oil; Transesterification reaction; Alternative fuel; Transport fuel.

1. Introduction

Biodiesel is the fuel mainly derived from vegetable oils, animal fats, biomass etc. It is the fuel composed of mono-alkyl esters of long chain fatty acids designated as B100 and meeting the requirements of ASTM D6751 standard [1,

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2]. It is a liquid fuel generated from biological resources and a renewable source of energy [3, 4]. Different types of biodiesels are available (depending upon the source that they are extracted from) such as: bioethanol [5], karanja [6], jatropha [7], castor [8], sunflower and mustard [9] etc. According to the United State Energy Information Administration (USIA), biodiesel can serve as a substitute for petroleum-derived gasoline and diesel or distillate fuel [10]. Biofuels are low emission, non-toxic, safer and environmentally acceptable source of energy [11]. For these reasons the production and consumption of biodiesel has rapidly grown in the last few decade. At present biodiesel provides around 3% of the world total transport fuel on energy basis. Several factors can contribute to rise in biodiesel demand. Salient drivers are increasing oil prices over the past decade, environmental pollution and gradually decreasing the fossil diesel resources etc. These factors have led to increased public support for renewable fuels [12-14]. The sources of biodiesels were investigated and now the investigation is being continued to find new resources.

At present, world's majority of the biodiesels are produced from edible oil resources which lead to increase in food price and create pressure on land. For these reasons the world is moving towards such type of biodiesel resources which are nonedible, biodegradable, safer and low pollutant. In Australia, 90% of biodiesels are produced from non-edible resources [15]. Only 10% biodiesel produced from edible sources. Australia started producing biodiesel in 2004, 100 barrels per day and increasing demand it reached to 9100 barrel per day in 2011. Research in Australia is being focused on how its feedstocks can be used for biodiesel resolving the challenges associated with its production [16]. With continued efforts in this direction this study reviewed the potential of moringa seed oil as prospective feedstocks. The growth, habitat, distribution and production of biodiesel from the species are briefly discussed in this paper. The lifecycle of the moringa biodiesel has been developed in this study. The physical and chemical fuel properties of the biodiesel are compared with traditional fossil diesel. The study aimed to summarize the literature available on engine performance and emission study and briefly discussed for better understanding of the prospective species as a sustainable alternative source of transport fuel.

2. Moringa oleifera (growth, habitat, distribution)

Moringa oleifera is evergreen, fast growing, deciduous and widely cultivated species. It has some common English names such as moringa, drumstick tree, horseradish tree, benzoil tree etc. [17]. It grows in tropical and sub-tropical areas. It requires rainfall about 250-2000 mm depending on soil condition. It grows best in dry sandy soil and tolerates poor soil with *pH* range 5 to 9. It is distributed from Africa, Asia, Latin America and Oceania countries including Australia. The distribution map for moringa oleifera in Australia is presented in Figure 1. This species is widely distributed in Queensland, Northern Territory and Western Australia. The taxonomical or scientific classification of moringa oil tree is also presented in Table 1. Moringa oil has many medicinal usages and also has significant nutritional value [18]. Literature reported that moringa oil has good potential for biodiesel production based on a recent survey conducted on 75 indigenous plant derived non-traditional oils [19].

Table 1. Taxonomical classification of moringa oil tree.

Taxonomical classification	
Kingdom	<i>Plantae</i>
Sub-kingdom	<i>Angiosperms</i>
Phylum	<i>Charophyta</i>
Class	<i>Equisetopsida</i>
Subclass	<i>Magnoliidae</i>
Order	<i>Brassicales</i>
Family	<i>Moringaceae</i>
Genus	<i>Moringa</i>
Species	<i>Moringa oleifera</i>

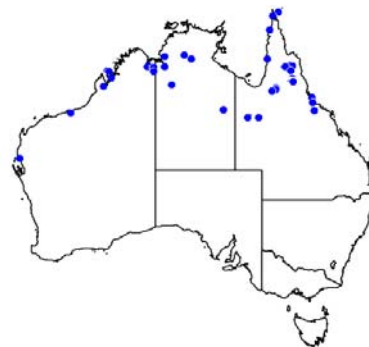


Figure 1. Distribution map for moringa species in Australia [20].

3. Life cycle for biodiesel production

3.1 Cultivation and harvesting

The biological life cycle of the moringa species and different steps for biodiesel production is presented in Figure 2. Moringa plant can be grown by direct seeding and cuttings. If water is available for irrigation, moringa trees can be seeded directly and grown anytime during the year. On the other hand, cuttings should be 45cm to 1.5m long and 10cm thick can be planted directly or planted in sacks in the nursery. The tree can reach a height of 10 to 12m and the trunk can reach a diameter of 30 to 45cm.

When the plant is grown up from the cuttings the first harvest can already take place 6 to 8 months after the plantation. Often, the fruits are not yielded in the first year and the yield is generally low during the first years. By year 2 it produces around 300 pods, by year 3 around 400 to 500 kg. A good tree can yield 1000 pods or more.

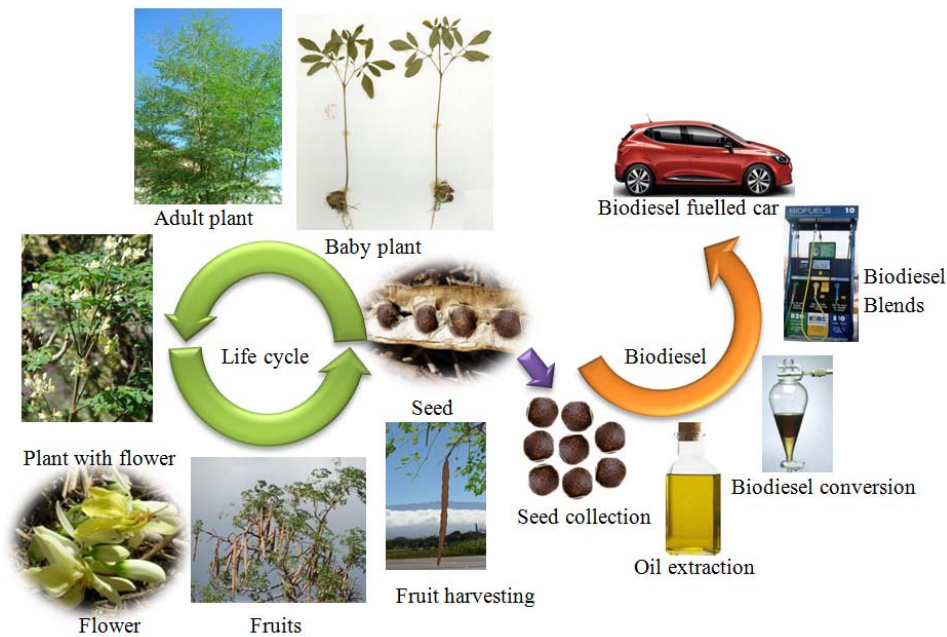


Figure 2. Life cycle of *moringa oleifera* and biodiesel production steps.

3.3 Seed collection and oil extraction

The seed contains 38-40% of oil and 25-30% of moisture. After seed collection, the moisture can be removed by drying. One estimate for yield of oil from kernels is 250 liters per hectare [21]. Anwar and Bhanger [17] studied on moringa seed oil and analyzed different physical and chemical properties of the oil. The oil contents of moringa seed was found to be 38 to 42% using hexane extraction method. Protein, fiber and ash contents were found to be 26.5 to 32%, 5.8 to 9.29% and 5.6 to 7.5%, respectively. On the other hand, Rashid et al. [22] performed an experimental work on oil extraction from moringa seed and afford 35% in w/w crude moringa oil. The oil can also be extracted by traditional mechanical extraction method. Biodiesel can be converted by transesterification reaction.

3.4 Biodiesel conversion by transesterification

Transesterification is one of the efficient ways for biodiesel conversion from vegetable oil. It can be performed in several ways such as catalytic and non-catalytic transesterification [23] depending on the properties of the crude vegetable oil. The total reaction is presented in Figure 3. Several studies have been conducted on transesterification reaction at different temperature. For example, Rashid et al. [24] studied on biodiesel conversion from crude

moringa oil and got expected results. The results of the reaction are presented in Table 2.

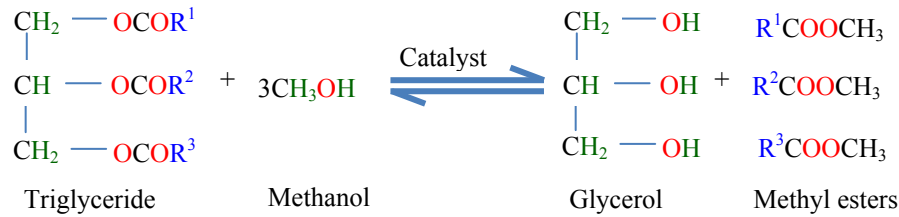


Figure 3. Transesterification reaction for biodiesel conversion from crude moringa oil [24]

Table 2. Transesterification reaction results for biodiesel conversion from moringa oil [24].

Standard order	Molar ratio	Catalyst concentration (%)	Temperature (°C)	Reaction time (min)	Observed methyl esters (wt.%)	Predicted methyl esters (wt.%)	Residual values
1	5.2:1	1.00	35	73	86.35± 0.88	86.72	- 0.37
2	5.2:1	0.50	55	73	87.30 ± 1.25	87.23	0.07
3	7.5:1	1.25	45	55	81.00 ± 1.40	79.42	1.58
4	7.5:1	0.75	45	90	93.50 ± 1.41	92.95	0.55
5	7.5:1	0.75	45	55	91.20 ± 1.15	90.87	0.33
6	7.5:1	0.75	45	55	91.73 ± 1.74	90.87	0.86
7	7.5:1	0.75	45	55	91.00 ± 1.26	90.87	0.13

3.5 Fatty acid profile of the moringa oil

Several researchers investigated the fatty acid profile of moringa oil and found that more than 70% of oleic acid. Rashid et al. [22] and Silva et al. [25] etc. studied the fatty acid profile of the moringa oil separately their combined results are presented in Table 3. The Table compared the fatty acid profile of the moringa oil with soybean, palm, sunflower and rapeseed oil. It has been found that the oleic acid content of moringa oil is 72.2% which is the highest level with respect to other oils.

Table 3. Fatty acid profile of moringa oil compared with soybean, palm, sunflower and rapeseed oil.

Fatty acid	Chemical name	Structure	Moringa oil	Soybean oil	Palm oil	Sunflower oil	Rapeseed oil
Palmitic	Hexadecanoic	16:0	6.5	11.0	44.1	6.4	3.6
Palmitoleic	9-hexadecanoic	16:1	2.0	-	-	-	-
Stearic	Octadecanoic	18:0	6.0	4.0	4.4	4.5	1.5
Oleic	cis-9-Octadecanoic	18:1	72.2	23.4	39.0	24.9	61.6
Linoleic	cis-9, cis-12-Octadecanoic	18:2	1.0	53.2	10.6	63.8	21.7
Arachidic	Eicosanoic	20:0	4.0	-	0.2	-	-
Gadoleic	11- eicosanoic	20:1	2.0	-	-	-	1.4

3.6 Characterization of the fuel properties

The fuel properties of the biodiesel are very important to consider as an engine fuel. The fuel properties of the moringa oil compared other biodiesels and the standard values are presented in Table 4. The flashpoint temperature of the moringa oil is 162°C. This value is higher than the minimum requirements of ASTM D975 standards. The high flashpoint temperature of the moringa oil is a beneficial safety feature, as this fuel can safely be stored at room temperature. One of the major problems associated with the use of biodiesel is its poor temperature flow property, measured in terms of cloud point, and pour point temperatures. It has high values of cloud and pour points, both are 17°C, like those reported for palm oil biodiesel (14 to 15°C). Moringa oil contains unsaturated fatty acid of 72.2% expects to possess good cloud, flash and pour point. However, the relatively high content of behenic acid, C22 (7.2%), which possesses an even higher melting point than palmitic acid, C16:0 (6.5%) or stearic acid, C18:0 (6.0%) is likely to exert a greater effect on the cloud, flash and pour point. Other properties are within acceptable range to consider it as a biodiesel.

Table 4. Fuel properties of moringa oil compared with other biodiesel and ASTM standards [24].

Fuel property	Unit	Moringa oil	BLT oil	Castor oil	Palm oil	Fossil diesel	ASTM test method	Limit	References
Density at 15°C	Kg/m ³	875	869-888	913-920	879.3	820-860	ASTM D1298	880.0	[26]
Viscosity at 40°C	cSt	4.80	7.724	-	4.9	2.0 to 4.5	ASTM D445	1.9-6.0	[23, 27]
Calorific value	MJ/kg	43.28	41.397	38.70	40.2	44.8	-	-	[23, 27]
Cetane number	-	67.0	57.3	-	52	46	ASTM D4737	47 min	[23]
Flash point	°C	162	151	> 160	181	60 to 80	ASTM D975	130	[23]
Pour point	°C	17.0	4.3	-	14	-35 to -15	ASTM D975	-15-16	[23, 27]
Cloud point	°C	17.0	13.2	-13.4	15	-15 to 5	ASTM D975	-3-12	[23, 27]
Ash content	% (m/m)	0.010	0.026	-	0.0066	100 max ^m	ASTM D482	-	[23, 28]
Lubricity	HFRR;µm	139.0	-	-	-	0.460mm	IP 450	520	[23, 28]

4. Engine performance test

Engine testing can be categorized based on performance parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) etc. Emission study is one of the most relevant tasks for complete study of a biodiesel which is attributed to NO_x, CO, CO₂, HC and PM emissions. Summary of some of relevant studies pertaining to performance and emission products is presented in Table 5. The Table shows that in all experimental studies BP decreases, BSFC slightly increases and BTE goes down for moringa biodiesel when compared with the fossil diesel. In case of emission studies, Raghu et al. [29] found that the only parameter NO_x increases and all other parameters such as CO, CO₂, PM and HC are decreased. They found that NO_x decreases and other parameters increases because they used different combustion strategies.

Table 5. Summary of the engine performance and emission study using moringa biodiesel compared with fossil diesel.

Experimental setup	Blend used	Performance parameters			Emission parameters					Reference
		BP	BSFC	BTE	NO _x	CO	CO ₂	PM	HC	
1-C, 4-S, diesel engine	B10, B25	-	↑ Slightly higher	Slightly lower	↑	↓	-	↓	↓	[30]
4-C, 4-S, diesel engine	B10, B20	Decrease	5.13-8.39% ↑	Lower	↑	↓	-	-	↓	[31]
4-C, 4-S, diesel engine	B0, B10	4% lower	Slightly higher	-	↑	↓	↑	-	↓	[32]
4-C, 4-S, diesel engine	B5, B10	Lower	Higher about 5%	Lower	-	↓	↓	-	↓	[33]

Note: The symbol used B5, B10 and B20 as biodiesel 5%, 10% and 20% respectively. Other symbols like ↑ refer to increase, ↓ denoted as decrease and – represents not measured the parameter.

5. Conclusions

The study concluded that *moringa oleifera* is one of the prospective industrial crops for biodiesel production in Australia. The species is widely distributed in Queensland, Northern Territory and Western Australia where there is suitable weather and soil condition which may help grow faster. It has many acceptable fuel properties within ASTM standard limits and comparable fatty acid profile with respect to other species except oleic acid (72.2%). This high level of oleic acid content appears to result in its good cloud, flash and pour point. The results on engine performance and emission study show that the biodiesel extracted from this source has lower performance and slightly higher NO_x emission with respect to fossil fuel. But this biodiesel has lower emissions of CO, CO₂, PM and HC compared to fossil diesel. The scant studies on emission show that further studies are needed on engine performance and emission studies by applying different combustion strategies.

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6th BSME International Conference on Thermal Engineering (ICTE 2014)

Thermal simulation and energy consumption analysis of two houses in St. John's, Newfoundland

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Abstract

In this paper simulation results of two typical houses in St. John's are presented using BEOpt (Building Energy optimization) software. Simulation is done using one-year weather data, typical thermostat settings and occupation of two houses. BEOpt provides capabilities to evaluate residential building designs and identify cost-optimal solution at various levels of whole-house energy savings along the path to zero net energy. It was noticed that the annual energy consumption determined using simulation in BEOpt is almost same as the actual energy consumption, logged with a sampling time of 2 minutes for both the houses. This simulation, analysis and a comparison is necessary to validate the thermal model of houses. The developed model of the houses could be used to design a renewable energy system or study human behaviour impact on the house energy consumption. Simulation results and a detailed analysis of the logged data are presented in the paper.

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Keywords: Energy analysis; Energy saving; House power consumption; Building simulation; BEOpt

1. Introduction

According to statistical agency of Canada [1] the total population of Newfoundland & Labrador is 526,896. Due to long winter all houses in Newfoundland are heated for more than 6 months a year. Many houses are electrically heated. The total electricity consumption of each house varies with type and size of the house, no of occupants etc. Electricity consumption in each house is logged and recorded once a month by the utility company [2]. A much faster rate energy consumption logging is required for energy analysis of a house. Simulation software like BEOpt can be used to analyze and optimize the energy consumption in a house.

A number of house energy analyses technique and software have been published in literature. Christopher in his paper [3], used a software HOT2000 to analyze the annual energy consumption of an existing house in the city of

Thessaloniki, Greece and compared the simulation result with the actual data from the annual utility bills. They concluded that on energy saving, climatic conditions and the type of building materials have noticeable impact on energy efficiency of a single family house. Miha [4] introduced a calculation model which uses different quality parameters of a house, depending on their availability. The statistical samples for the evaluation process were taken from a Slovenian single-family house. Floridesa [5] used TRNSYS program to study a typical house heating and cooling load variation for different building constructions used in Cyprus. It was concluded that better roof insulation results in a reduction of cooling load up to 45.5% and heating load up to 75%. Promoting a house as zero energy and saying that it is energy efficient are not enough to convince customers to choose this type of house. The purpose of André Stephan's [6] study was to detect barriers to and opportunities for promoting nearly zero-energy houses. They surveyed on the basis of end user satisfaction with zero energy houses. End users appreciate comfort in passive houses mainly because of better winter thermal comfort and better indoor air quality. The study indicates that energy costs are an important aspect to choose a nearly zero-energy dwelling. A barrier to select zero energy houses might be a perception of insufficient summer comfort and air quality. From this study [7], it can be concluded that the extra cost of the low-energy house is 4% and of the passive house is 16% in comparison with the standard house. Insulation material and ventilation are the main reasons for this extra cost. Low energy house is more profitable than the passive house and even when energy prices increase significantly. Authors [8, 9] presented an energy and economic analysis of a zero energy house with solar application and a conventional house. Detailed house energy simulation and a comparison of data with the logged data are missing in the literature. This paper presents simulation results of two houses in newly developed software and compares results with actual logged data.

2. House energy analysis

2.1. House selection

Two typical electrically heated houses in St. John's are selected for the energy analysis. First one (house-1) is a two storey building with a semi-finished basement. Other house (house-2) is a two storey house with a garage attached to it. From the utility company and using a data logger the total energy consumption data was logged for more than a year for both the houses.

2.2. Energy analysis

According to utility company total electricity consumption for house-2 was 27300 kWh in the year 2012 (fig. 1(a)) and for house-1 total consumption was 15747 kWh in year 2010. Again using a data logger, data of a whole year has been logged for both the houses. Sampling was done once every 2 minutes. Fig. 1(a) & Fig. 2(b) shows the monthly logged data values in the chart, from Jan (2012-2013) and from September 2003 to August 2004 for house-2 and house-1 respectively. For both the houses, collected and logged power consumption data follows a similar pattern. In Fig. 1(a) & Fig. 1(b) we can see there is a mismatch between the measured and collected data by the utility company. It is because some data logger values were missing but the main reason of mismatch is that utility company do not measure energy consumption for 3 to 4 winter months in a year (meter access is limited due to snow). Utility send an estimated bill and correct that later when all snow has melted away. Also the year-long data is adjusted using year 2012 and 2013 power consumption data. Fig. 2(a) shows monthly energy consumption of house-1 from August 2003 to August 2004 as reported by the utility company. On the other hand Fig. 2(b) shows the measured energy consumption for the year 2003-2004. Energy consumption in the year 2003-2004 was maximum in January 2004 (2084kWhr) while it was minimum in April 2004 (only 237 kWhr) [9]. It is clear from this data that measurements were not done at a regular interval and it also includes few estimated values. In other words utility reported measurements are not a good indication of actual energy consumed in the house during winter months when their meter is not accessible. If we compare data in Fig. 2(a) and Fig. 2(b) we find similarity in pattern but energy consumption value reported by the Newfoundland power Fig. 2(a) and measured value Fig. 2(b) for the month of April 2004 do not match. This mismatch is because of adjustment done by the Newfoundland power during that month. Fig. 3(a) shows power consumption on a typical winter day in house-2. The start time of the data is 12.01 am at night. We can see that the main power consumption is due to heating. It is indicated that most heating

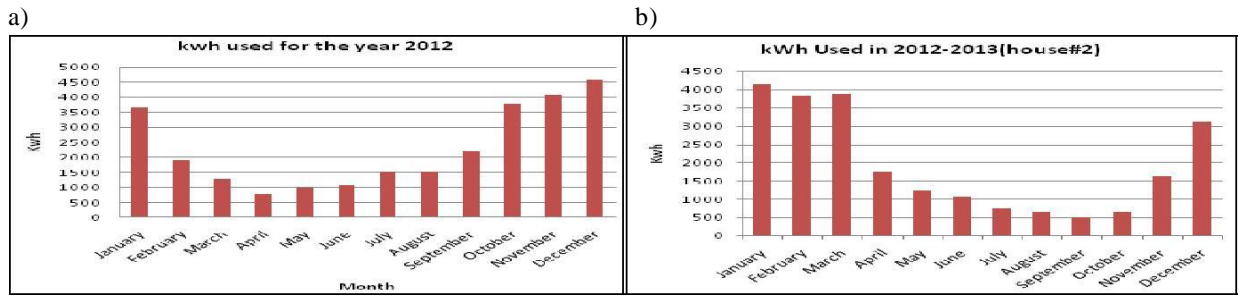


Fig. 1. (a) Energy consumption by the utility in year 2012 of house-2; (b) Measured electricity consumption of year 2012-013.

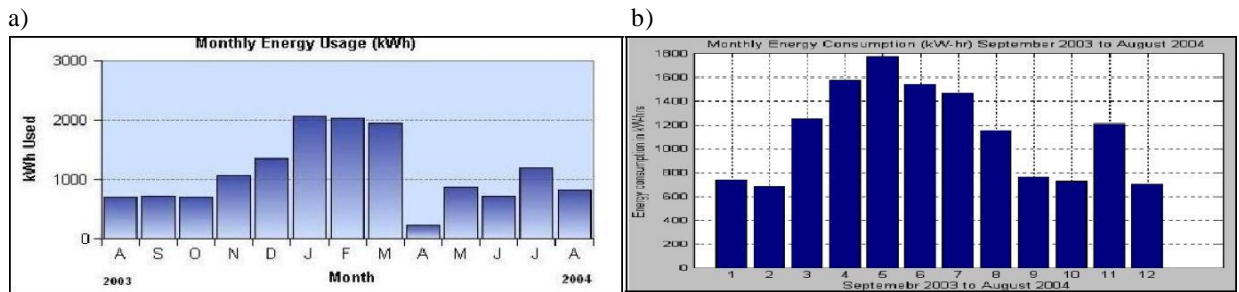


Fig. 2. (a) Energy usage provided by the utility (2003-2004) for house-1; (b) Measured monthly energy consumption from Sept. 2003 to August 2004 for house-1.

was done during night and late evening. Similarly Power consumption for the same house on a typical summer day is shown in Fig. 3(b). We can see there is no house heating power for the day. Another major electrical load was electric water heater. In Fig. 4(a) hourly averages for a day in winter is shown using bar chart. We can conclude from this chart that consumption is high at night, late evening and in early morning. Similarly hourly average of a day in summer is shown in Fig. 4(b) where it can be noticed that the consumption is high in the afternoon. Again for

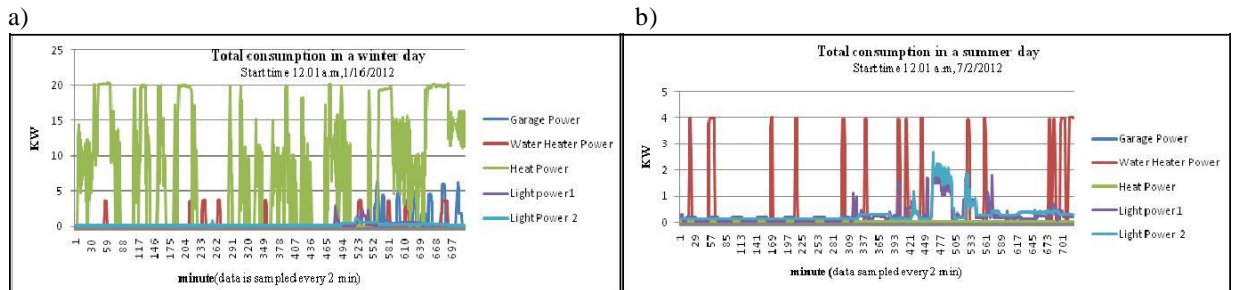


Fig. 3. (a) Power consumption in a typical winter day of year 2012; (b) Power consumption in a typical summer day of year 2012.

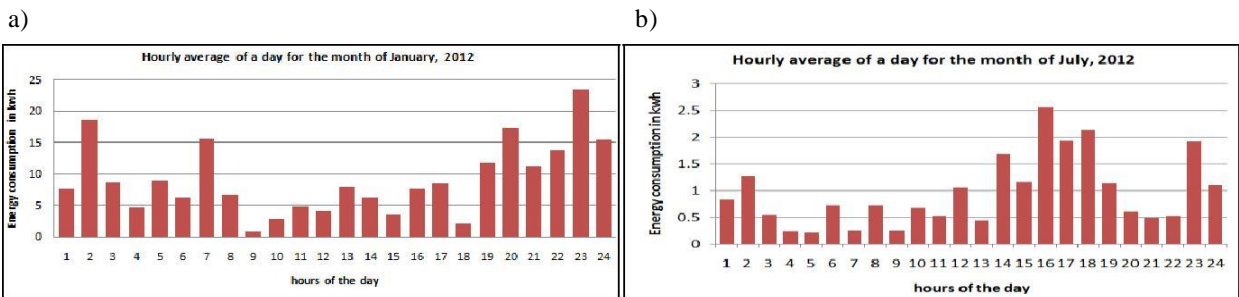


Fig. 4. (a) Hourly average of a day for the month of January, 2012; (b) Hourly average of a day for the month of July, 2012.

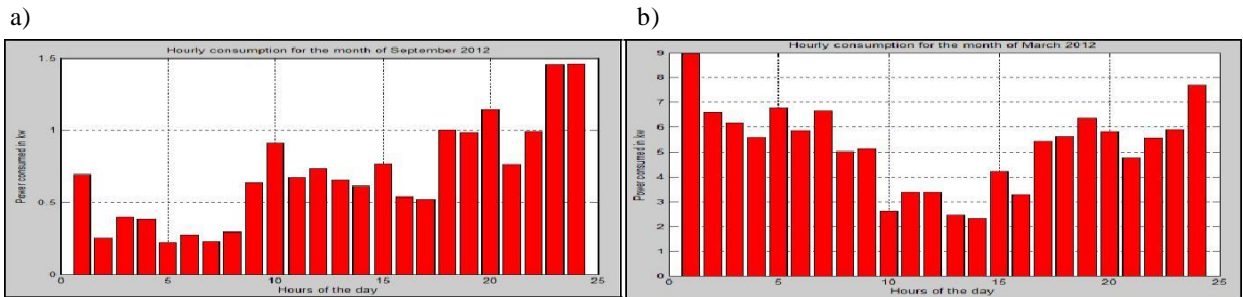


Fig. 5. (a) Hourly average power consumption in September; (b) Hourly average power consumption in March of house-2.

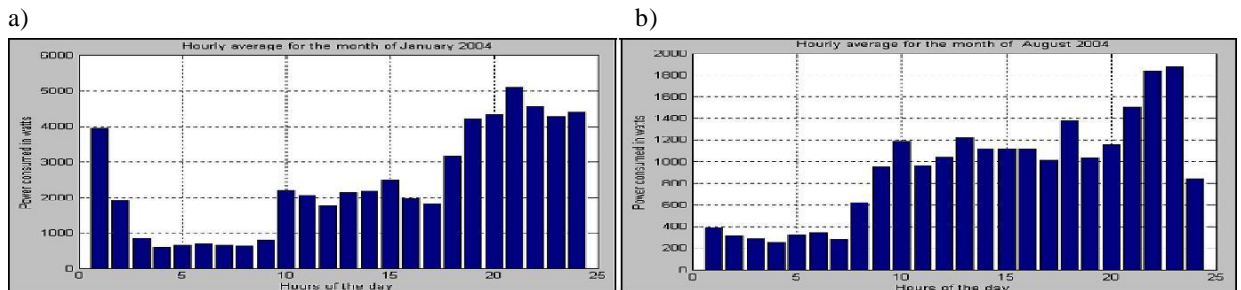


Fig. 6. (a) Hourly average power consumption in January; (b) Hourly average power consumption in August.

house-2, from Fig. 5(a) & 5(b) we observe minimum hourly power consumption was below 1.5 kW in September whereas the maximum hourly consumption was 9kW in the beginning of March in year 2012. It is observed from Fig. 6(a) that the maximum average hourly power consumption was in January 2004, which exceeded 5000W level. Similarly from Fig. 6(b) the minimum hourly power consumption was 250W in early hours of the day in August 2004. The hourly power consumption graphs are generated using Matlab code and using all the collected data, sampled every 2 min by the data logger.

3. Houses Simulation in BEopt

Both the houses are simulated in BEopt software [10]. For better analysis of house-2, garage and main house is simulated and analyzed differently instead of a single design.

3.1. Input parameters

For simulation in BEopt there are three screens where the inputs are inserted, which are Geometry screen, site screen, input screen. The input parameters for both the houses are given in table-1 which are used in input screen. The actual area of the house window is calculated and then used as input. In house-2 main house and garage are simulated separately. Every input in garage is same as the main house input, except that there are no major appliances or water heater in the garage. And for lighting the consumption is chosen 596kWh/yr. The window area ratio is also different. Weather data [11] for St John's is used in geometry screen and other house interest rate values [12] in site screen are inserted from a bank website.

3.2. Simulation result analysis

The output results analysis can be done by three different modes in BEopt, which are design mode, optimization mode and parametric mode. In this paper design mode is used for energy consumption analysis of one year for two houses. The inputs are given same as the actual house. As shown in Fig. 7 the energy consumption of house-1 for one year came as 16849 kWh/yr, whereas the actual consumption for the house is 15747 kWh/yr which is very

Table 1. Input parameters used in BEopt for both houses

Option screen	House#1	House#2
Operation		
Heating set point	60F, at night time it remains off	
Cooling set point	100 F	
Humidity set point	65% RH	
Misc electrical load	0.25	
Misc hot water load	12.5 gal/day/person	
Natural ventilation	Cooling months only	None.
Walls		
Wood stud	R-21 Fiberglass batt, gr-1, 2*6, 24 in o.c	
Wall sheathing	OSB	
Exterior finish	Vinyl, light	Vinyl, medium/dark
Ceiling/Roofs		
Unfinished attic	Ceiling R-44 Fiberglass, vented	
Roof Material	Asphalt shingles, dark	
Foundation/Floors		
Slab	4ft R-5 perimeter, R-5 gap	2ft R-10 perimeter, R-5 gap
Interzonal floor	None	R-13 fiberglass batt
Thermal Mass		
Floor mass	wood surface	
Exterior wall mass	½ inch drywall	
Partition wall mass	½ inch drywall	
Ceiling mass	1/2 inch drywall	
Windows & Doors:		
Window areas	A new input to the software according to the window area	
Windows	Double pane, medium gain, low e, non- metal frame, Air fill.	
Air flow		
Air leakage	4 ACH50	2 ACH50
Mechanical ventilation	HRV 70%	
Major Appliances		
Refrigerator	18 cu ft, EF=21.9, top freezer	
Cooking range	Electric	
Dish washer	290 annual kwh	
Clothes washer	Energy star, cold only	
Clothes dryer	Electric	
Lighting	80% fluorescent hardwired plugin.	
Space conditioning		
Electric baseboard	100% efficiency	
Duct	7.5% leakage, R-8	
Water heating		
Water heater	Electric standard	
Distribution	Uninsulated, Homerun, PEX	

close. Again for house-2 the actual consumption of the house measured from the data logger is 23116.09 KWh/yr. But the simulation shows the total house consumption is 31029 KWh/yr (Fig. 8. (a)), which is noticeably higher than the actual power consumption. Reason is that only three occupants live in this big house but BEopt Software considers more occupants for such a big house. As a result the output shows higher electricity consumption than the actual house consumption. Energy consumption of the garage for one year came as 1090 KWh/yr(Fig. 8.(b)),

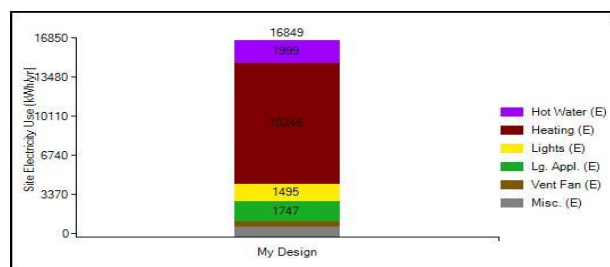


Fig. 7. Electricity consumption of one year for house-1

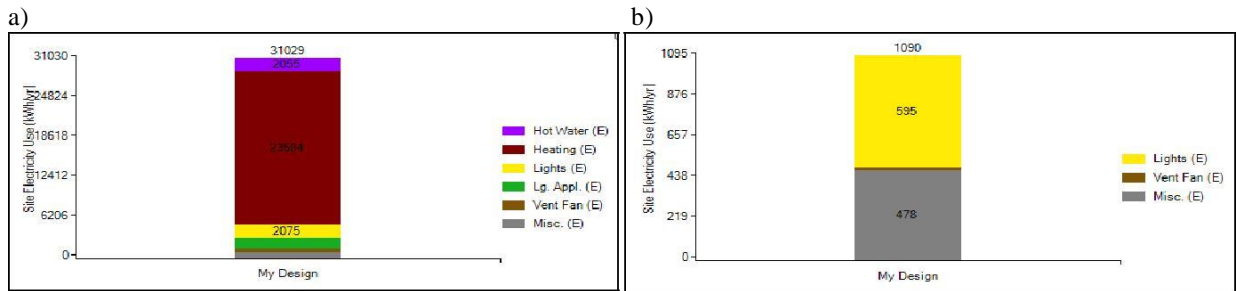


Fig. 8. (a) Electricity consumption of one year for house-2 (main house); (b) Electricity consumption of one year for house-2 (garage).

whereas the actual consumption is 1190.56 kWh/yr, which is very close to 1090 kWh/yr. So for both the houses simulation result matches with the measured data. House simulation in BEOpt can be used to optimize insulation and energy saving.

4. Conclusion

Two houses in St. John's, Newfoundland have been considered to analyze the power consumption for one year. Power consumption data for both the houses is collected from utility company and then compared with the measured values from data logger. Collected and measured values of energy consumption follow a similar pattern. Data acquisition systems were installed in each home to give a true picture of energy consumption. For a detailed analysis, houses are simulated in BEOpt and the simulation results showed that the output for energy consumption for one year is almost equal to the measured energy consumption of both the houses. Simulation is done using one-year weather data, typical thermostat settings and occupation of the houses. Daily, monthly and yearly data can be analyzed to understand the exact power consumption nature of the houses. Hourly averages of each month and energy consumption in a winter day and in a summer day are shown by a time series plots. Such plots are necessary to design a renewable energy system for a house, manage demand side and also to study human behaviour and energy usage.

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- [10] <http://beopt.nrel.gov/>
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Effect of Compression Ratio on the Performance, Combustion And Emission From A Diesel Engine Using Palm Biodiesel *Ambarish Datta (India), Gaurav Paul (India), Bijan Kumar Mandal (India)*

Abstract

The ever increasing green house gas concentration and projected shortage of fossils fuel necessitate the finding of an alternative to replace the conventional diesel fuel. The most promising alternative to diesel is biodiesel due to the closeness of thermo-physical properties of it and diesel. The biodiesel can be available as it can be easily produced from different vegetable oils through a chemical reaction called transesterification. However, some constrains are still there to use it in an unmodified diesel engine. The experimental works are most acceptable and these provide the actual results correctly. But, it is not always possible to set up the experimental test rig under all condition. Furthermore, these consume more time and cost. From this perspective, the authors have tried to numerically simulate an unmodified conventional diesel engine fueled with palm stearin methyl ester and petro-diesel at three compressions ratios of 16, 17 and 18. For the above said purpose, performance, emission and combustion characteristics of a single cylinder, naturally aspirated, water cooled, direct injection, four stroke diesel engine at a constant speed of 1500 rpm have been simulated using Diesel-RK. The simulation results show that, from the energetic point of view of the engine, brake thermal efficiency decreases and brake specific fuel consumption increases with the use of palm stearin methyl ester at same operating condition. While using the palm stearin methyl ester, increase in compression ratio increases the thermal efficiency due to better air-fuel mixing. Whereas increase in compression ratio results in the decrease of the brake specific fuel consumption of the engine. Form the combustion characteristics it has been observed that the higher compression ratio results in higher in cylinder pressure and higher heat release rate as well as lower ignition delay. The NO_x and CO₂ emission are increased at higher compression ratio due to the higher pressure and temperature. On the other hand, the specific PM emission and smoke opacity are less at higher compression ratio because of complete combustion of the fuel.

Keywords: Performance, Combustion, Emission, Biodiesel



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Numerical Investigation on the Effects of EGR on CI Engine Characteristics Using Soyabean Biodiesel

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Abstract

In this work an attempt has been made to numerically investigate the effect of soyabean biodiesels on an unmodified CI engine and then to study and reduce the NO_x emission by the introduction of exhaust gas recirculation (EGR) technique at the rates of 10% and 20% . Compared to no EGR condition for the neat biodiesel, the NO_x emission is reduced by 44% and 70% with 10% and 20% EGR respectively. But the increase in the EGR rate deteriorates the engine performance and increases the emissions, other than NO_x. Thus, EGR helps in reducing NO_x emission but its rate of introduction has to be bounded by a limit.

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Keywords: Biodiesel; EGR; NO_x Emission; BSFC; Brake Thermal Efficiency

1. Introduction

The main driving source of present day transportation system is the conventional fossil fuels, which are classified as non-renewable sources of energy. With the recent rise in the demand of these fossil fuels due to increasing number of vehicles, the extinction of these fuels in the near future is quite evident. In addition to this, other harmful effects of these fuels include global warming, which has become a serious agenda for the present world. The human health is also very susceptible to the emissions from the vehicles which are run by traditional fossil fuels. All these

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lead to the search for an alternate and clean source of energy that can reduce our dependency on the conventional energy sources and also at the same time reduces pollutant formation during combustion. Among all the viable replacements tried in the past few decades, biodiesels have found a suitable spot due to their similarity in the physical and chemical properties with that of conventional diesel fuel. Moreover, in a country like India it is observed that biodiesel can be a viable alternative automotive fuel and India has huge potential for biodiesel production from non-edible type oil seeds, like karanja and ratanjyot [1-3].

Nomenclature

\dot{m}_j	mass flow rate of j^{th} species
m	total mass within the control cylinder
Y_i^j	stoichiometric coefficients on the product side
Y_i^{cyl}	stoichiometric coefficients on the reactant side
Ω_i	dimensionless integral of order unity dependent on the force interaction during a collision of i^{th} species
P	cylinder pressure
T_z	temperature in a burnt gas zone
R	gas constant
ω	angular crank velocity
$[\text{NO}]_e$	equilibrium concentrations of oxide of nitrogen
$[\text{N}_2]_e$	equilibrium concentrations of molecular nitrogen
$[\text{O}]_e$	equilibrium concentrations of atomic oxygen
$[\text{O}_2]_e$	equilibrium concentrations of molecular oxygen
V	current volume of cylinder
q_c	cycle fuel mass
dx/dt	heat release rate

Many works have been carried out by various researchers to investigate the compatibility of biodiesels and their blends with conventional diesel in an unmodified CI engine. Investigations have shown that biodiesels may be promising fuels for CI engines in the near future. However, the use of biodiesels deteriorates the engine performance, but gives a cleaner exhaust, except for NO_x emission which tends to increase. A suitable way to reduce this drawback of biodiesels is the introduction of exhaust gas recirculation (EGR) technique. Exhaust gas recirculation (EGR) is a nitrogen oxide (NO_x) emissions reduction technique used in petrol and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders [4]. In a diesel engine, the exhaust gas replaces some of the excess oxygen in the pre-combustion mixture [5]. Because NO_x forms primarily when a mixture of nitrogen and oxygen is subjected to high temperature, the lower combustion chamber temperatures caused by EGR reduces the amount of NO_x the combustion generates (though at some loss of engine efficiency) [4]. Machacon *et al.* [6] studied the effect of EGR with O_2 enrichment on the exhaust emissions of diesel engine. They concluded that higher EGR with O_2 enrichment gives lower NO_x emissions and smoke. Ghazikhani *et al.* [7] found an increase in CO and HC emissions with the use of the effect of EGR in a HCCI engine. Hribernik and Samec [8] experimentally found that for his heavy duty turbocharged diesel engine, NO_x emission decreased substantially at 7.6% EGR and at 21.5% EGR and it was as high as 65%. The O_2 percentage decreased and HC emissions increased slightly; whereas the CO and particulate emissions tripled with 21.5% EGR. In case of the combustion parameters, it was seen that the peak cylinder pressure decreased with the increase in the EGR rates. It was further observed that 14.2% EGR was optimum as it reduced NO_x emission by 50% with a satisfactory increase in CO and particulate emissions.

Literature is rich with experimental work on EGR and numerical works are very few. Again when compared between the two, numerical work consumes much less time and cost than the experimental ones. As such the primary motive of this work will be to numerically investigate the effect of biodiesels on an unmodified CI engine and then to study and reduce the NO_x emission by the introduction of EGR. The test engine used in this work is a 4-stroke, water cooled, single cylinder TV1 engine which is fueled with pure diesel and pure soyabean biodiesel at

standard condition (no EGR) initially and then 10% and 20% EGR rates, while running with pure biodiesel. The performance, combustion and emission characteristics of the engine have been simulated using commercially available software, Diesel-RK.

2. Simulation Model

The simulation is carried using commercial software Diesel-RK which is based on the numerical solution of different conservation equations. Following Hamdan and Khalil [9], the conservation equations for overall mass, different species and energy are presented in Eq. (1), Eq. (2) and Eq. (3) respectively.

$$\frac{dm}{dt} = \sum_j \dot{m}_j \tag{1}$$

$$\dot{Y}_j = \sum_j \left(\frac{\dot{m}_j}{m} \right) (Y_i^j - Y_i^{cyl}) + \frac{\Omega_i W_{mw}}{\rho} \tag{2}$$

$$\underbrace{\frac{d(\mu)}{dt}}_{\text{Internal Energy}} = \underbrace{-p \frac{dv}{dt}}_{\text{Displacement Work}} + \underbrace{\frac{dQ_{ht}}{dt}}_{\text{Heat Transfer}} + \underbrace{\sum_j \dot{m}_j h_j}_{\text{Enthalpy Flux}} \tag{3}$$

Out of all the oxides of nitrogen, NO is predominant in diesel engine [10]. Therefore; only NO formation is considered. NO can also be formed through different mechanisms, but the model used here has taken care of NO formation through only thermal or Zeldovich mechanism. Similar NO formation model has been used by Kuleshov [11] for simulation of direct injection diesel engine. The oxidizing of nitrogen is on the chain mechanism and basic reactions are as follows:



Rate of this reaction depends on concentration of atomic oxygen. The concentration of NO in combustion products can be obtained by using the following equation [12]:

$$\frac{d[NO]}{d\theta} = \frac{p \cdot 2.333 \cdot 10^7 \cdot e^{-\frac{38020}{T_z}} [N_2]_e \cdot [O]_e \cdot \left\{ 1 - \frac{[NO]}{[NO]_e} \right\}}{R \cdot T_z \cdot \left(1 + \frac{2365}{T_z} \cdot e^{-\frac{3365}{T_z}} \cdot \frac{[NO]}{[O_2]_e} \right)} \cdot \frac{1}{\omega} \tag{5}$$

Soot formation rate in a burning zone and Hartige smoke level are calculated as:

$$\left(\frac{d[C]}{dt} \right)_K = 0.004 \frac{q_c}{V} \frac{dx}{dt} \tag{6}$$

$$\text{Hartige} = 100 [1 - 0.9545 \exp(-2.4226[C])] \tag{7}$$

Similar equations are used to calculate Bosch smoke number and Factor of Absolute Light Absorption (K). Particulate matter emission is calculated by using an equation from the work of Alkidas [13] as:

$$[PM] = 565 \left(\ln \frac{10}{10 - \text{Bosch}} \right)^{1.206} \quad (8)$$

3. Experimental Setup and Properties of Fuels used

The experiment is carried out on a Kirloskar made, single cylinder, constant speed, variable compression ratio TV1 engine with pure diesel without EGR to generate data for the validation of the numerically simulated results. The specifications of the test engine are given in table 1. The thermo-physical properties of diesel and soyabean biodiesel used for this work have also been shown in table 2.

Table 1 Engine Specifications

Manufacture	Kirloskar
Ignition type	CI (4-stroke)
No of cylinder	1
Type	TV1
Type of cooling	Water cooled
RPM	1500
BHP	3.5 KW
Bore diameter	87.5 mm.
Stroke length	110 mm.
Connecting rod length	234 mm.

Table 2 Properties of Soyabean Biodiesel and Diesel

Property	Soyabean biodiesel	Diesel
Mass Fractions (%)		
Carbon	0.773	0.87
Hydrogen	0.118	0.126
Oxygen	0.121	0.004
Low Heating Value (MJ/kg)	36.45	42.5
Cetane Number	51.3	48
Density at 323K (kg/m ³)	862	830
Dynamic Viscosity coefficient (Pa.s)	0.00463	0.003
Molecular Mass	292.5	190

4. Results and Discussions

The Diesel-RK software is first run with neat mineral diesel without any EGR and the predicted values are compared with those of experimental results for the same operating conditions. The comparison has shown a good agreement. Expecting that the validation will hold good for the EGR conditions also, numerical simulation of various performance, combustion and emission parameters of the test engine fuelled with soyabean oil methyl ester at three different exhaust gas recirculation (EGR) rates, viz. 0% EGR or pure soyabean biodiesel with no EGR, 10% EGR and 20% EGR, has been carried out. The results of which, along with their comparison with pure diesel as baseline fuel, have been presented in this section.

4.1. Brake thermal efficiency

Figure 1 shows the variation of brake thermal efficiency with brake power for the three different EGR rates. It is seen that increase in the EGR rate decreases the brake thermal efficiency. This may be due to the oxygen deficiency caused by using EGR, which leads to incomplete combustion [14]. Thus, the highest brake thermal efficiency of 31.5% is shown by the 0% EGR condition and the lowest efficiency of 29.8% is shown by 20% EGR condition. The efficiency of the engine with diesel fuel is found to be more than any conditions of biodiesel considered here.

4.2. Brake specific fuel consumption

As mentioned above, usage of EGR reduces the engine power due to incomplete combustion owing to the oxygen deficiency in the intake. Thus, in order to produce the same power output as that of 0% EGR condition, more fuel is required which eventually increases the brake specific fuel consumption (BSFC). Thus, highest BSFC is that of 20% EGR condition and the lowest is that of without any EGR, but the change is small throughout the load range as observed in figure 2. However, it can also be observed that the BSFC obtained for pure diesel without EGR is less than with biodiesel fuel without EGR. This can be explained from the fact that the lower heating value of diesel (42.5 MJ/kg) is approximately 16.5 % higher than that of soyabean biodiesel.

4.3. NO_x emission

The formation of NO_x is dependent on the peak cylinder pressure and temperature. When EGR system is used, it dilutes the fresh charge at the intake and lowers the flame temperature [15], resulting in a decrease in cylinder pressure and temperature. This eventually contributes in a significant reduction in NO_x emission as can be seen in figure 3; highest NO_x is formed at 0% EGR condition. Whereas, 10% EGR rate reduces NO_x emission by almost 40% and 20% EGR reduces NO_x by more than 65%. It can be further noted that NO_x emission with biodiesel is much higher than that with the mineral diesel at no EGR conditions and even 10% EGR lowers down the NO_x emission below the level obtained using diesel without EGR.

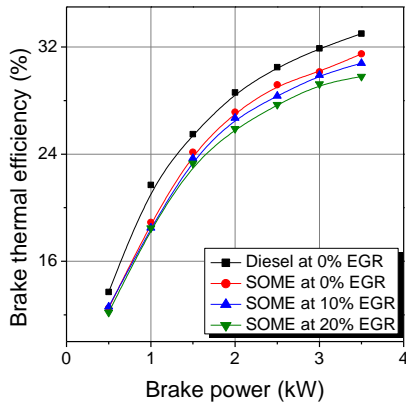


Fig. 1. Variation of BTE with brake power for different EGR rates

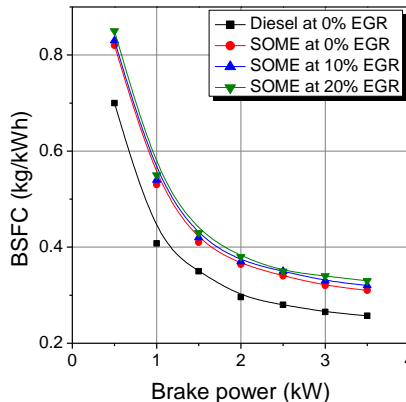


Fig. 2. Variation of BSFC with brake power for different EGR rates

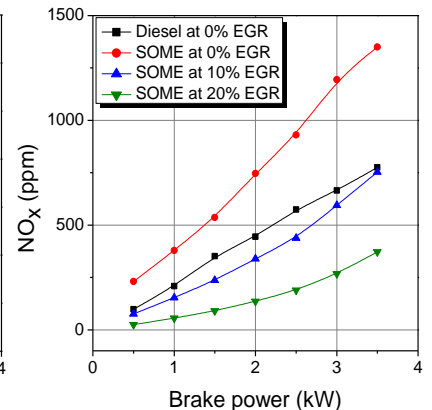


Fig. 3. Variation of NO_x emission with brake power for different EGR rates

4.4. CO_2 emission

Figure 4 shows the variation of CO_2 emission with brake power for the three different EGR rates. It can be seen that the increase in EGR rates gives rise to a slight increase in the CO_2 emission. Though usage of EGR system leads to poor combustion that will in return suppress the oxidization of carbon monoxide to CO_2 , the increase in CO_2 emission may be due to the presence of CO_2 already present in the exhaust gas re-circulated and the oxidization of carbon monoxide present in the fraction of the exhaust gas due to the relative higher intake temperature.

4.5. Particulate matter and smoke emission

The variations of smoke and specific PM emissions with brake power for the different EGR rates have been shown in figure 5 and figure 6 respectively. As particulate emission (PM) from CI engine are primarily due to improper combustion and combustion of heavy lubricating oil and smoke formation occurs primarily in the fuel-rich zone of the cylinder, at high temperatures and pressures [16]. Introduction of EGR system will tend to increase PM and smoke emissions as it leads to poorer combustion. Exhaust gas re-circulation reduces the overall air-fuel ratio which enhances the increase in particulates. Also, the re-circulated exhaust gas contains particulates which further contribute in raising PM and smoke level [14]. Thus, the lowest PM and smoke emission is shown by 0% EGR condition and the highest is shown by 20% EGR condition. However, the values are much less than with diesel.

5. Conclusion

The following conclusions can be drawn from this numerical investigation of the CI engine characteristics using soyabean biodiesel (SOME) with exhaust gas recirculation technique. The use of SOME deteriorates the engine performance but gives a cleaner exhaust, compared to that of diesel. However, SOME gives a significant rise in NO_x emission (1350 ppm) compared to diesel (775 ppm). Compared to no EGR condition for the neat biodiesel, the NO_x

emissions are reduced by 44% and 70% with 10% and 20% EGR respectively. On the contrary, brake thermal efficiency decreases with the increase in EGR rate. Brake specific fuel consumption (BSFC) increases by 3.2% and 6.5% respectively for the same. Particulate matter (PM) emission increases by 15.4% and 66.6% and smoke emission increases from 0.34 BSN (bosch smoke number) to 0.43 BSN and 0.58 BSN for 10% and 20% EGR respectively. So, the introduction of EGR helps in reducing the NO_x emission which is a major problem when a CI engine is run with biodiesel. However, there is a limit to the EGR rates to be used as the EGR reduces the NO_x emission at the cost of engine performance and other harmful exhaust at the tailpipe.

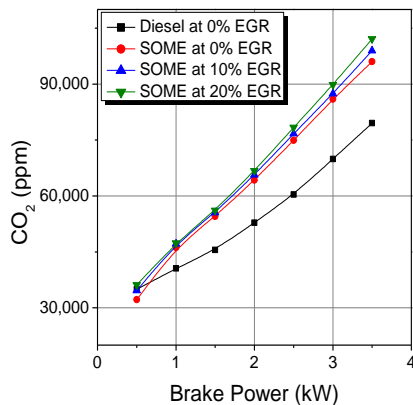


Fig. 4. Variation of CO_2 emission with brake power for different EGR rates

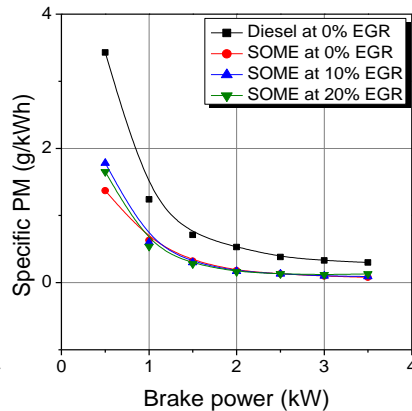


Fig. 5. Variation of specific PM emission with brake power for different EGR rates

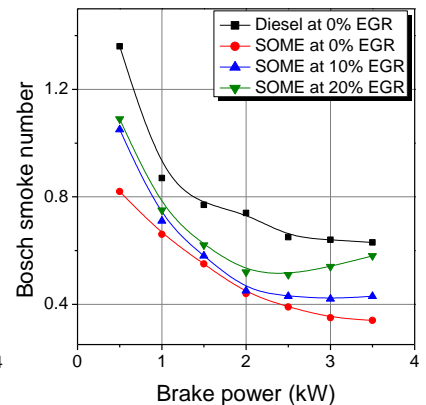


Fig. 6. Variation of smoke emission with brake power for different EGR rates

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6th BSME International Conference on Thermal Engineering (ICTE 2014)

Oil Extraction from Pine Seed (*Polyalthia longifolia*) by Solvent Extraction Method and its Property Analysis

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Abstract

The present study represents the conversion of biomass solid waste in the form of pine seed into bio-oil by solvent extraction method. Hexane is used as solvent in this process which forms miscella (mixture of solvent and oil). Solvent is recovered by distillation from miscella. The oil obtained was analyzed for their properties as an alternative fuel and was compared with petroleum product and other biomass derived oil. The fuel properties compared were higher calorific value, density and viscosity.

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Keywords: Pine seed, bio-oil, solvent extraction.

1. Introduction

Energy consumption of the world is increasing day by day. However, the conventional sources of energy (oil, gas, coal, etc.) are decreasing with increasing energy consumption, which is alarming for modern civilization. Contemporary geological knowledge, backdated reserve figures and accurate production histories generate convincing evidence suggesting that the peak of all liquid hydrocarbons comes around 2010. Economic development and prosperity over the past century has been built on cheap and abundant oil-based energy.

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After the production peak, as supplies decline and prices rise (with rising population and continued industrial development for oil will continue to increase), the world will have to use less fossil fuel or find alternate source of energy [1]. Energy is classified as renewable energy and non-renewable energy. Coal, petroleum, natural gas, propane and uranium are the non-renewable source of energy. Biomass, geothermal, hydropower, solar and wind are the renewable source of energy. In energy consumption scenario, contribution of renewable energy sources are around 7 percent. Energy from biomass is near about half of the total renewable energy [2]. The generation of biomass waste in Bangladesh is quite high. Pine seeds are one of solid waste available in our country. Generally, oil is extracted from non-edible seeds by pyrolysis or by crushing. Three products are usually obtained in a pyrolysis process: liquid, solid char and gases [3,4]. Another common way of oil extraction from non-edible seeds is solvent extraction method. The solvent extraction method recovers almost all the oils and leaves behind only 0.5% to 0.7% residual oil in the raw material. The solvent extraction method can be applied directly to any low oil content raw materials and therefore its industrial application is increasing day by day [5]. So the solvent extraction method for pine oil extraction and properties of pine oil are analyzed in this research.

2. Material and method

Samples of discarded seeds of pine (*Polyalthia longifolia*) were used in this study. The seeds were collected and cleaned by washing in water after that sun-dried for two weeks. Fig.1 shows picture of collected pine seeds. Seeds were separated from the seed coats manually after drying the seed in the sun light. The dried seeds were granulated into coarse particles using hammer. Then the sample seeds were dried on the wood-burning oven, powdered it manually using millstone. Fig. 2 shows steps of feedstock preparation of pine seeds for solvent extraction process.



Fig.1 Photograph of pine seeds



Fig.2 (a) Crushing, (b) Seed bark separation, (c) Final crushing and (d) Powder production.

The prepared sample were taken inside a thimble made from thick filter paper, which was loaded into the main chamber of the Soxhlet extractor. The Soxhlet extractor was placed onto a flask containing the extraction solvent. The Soxhlet extractor was placed onto a flask containing the extraction solvent. The Soxhlet was then equipped with a condenser. The solvent was heated to reflux. The solvent vapour travelled up a distillation arm, and flooded into the chamber housing the thimble of solid. The chamber containing the solid material was slowly filled with warm solvent. When the Soxhlet chamber was almost full, the chamber was automatically emptied by a siphon side arm, with the solvent running back down to the distillation flask. After many cycles the desired compound was concentrated in the distillation flask. In our extraction hexane was used as solvent. The miscella, a mixture of oil and solvent, from the distillation flask, which was concentrated, was taken off for distillation. Fig.3 shows pine oil extraction using Soxhlet extractor.



Fig.3 Photograph of Soxhlet extractor

3. Results and property analysis

Fig. 4 shows the extracted oil from pine seed by solvent extraction method. The following properties of pine seed oil were measured and compared with different fuel: Calorific value, density and viscosity.



Fig.4 Extracted pine oil

3.1 Comparison of calorific value

Fig.5 shows comparison of calorific value of different oil at definite temperature. From this figure it is shown that the calorific value of the extracted pine oil is higher than the calorific value of pyrolytic pine oil but lower than that of diesel fuel. The pine oil is favourable than other oils because water is not added in solvent extracted pine oil whether water is added in pyrolytic oil by hydrolysis reaction. Since higher calorific value is one of the important parameter for using the oil as fuel and also for better performance, extracted pine seed oil can be used as an alternative fuel.

3.2 Comparison of density

The density of oil, being directly dependent upon the hydrogen and carbon content, is related to the calorific value of the oil. Therefore, higher dense fuel is less required in volume than lower dense fuel to obtained same amount of calorific value. Fig.6 shows the comparison of density of different oil at definite temperature. This figure also indicates that the density of the extracted pine oil is slightly higher than diesel fuel. It also shows that the density of extracted and pressed oil (extracted pine oil, neem oil, pitraj oil and castor oil) is near about to density of diesel, but the density of pyrolytic oil (pyrolytic pine oil, date seed oil, waste paper oil, sugarcane baggage oil, jute stick oil) is higher than the density of diesel. From the comparison, it is shown that the density of pine oil is favourable than other oils because solvent extracted pine oil contains small amount of impurities found by distillation process. Therefore, alternative use of extracted pine oil can be considered as fuel directly or can be blended with another fuel.

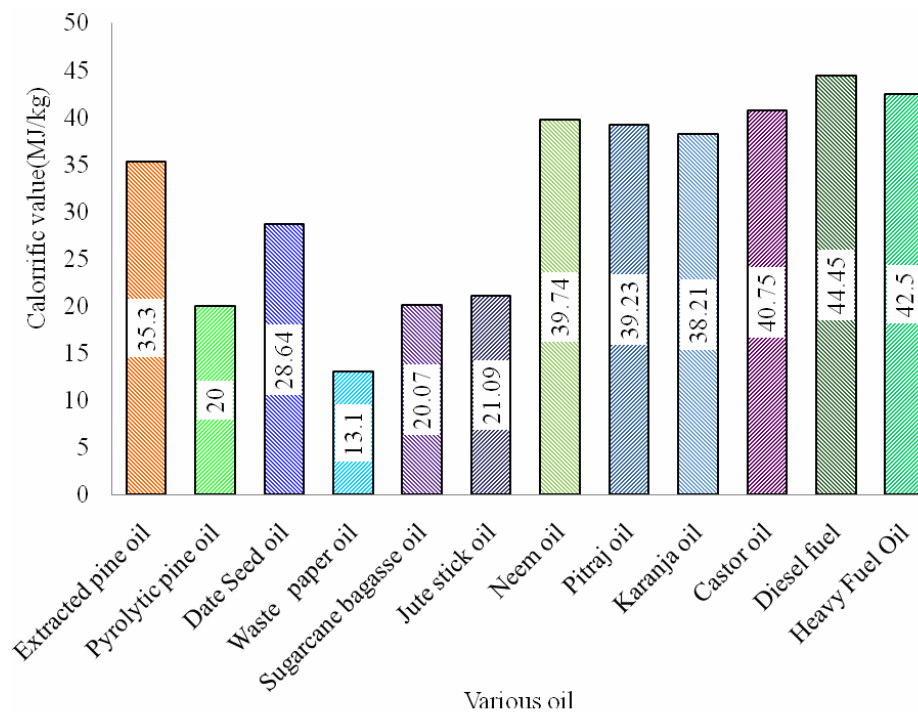


Fig.5 Comparison of Calorific value of different oil at 30°C

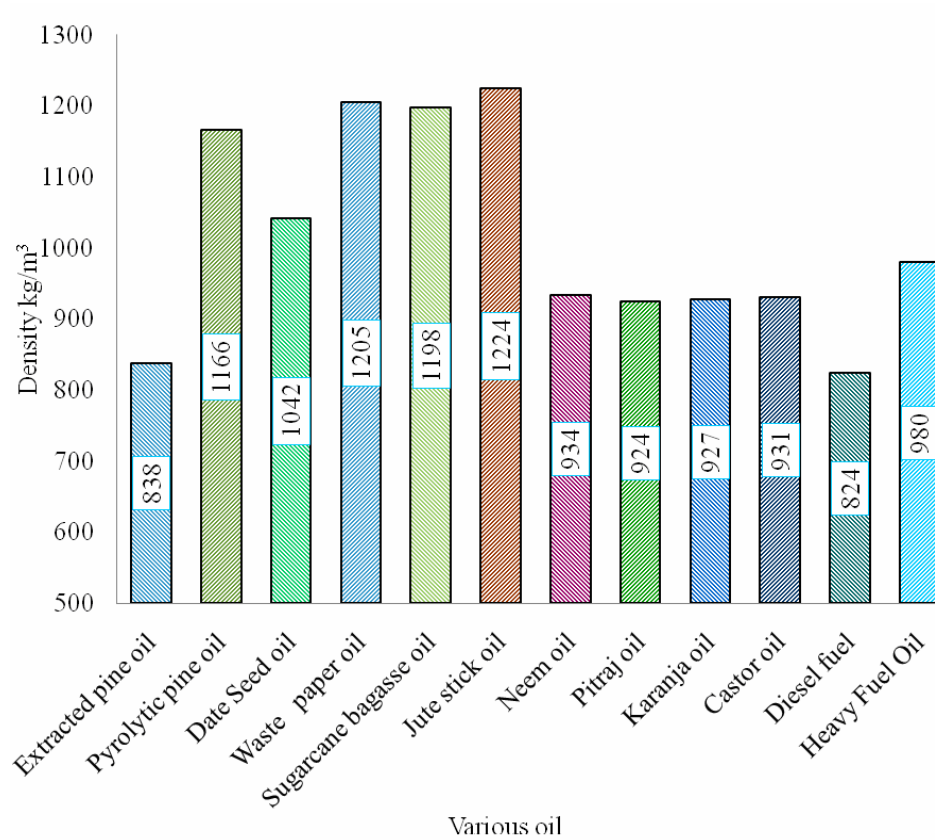


Fig.6 Comparison of density of different oil at 30°C

3.3 Comparison of viscosity

Table. 1 shows the comparison between kinematic viscosity and dynamic viscosity of different oil at definite temperature. From this it was found that kinematic viscosity and dynamic viscosity of the extracted pine oil is lower than pyrolytic pine oil but higher than the kinematic viscosity and dynamic viscosity of diesel fuel. Although the oil having kinematic viscosity and dynamic viscosity higher than the diesel may be used as fuel at different purpose by blending. From the comparison, it is shown that the kinematic viscosity and dynamic viscosity of pine oil is favorable than other oils. So, it will be easy to pump and atomize in order to achieve finer droplets for proper mixing and hence extracted pine oil may be an alternative option of conventional fuel.

Table.1: Kinematic & dynamic viscosity of different oils

Sample	Kinematic viscosity (in centistoke)[@ 30°C]	Dynamic viscosity (in centipoise)[@ 30°C]
Extracted pine oil	10.43	8.74
Pyrolytic pine oil [6]	12.15	14.17
Date Seed oil [7]	6.63	6.9
Waste paper oil [8]	2	2.4
Sugarcane bagasse oil [9]	89.34	107.03
Jute stick oil [10]	12.8	15.67
Neem oil [11]	89.79	85
Pitraj oil [11]	79.65	75
Karanja oil [11]	86.91	82
Castor oil [11]	94.80	90
Diesel fuel [12]	3.3	2.7
Heavy Fuel Oil [13]	200	196

Conclusions

The results of the work can be summarized as follows:

- (1) The higher calorific value of the extracted pine oil is 34.65 MJ/kg which is higher than pyrolytic pine oil but lower than that of diesel fuel.
- (2) The density of the extracted pine oil is lower than pyrolytic pine oil but slightly higher than diesel fuel.
- (3) The kinematic viscosity and dynamic viscosity of the extracted pine oil are 19% and 62% lower than pyrolytic pine oil respectively.

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Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics in Diesel Engine

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Abstract

Exhaust gas recirculation (EGR) is the one of the technique of reducing the oxides of nitrogen in the exhaust from internal combustion engine. This paper investigates the effect of EGR on the performance of a diesel engine in terms of brake specific fuel consumption (BSFC), brake thermal efficiency, as well as emissions of carbon dioxide (CO₂), carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxides (NO_x). Experiments have been conducted on a double cylinder, water cooled, four-stroke, direct injection diesel engine with diesel as fuel at a constant speed of 1600 rpm using 0% to 10% exhaust gas recirculation. The analysis of experimental data shows that there is a significant reduction in NO_x emission with the use of EGR technique. However, it has been also observed that emissions of CO, CO₂ and HC are increasing to some extent with EGR. The BSFC increases with the increase of EGR rate. A marginal decrease in brake thermal efficiency has also been noticed when EGR technique is used.

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Keywords: BSFC; EGR; Brake Thermal Efficiency; NO_x Emission

1. Introduction

Today the diesel engine is a very important prime mover being used in buses, trucks, tractors and other stationary industrial application. In a diesel engine high compression ratio produces the high temperatures required to achieve auto-ignition and the resulting high expansion ratio makes the engine discharge less thermal energy in

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the exhaust [1]. During the combustion process the chemical energy in the diesel fuel is transformed in mechanical energy with the formation of reaction products, which leave the engine through the exhaust into the atmosphere [2]. Diesel engines are assumed as a good alternative to gasoline engines because they produce lower amount of emissions. On the other hand, higher emissions of oxides of nitrogen (NO_x) and particulate matter (PM) have been noticed as major problems. Although, major constituents of diesel exhaust include carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM) are present in smaller but environmentally significant quantities [3]. NO_x comprise of nitric oxide (NO) and nitrogen dioxide (NO_2) and both are considered to be deleterious to humans as well as environmental health. NO_2 is considered to be more toxic than NO. It effects human health directly and is precursor to ozone formation, which is mainly responsible for smog formation. The ratio of NO_2 and NO in diesel engine exhaust is quite small, but NO gets quickly oxidized in the environment, forming NO_2 . Since diesel engine mainly emits NO hence attention has been given to reduce the NO formation [7]. In this work, experiments have been carried out in a double cylinder, water cooled, four stroke, direct injection diesel engine with exhaust gas recirculation technique (EGR) using diesel fuel at different percentage of EGR and the performance and emission characteristics of the engine have been studied

Nomenclature

BSFC	Brake specific fuel consumption
EGR	Exhaust gas recirculation
\dot{m}_{EGR}	Re-circulated exhaust gas mass
\dot{m}_{air}	Fresh air mass flow with opened EGR valve

1.1. Exhaust Gas Recirculation

Basically the use of EGR is to solve the problem of excessive NO_x emission from the diesel exhaust. EGR is operated by re-circulating the gas produced by the diesel engine exhaust back to the engine cylinder, so that the exhaust gas which is re-circulating replaces some of the excess O_2 in the pre-combustion mixture. At higher temperature, the formation of NO_x will be faster. Chemical gases are formed from the chemical reaction between nitrogen N_2 and O_2 in the combustion chamber. When these gases react with HC with the presence of sunlight, a black haze will appear in the skies known as smog. The EGR reduces the amount of NO_x in the exhaust gas emission by re-circulating it into the intake manifold where it mixes with air-fuel-ratio charge. The result of the mixing of inlet air with re-circulated gas is that peak combustion temperature and pressure are reduced by diluting the mixture of air-fuel-ratio at these conditions. Generally, EGR flow is divided into three conditions. Firstly is high EGR flow. High EGR flow is necessary during cruising and mid-range acceleration and it happens when the combustion temperature is very high. Secondly is low EGR flow which is necessary at low speed and light load condition. Lastly, no EGR, which could affects engine operating efficiency or vehicle. Basically the exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find an oxygen molecule to react with, as there are inert molecules around. This slows down the combustion speed and thus reduces the peak combustion temperature, as the same amount of energy is released over a longer period of time. The energy is also used to heat up a larger gas portion than it would without EGR. As the air is diluted with exhaust gas, the mass of a gas portion containing the needed amount of oxygen gets enhanced bigger. Another effect is the change in heat capacity. Exhaust gas has a higher specific heat capacity than air, due to the CO_2 molecule's higher degree of freedom. So for the same amount of combustion energy a gas mass containing EGR will get a lower temperature than pure air. The lower combustion temperature directly reduces the NO_x formation, as the NO_x formation rate is highly temperature dependent, More EGR leads to a lower oxygen concentration. Another way to express the amount of EGR is the EGR-rate, which is defined as follows:

$$\text{EGR [\%]} = \left(\frac{\dot{m}_{EGR}}{\dot{m}_{EGR} + \dot{m}_{air}} \right)$$

A brief discussion of some important research finding is presented. Agarwal *et al.* [1] studied the effect of EGR on performance emission deposits and durability of a constant speed compression ignition engine. They concluded

that thermal efficiency has been slightly increased and BSFC has been decreased at lower loads with EGR compared to without EGR. But at higher loads, thermal efficiency and BSFC were almost similar with EGR than without EGR. Exhaust gas temperature has been decreased with EGR. Hydrocarbons, carbon monoxide and smoke opacity have been increased with EGR, but NO_x emission decreases significantly. EGR can be applied to diesel engine without sacrificing its efficiency and fuel economy and NO_x reduction can thus be achieved. The increase in CO, HC and PM emissions can be reduced by using exhaust after-treatment techniques, such as diesel oxidation catalysts (DOCs) and soot traps. Zala *et al.* [2] investigated experimentally optimization of EGR rate on multi cylinders 4-stroke diesel engine. They observed that NO_x emission was reduced by about 80% because of EGR and the emissions of CO and HC were higher than those in the operations with diesel fuel, without EGR. They also noticed a slight decrease in brake thermal efficiency because of EGR and up to 20% load i.e., 3 kW brake power, NO_x emission was within acceptable limit and hence EGR can be eliminated up to 20% load. They concluded that engine can be run without any abnormality when modified to implement EGR in it. NO_x emission reduction of about 80% is achieved with 40% EGR rate. However, average fuel consumption was increased by about 11% and average CO emission was increased by about 67% with 40% EGR rate which are the drawbacks of EGR. HC emission increases by about 170% because of 40% EGR rate but the value still remains within the acceptable limits. Hussain *et al.* [3] studied experimentally the effect of EGR on performance and emission characteristics of a three cylinder direct diesel injection compression ignition engine. They observed reductions in NO_x and exhaust gas temperature but emissions of particulate matter (PM), HC and CO increased with usage of EGR. Thermal efficiency has been slightly increased and BSFC has been decreased at lower loads with EGR compared to without EGR. But at higher loads, thermal efficiency and BSFC were almost similar with EGR than without EGR. Exhaust gas temperature has been decreased with EGR, but NO_x emission decreases significantly. They noticed that 15% EGR rate is found to be effective to reduce NO_x emission substantially without deteriorating engine performance in terms of thermal efficiency, BSFC and emissions. Walke *et al.* [4,6] experimentally investigated the impact of EGR on the performances of diesel engine and the impact of EGR on the reduction of oxides of nitrogen. They noticed a considerable reduction in oxides of nitrogen (NO_x) and also there was a reduction of brake thermal efficiency with increase in EGR rates. However, this reduction was marginal. Brake specific fuel consumption (BSFC) increased marginally with increasing exhaust gas recirculation rates at high load. They finally concluded that the exhaust gas recirculation (EGR) has definite impact on NO_x reduction.

Table 1: Specification of experimental engine

Manufacturer	Kirloskar Oil Engines Ltd.
No of cylinder	2
No of stroke	4
Type	AV ₂
Engine No	11.1001/81801
RPM	1600
BHP	10 (7.35 kW)
Bore diameter	80 mm
Stroke length	110 mm
Coolant	Water
Injection timing	23° before TDC
Method of loading	Hydraulic Dynamometer

Table 2: Specification of gas analyser

Sl.No.	Item	Specification
1.	Gases Measured	Carbon dioxide, Carbon monoxide Hydrocarbon and Nitric oxide, oxygen
2.	Principle	Non-Dispersive Infrared for CO, CO ₂ and electrochemical sensor for O ₂ and NO.
3.	Range	CO: 0-15.0%, CO ₂ : 0-20.00%, O ₂ : 0-25.00%, NO _x :0-5000 ppm, HC:0-30000 ppm,0-5000ppm
4.	Data Resolution	CO, CO ₂ and O ₂ :0.01%, HC, NO:1ppm
5.	Accuracy	CO: ± 0.06% Vol, CO ₂ : ± 0.5% Vol, HC: ± 12 ppm Vol, O ₂ : ± 0.1% Vol, NO _x : ± 5 ppm

2. Experimental Details

The experiments have been carried out in Kirloskar diesel engine. The specification of tested engine is given in table 1. The engine is coupled directly to the hydraulic dynamometer of maximum capacity 20 kgf. The experiments have been conducted at a rated speed of 1600 rpm water pressure kept constant at 1 kg/cm². Figure 1 shows a general view of the EGR system. The rpm has been measured directly from the tachometer attached with engine. The outlet temperature of cooling water has been measured directly by using thermometer. The hydraulic dynamometer is provided to test the engine at different loading conditions and measured the brake power. Control valves are installed to control the flow of exhaust gas to the engine. In the experimental setup three known diameter orifice meters are installed for measuring the re-circulated exhaust gas flow, ambient air flow and mixing flow. Every

orifice meters connected with U tube manometer for the flow measurement. The U tube manometer adjusts with the centimeter scale from which we can measure the pressure difference for the particular flow. From the pressure difference, the flow rate is calculated. A digital gas analyzer is also fitted in the exhaust line of the engine to measure the NO_x , CO , CO_2 and HC of exhaust gas mixture. The detail specification of the gas analyzer is given in table 2.

2.1. Experimental Setup

A general cross sectional view of exhaust gas recirculation technique is shown in Figure 1. From the figure, it is clear that a part of exhaust gas is controlled by control EGR valve and re-circulated then mixed at the (A) indicating portion with the incoming fresh air and go to the intake for combustion.

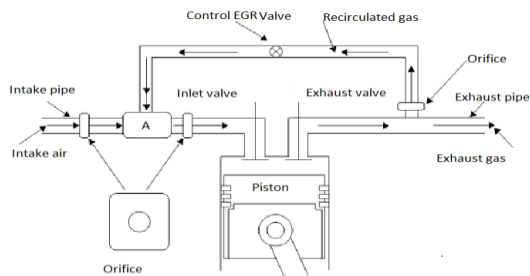


Figure.1.a. General View of Exhaust Gas Recirculation Technique



Figure.1.b. Pictorial View of Experimental setup

3. Result and Discussion

3.1. Effect of EGR on Brake Thermal Efficiency

The brake thermal efficiency gives an idea of output power generated by the engine with respect to heat supplied in the form of fuel. It is the true indication of the efficiency with which the thermodynamic input is converted into mechanical work. Figure 2 represent the effect of brake power on the brake thermal efficiency for without EGR and with different EGR rates. It is observed that with increase in brake power the brake thermal efficiencies increases for all the cases. Brake thermal efficiency decreases with increase in EGR rates at all loads and the reduction is more at full load [12]. At full load with 5% and 10% EGR rates the brake thermal efficiency decreasing approximately by 3.74% and 14.48% respectively. This may be due to the oxygen deficiency at higher load which leads to incomplete combustion.

3.2. Effect of EGR on Brake Specific Fuel Consumption

Figure 3 shows the variations of brake specific fuel consumption (BSFC) with brake power at without and with different EGR rate conditions, BSFC is found to be decrease with increase in load. This is due to the higher percentage increase in brake power with load as compared to the increase in fuel consumption. The BSFC tend to increase with increasing different EGR rate. At full load with 5% and 10% EGR rate the BSFC increased approximately by 3.86% and 16.93% respectively. This increase in BSFC is due to the negative effect of EGR on combustion which lead to incomplete combustion due to which a tendency to have fall of speed, thus to keep the engine run on constant speed it required more BSFC compared to without EGR.

3.3 Effect of EGR on Carbon dioxide (CO_2)

The variation of carbon dioxide with brake power of the engine at without EGR with different EGR rate is shown in Fig.4. The figure reveals that the formation of carbon dioxide is 5.34% by volume at full load without EGR, while it is 6.57% by volume with 5% EGR and 7.72 % by volume with 10% EGR at the same load that is with increase in

percentage of EGR carbon dioxide is increasing. The possible reason may be of this increase in CO₂ emissions in case of EGR the presence of CO₂ in exhaust gas.

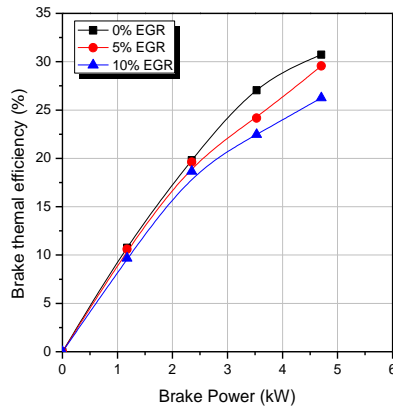


Fig. 2. Variation of brake thermal efficiency with brake power for different EGR rates

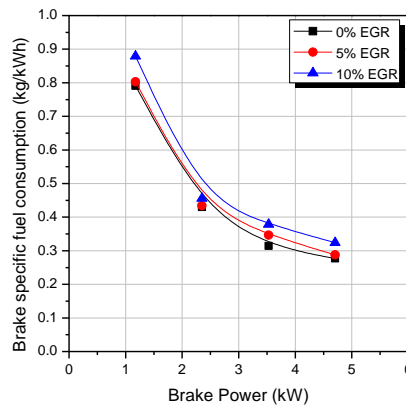


Fig. 3. Variation of BSFC with brake power for different EGR rates

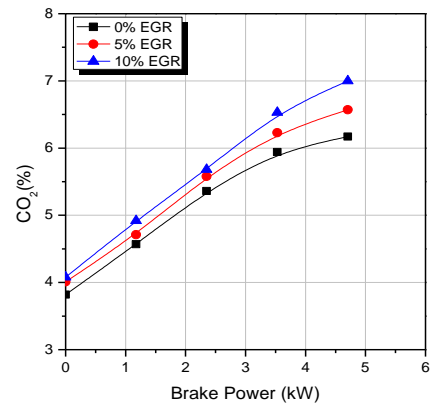


Fig. 4. Variation of CO₂ with brake power for different EGR rates

3.2. Effect of EGR on Carbon monoxide (CO)

Figure 5 shows variation of CO with respect to brake power without EGR and with different EGR rates. It shows that the CO emission has the tendency to decrease slightly with increase in brake power initially and thereafter increases sharply near higher load conditions for all the cases i.e. without and with different EGR rates [13]. Drastic increase of CO emission at higher loads is due to rich mixture at higher loads than that of at lower loads. A marginal increase in CO emission is found due to the introduction of EGR which reduces the availability of fresh charge.

3.3. Effect of EGR on Hydrocarbon (HC)

Figure 6 shows variation of HC with respect to brake power without EGR and with different EGR rate. In the graph HC emission shows the tendency to decrease initially and thereafter increases sharply near higher load condition for all the cases i.e. without EGR with different EGR. The increase of HC emission at higher load is due to rich mixture at higher loads than that of at lower loads. The value of HC at different EGR rate supports the idea that at high EGR rates high loadings, the combustion becomes incomplete producing much higher HC in exhaust gases.

3.4. Effect of EGR on Oxides of nitrogen (NO_x)

The variation of oxides of nitrogen with brake power at without EGR, with different EGR rates are depicted in Fig.7. It shows that NO_x emission has the tendency to increase with increase in brake power for all the cases. NO_x formation is a strong function of temperature. Higher the temperature, higher is the NO_x formation. The presence of high temperature gas inside the cylinder will create a favorable condition for reaction of atmospheric nitrogen with oxygen. This is the main reason for higher NO_x emission at higher load. It is also observed from the figure that NO_x emission for without EGR is 516 ppm at full load whereas with 5% and 10% EGR, the corresponding values are 400 ppm and 135 ppm respectively. Also, with the increase in the rate of EGR, NO_x emission is decreasing. This is due to the fact that EGR admits the inert gases in the chamber which have specific heat higher than that of air, so they absorb the heat of combustion and ultimately decreases the flame peak temperature in the combustion chamber resulting in lower NO_x emission [14].

4. Conclusions

An experimental investigation have been carried out on a double cylinder four stroke, water cooled diesel engine operated on diesel fuel with exhaust gas recirculation. From the analysis of the experimental data it can be

concluded that EGR is a very useful technique for reducing the NO_x emission from diesel engine. Brake thermal efficiency decreases particularly at higher loads and brake specific fuel consumption (BSFC) increases with EGR rates compared to without EGR at all loads. From the emission point of view, it is observed that with the implementation of EGR, the amounts of CO_2 , HC and CO increase in the exhaust. The most important and advantageous observation is that EGR reduces NO_x to a great extent which is approximately 22.48% (516 ppm to 400 ppm) and 73.83% (516 ppm to 135 ppm) with 5% and 10% EGR rate respectively.

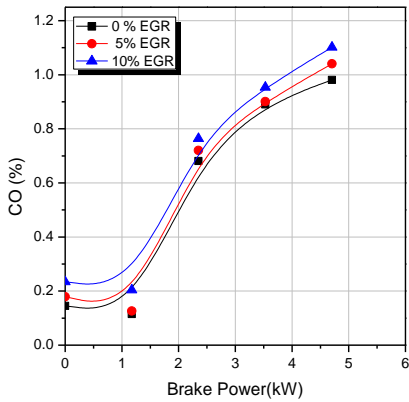


Fig. 5. Variation of CO with brake power for different EGR rates

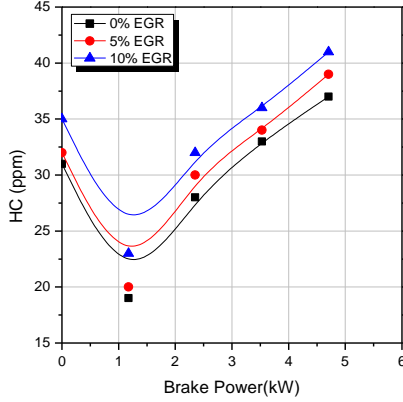


Fig. 6. Variation of HC with brake power for different EGR rates

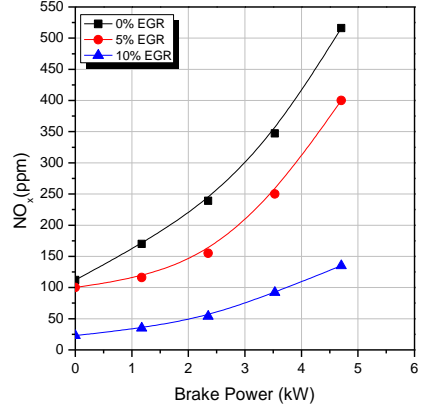


Fig. 7. Variation of NO_x with brake power for different EGR rates

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Technical and economic feasibility of solar pump irrigations for eco-friendly environment

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Abstract

This paper presents the technical and economic suitability of solar pump irrigations of rice and no-rice crops. Four submersible solar pumps (1050 W_p) were installed in different locations of Bangladesh for irrigating rice, wheat and vegetables. The solar pump was used for drip irrigation and furrow irrigation for cultivation of brinjal and tomato during 2010-13. Water savings by drip irrigation over furrow irrigation for brinjal and tomato were 53.25% and 56.16%, respectively. For cultivation of wheat about 430 mm water was required and the yield was 3.00 t/ha. Water required for boro rice cultivation in Magura was 1024 mm and in Barisal it was 1481 mm. Cultivations of solar irrigated wheat (BCR 2.31), tomato (BCR 2.22) and brinjal (BCR 2.34) were economically profitable but *boro* rice was not economically profitable (BCR 0.31). Diesel engine operated irrigation pump emits carbon dioxide but solar pump is an environment friendly irrigation technology.

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Keywords: Solar pump; PV panel; drip irrigation; tomato, brinjal; rice

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1. Introduction

Ever increasing fuel cost and doubtful availability of electricity hampers the irrigation for crop production in Bangladesh. There are about 1.71 million irrigation pumps in Bangladesh among them 83% are diesel engine operated and 17% are electricity operated [1]. The demand of electricity in irrigation is growing up since the cost of electric power driven pump is lower compared to the diesel driven pump. Solar pump may be an alternative for small scale irrigation for crop production in the off-grid area of Bangladesh. Being a tropical country, Bangladesh is endowed with abundant supply of solar energy. The ranges of solar radiation are between 4.0 and 6.5 kWhm⁻²day⁻¹ and the bright sunshine hours vary from 6 to 9 hours/day [2-3]. In Bangladesh about 60% land is under irrigation. There is a vast area to be irrigated where most of the areas (Charland, coastal area, hilly area, etc.) have no grid connection. Solar PV pump may be used for irrigating these lands for better crop production and to increase cropping intensity.

Abu-Aligah [4] reported that in locations where electricity is not available photovoltaic pumping system is a good option for irrigating crops and supplying drinking water. Namibia Renewable Energy Programme (NAMREP) conducted a study on feasibility of solar pump in Namibia [5]. This report furnished that for small to medium sized wells, solar photovoltaic pump was much cheaper on a life cycle cost basis than diesel-powered pumps. When looking beyond the original purchase price, solar pumping systems costed from 22-56% of diesel pumps cost and can achieve a payback over diesel engine operated pump little as 2 years. Hahn [6] reported that in regions with high insolation levels, photovoltaic pumping systems were technically suitable for use, beneficial for the environment and were able to yield cost advantages over diesel engine driven pumps.

Burney et al. [7] conducted a study in the rural Sudano–Sahel region of West Africa. They reported that solar-powered drip irrigation significantly augmented both household income and nutritional intake, particularly during the dry season, and was cost effective compared to alternative technologies. Zieroth [8] conducted a feasibility study on water supply by solar pump in Mauke, Cook Island. Cost of solar pump use was US\$ 0.16 per m³ as compared to US\$ 0.22 per m³ for the diesel powered pump. A solar photovoltaic pump operated drip irrigation system was designed and developed for growing orchards in arid region considering different design parameters like pumps size, water requirements, the diurnal variation in the pressure of the pump due to change in irradiance and pressure compensation in the drippers [9]. In 1999 and 2000, cabbage and peppers, respectively, were grown comparing solar and conventionally powered drip irrigation systems at the Rutgers University Research and Extension Farm, Pittstown. The solar system was operated by a 1.5 horse power motor powered by 18 solar modules. Solar powered pumping systems were capable of delivering water from rivers and wells in volumes up to 2000 gallons/minute [10].

Solar pumps were found technically suitable for low lift small scale irrigation in Bangladesh during eighties. But these pumps were not then found economically viable due to high PV cost [11]. Moreover, these photovoltaic solar panels could not function well during cloudy and rainy weathers. Presently, much improved and cheaper solar pump sets are available. Using solar pumps on a large scale energy demand in irrigation systems can be reduced substantially. Therefore, this study was undertaken to evaluate the technical and economic performance of PV operated solar pumps at field conditions for irrigation in rice and non-rice crops.

2. Materials and Methods

2.1 Installation and testing of solar pump

Four China made submersible solar pumps (Lorentz, PS 1200) were installed in the four locations such as Gazipur, Barisal, Magura and Jamalpur. Among the four pumps, one was for surface water lifting (Barisal) and another three were ground water lifting. Each of the solar pumps was 2.2 hp motor capacity. In Jamalpur, Magura and Barisal the solar pumps were operated with 1050 solar panels fitted on fixed tracker. In Gazipur the pump was operated with 1440 W_p solar panel equipped with solar auto tracker. In all locations the delivery pipe was 38 mm diameter made with PVC. The delivery lifts of the pumps installed in Gazipur, Jamalpur and Magura were 33.5,

24.0, 24.0 m, respectively. In Barisal the solar pump was installed in a pond for surface water lifting and delivery lift ranged from 4.0 to 8.0 m. The performance of each of the pump was tested in the respective project sites. During the testing of each pump, solar radiation, generated voltage, current, lift, discharge and other relevant data were measured. Water discharge was measured by volumetric method using 50 L graduated water tank. A digital solar meter (Model: 776E, accuracy $\pm 3\%$, Digital Engineering, USA) was used to measure the global solar radiation.

2.2 Irrigation in brinjal

The solar pump was used for drip irrigation and furrow irrigation for brinjal cultivation in the experimental field of BARI (Bangladesh Agricultural Research Institute), Gazipur during rabi (October-April) season of 2010-11 and 2012-13. The soil type was loamy sand. The plot size was 40 m \times 13 m (520 m²). The brinjal varieties were BARI Begun-8 planted in 2010 and BARI Begun-6 planted in 2012. Two rows of brinjal were planted in each bed on 11 October in 2010 and 26 October in 2012. Row to row and plant to plant distances were 70 cm \times 70 cm. Fertilizers such as cowdung 9.5 t/ha, urea 375 kg/ha, TSP (Triple super phosphate) 155 kg/ha and MP (Murate of potash) 260 kg/ha were applied in brinjal field. Total dose of cowdung and TSP, one third of urea (125 kg/ha) and MP (86.7 kg/ha) were applied as basal dose during final land preparation. Two beds of brinjal were irrigated by the drip method having three water tanks, each of 500 liter water holding capacity. The drip sets were made with plastic pipes, water tank, capillary tubes, pegs etc. The soil moisture content was monitored by a digital soil moisture meter (TDR 300, accuracy $\pm 3\%$, Terf-Tec International, USA).

2.3 Irrigation in tomato

The solar pump was used for drip and furrow irrigations for tomato cultivation in the experimental field of FMPE Division of BARI, Gazipur during rabi 2011-12. The soil type was clay loam. The plot size was 40 m \times 13 m (520 m²). Six beds of tomato were irrigated by the drip method having three water tanks each of 500 liter water holding capacity. The tomato variety was BARI Tomato-14. Two rows of tomato were planted in each bed on 4 December, 2011. The age of seedlings was 31 days. Row to row and plant to plant distances were 60 cm \times 40 cm. Cowdung 10.0 t/ha, urea 600 kg/ha, TSP 500 kg/ha, MP 200 kg/ha, zinc 10 kg/ha and boron 8 kg/ha were applied in tomato field. Total dose of cowdung, TSP, MP, zinc, boron and one third of urea (200 kg/ha) were applied as basal dose before final land preparation. Rest of urea was applied in two splits, 20 days after transplanting and 45 days after transplanting. Tomato was harvested during the period of February to April 2012. Irrigation was applied when the soil moisture content became below the soil moisture content of 35% (w/v).

2.4 Irrigation in wheat

Wheat was cultivated in 496 m² land area in the experimental field of FMPE, Division, BARI, Gazipur during the rabi season of 2012-13. The wheat variety was BARI Gom-26. The date of sowing was 23 November 2013. Wheat was sown by bed planter. There were two rows on the bed and row spacing was 20 cm. Seed rate was 100 kg/ha. The field was fertilized with urea, TSP, MP and gypsum at 220, 180, 50, 120 kg /ha, respectively. Half of urea, the whole amount of TSP, MP and gypsum were applied at the time of final land preparation. The rest of urea was top dressed at crown root initiation (CRI) stage. Irrigation was applied in the bed. Irrigation was applied by flood method in the bed. The date of harvesting was 16 April 2013.

2.5 Irrigation in boro rice

The solar pump was used for flood irrigation of boro (January-April) rice field in the experimental field of Regional Agricultural Research Station, Rahmatpur, Barisal and Regional Spices Research Centre, Magura during boro season of 2011-12 and 2012-13. Each plot size was 17.5 m \times 12.5 m. The rice variety planted in Barisal was BRRI dhan28 and in Magura it was *Kazol Lota* (Aromatic rice). The ages of seedlings in Barisal and Magura were 36-40 days. The date of planting of seedlings in Magura was 4 February and in Barisal, 29 January. Row to row and

hill to hill distance was 20 cm. Urea 200 kg/ha, TSP 380 kg/ha, MP 140 kg/ha, zinc 15 kg/ha and boron 7 kg/ha were applied as basal dose before final land preparation. One third of urea was applied as basal dose and second one third urea was applied 27 DAT (days after transplanting). Rest one third urea was applied at 60 DAT.

2.6 Financial analysis

Total cost of solar pump for crop production is the sum of fixed cost and variable cost. Fixed cost is the sum of depreciation, interest on capital cost, repair, maintenance and shelter cost and cost of land use. Depreciation is often defined as the annual loss in value due to use, wear, tear, age, and technical obsolescence. Several methods or equations can be used to compute annual depreciation. The useful life of solar pump was assumed to be 20 years. Annual interest rate was considered 14% of the capital price of the pump. The variable cost is the sum of input cost and operating cost (fuel, oil, operator, etc.).

2.7 Calculation of carbon dioxide emission

Carbon dioxide (CO₂) emission from irrigation pump in Bangladesh was calculated from the total diesel consumed by the irrigations pumps in a year. Total numbers of irrigation pumps (DTW, STW and LLP) used in Bangladesh from 2000 to 2011 were obtained from the reports of Bangladesh Agricultural Development Corporation (BADC). Total quantity of diesel and electricity used by the irrigation pumps were also obtained from the secondary source of BADC [1]. Then electric power was converted to diesel power using the conversion factor that one MWh electricity equivalent to 200 liter diesel [12]. Carbon dioxide emission was calculated by multiplying 2.8 kg for 1 (one) liter of diesel fuel [13]. Then total quantities of carbon dioxide emissions from total numbers of irrigation pumps in different years were calculated.

3. Results and Discussions

3.1 Performance of solar pumps

Variation of discharge of solar pump with solar radiation at different times of a day was tested in Gazipur and presented in Fig. 1. The test was conducted on 11 June 2012 from dawn to dusk. It is observed from the figure that solar pump could not lift any water at low solar radiation (<60 W/m²). Discharge increased with the increase of solar radiation and it reached peak in the noon (12:00 m.) and then decreased gradually as solar radiation decreased. During the testing period the maximum discharge was found 111.0 L/min at 12.30 pm and average discharge was 61.24 L/min. Similar results were found for other pumps.

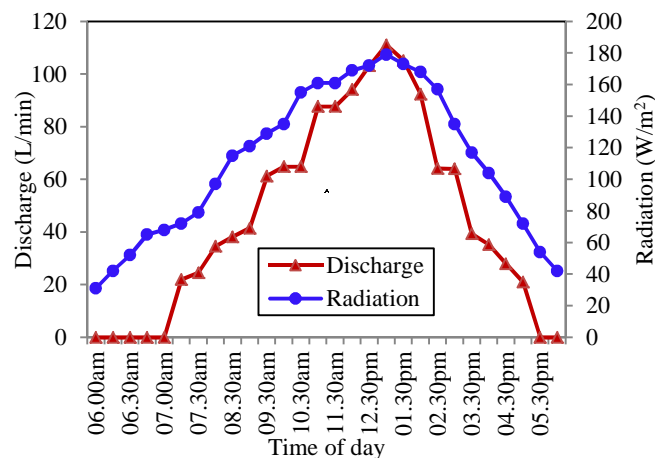


Fig. 1 Variation of discharge of solar pump with solar radiation at different times of a day in Gazipur.

3.2 Irrigation in brinjal

The solar pump was used for drip irrigation and furrow irrigation for brinjal cultivation in the experimental field of FMPE Division, BARI, Gazipur and during rabi 2010-11 and 2012-13 and also Regional Agricultural Research Station (RARS), Jamalpur during 2011-12. Table 1 shows yield of brinjal in different years and locations by drip and furrow irrigations. There were no significant differences of average fruit weights and yields of BARI Begun-8 and BARI Begun-7 between drip and furrow irrigations in both the years 2010-11 and 2011-12 in Gazipur and Jamalpur, respectively. But in 2012-13, significantly higher yield (at 5% level) of brinjal (BARI Begun-6) was obtained from drip irrigated plots (43.86 t/ha) than furrow irrigated plots (38.60) in Gazipur. Therefore, significant effect of drip irrigation was found for brinjal variety of BARI Begun-6 but not for BARI Begun-7 and BARI Begun-8. Besides this, BARI Begun-7 in Jamalpur and BARI Begun-8 in Gazipur were partially infected by leaf curl virus disease. Patel et al. [14] reported that for an application of 600 mm of water in drip yielded 33.5 t/ha (+26.3%) compared to 26.53 t/ha with surface irrigation.

Table 1. Yield of brinjal in different years and locations by drip and furrow irrigations.

Irrigation method	2010-11: Gazipur (BARI Begun-8)		2011-12: Jamalpur (BARI Begun-7)		2012-13: Gazipur (BARI Begun-6)	
	Average fruit weight (g)	Yield (t/ha)	Average fruit weight (g)	Yield (t/ha)	Average fruit weight (g)	Yield (t/ha)
Drip	85.31	26.49	80.42	27.29	523.16	43.86
Furrow	87.23	26.71	78.81	25.82	510.71	38.60
Significance	ns	ns	ns	ns	*	*

* Denotes significant at 5% level, ** denotes significant at 1% level and ns denotes not significant

Irrigation applied in drip and furrow irrigation methods in the years 2010-11, 2011-12 and 2012-13 for brinjal cultivation in Gazipur and Jamalpur are given in Table 2. Application of total irrigation in brinjal field in Gazipur during 2010-11 in drip and furrow methods were 54 mm and 131 mm, respectively. During the brinjal growing season, there was 330 mm rainfall. This is why irrigation required in both drip and furrow methods were less than the optimum irrigation (300-400 mm by furrow method) for winter brinjal [15]. Hence the water saving by drip irrigation over furrow irrigation for brinjal was about 58.78%. In Jamalpur irrigation applied during 2011-12 by drip and furrow methods were 228 mm and 453 mm, respectively. Water saving by drip method was 49.66%. During the growing season of brinjal, 126 mm rainfall was received in Jamalpur. In Gazipur during 2012-13, irrigations were applied 238 mm and 460 mm by drip and furrow methods, respectively. Water was saved by 53.25% by drip method over furrow method of water applications. In drip method, average water saving was 53.25%. Bhogi et al. [15] found 35 to 51% water saving from drip irrigation over furrow irrigation for brinjal cultivation. These results are in agreement with the findings of Sivanappan [16] in brinjal, tomato, chilli, okra and sweet potato.

Table 2. Irrigation applied in drip and furrow irrigations methods in different years for brinjal cultivation.

Methods of irrigation	2010-11: Gazipur (BARI Begun-8)		2011-12: Jamalpur (BARI Begun-7)		2012-13: Gazipur (BARI Begun-6)		Average water saving (%)
	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	
Drip	54	58.78	228	49.66	238	48.26	53.25
Furrow	131		453		460		

3.3 Irrigation in tomato

Yield of tomato in different years and locations by drip and furrow irrigations are shown in Table 3. There

was no significant difference of fruit weights and yields of BARI Tomato-14 between drip and furrow irrigation methods in Jamalpur. Yield of BARI Tomato-14 was comparatively low in Jamalpur than that of Gazipur because tomato was infected by bacterial wilt. Significantly higher fruit weights and yields of tomato were found in Gazipur from drip irrigated plots than those of furrow irrigated plots in both the year 2011-12 and 2012-13. In Gazipur, higher yield of tomato was obtained for BARI Tomato-14 in 2011-12 than BARI Tomato-15 in 2012-13. This might be due to the varietal effect as well as favourable climatic effect in the year 2011-12. Hartz and Hanson [17] reported that drip irrigation enhanced better nutrient uptake in tomato resulted higher yield and better quality.

Table 3. Yield of tomato in different years and locations by drip and furrow irrigations.

Irrigation method	2010-11: Jamalpur (BARI Tomato-14)		2011-12: Gazipur (BARI Tomato-14)		2012-13: Gazipur (BARI Tomato-15)	
	Average fruit weight (g)	Yield (t/ha)	Average fruit weight (g)	Yield (t/ha)	Average fruit weight (g)	Yield (t/ha)
Drip	55.36	35.64	60.98	62.95	69.75	39.92
Furrow	54.84	33.83	55.07	53.52	52.68	30.53
Significance	ns	ns	**	**	**	**

Irrigation applied in drip and furrow irrigations method in the years 2010-11, 2011-12 and 2012-13 for tomato cultivation in Gazipur and Jamalpur are given in Table 4. Total irrigation applied in tomato (BARI Tomato-14) field in Jamalpur during 2010-11 in drip and furrow methods were 249 mm and 568 mm, respectively. During the tomato growing season, 260 mm of rainfall was received in Jamalpur. Hence the water saving by drip irrigation over furrow irrigation for tomato was about 56.16%. Irrigation waters applied by drip and furrow methods in the year 2011-12 were 254 mm and 590 mm and in the year 2012-13 were 335 mm and 610 mm, respectively. Water savings by drip method over furrow method in 2011-12 and 2012-13 were 56.95% and 45.08%, respectively. Average water saving was 52.72%.

Table 4. Irrigation applied in drip and furrow irrigations methods in different years for tomato cultivation.

Methods of irrigation	2010-11: Jamalpur (BARI Tomato-14)		2011-12: Gazipur (BARI Tomato-14)		2012-13: Gazipur (BARI Tomato-15)		Average water saving (%)
	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	
Drip	249	56.16	254	56.95	335	45.08	52.72
Furrow	568		590		610		

3.4 Irrigation in wheat

Wheat (BARI Gom-26) was cultivated in bed during 2012-13 in Gazipur and was irrigated with furrow irrigation method. For cultivation of wheat about 430 mm water was used and the yield was 3.00 t/ha.

3.5 Irrigation in boro rice

Yield and yield contributing factors of solar irrigated boro rice cultivated in Magura and Barisal during 2011-12 are given in Table 5. It is observed from the table that significantly higher plant height was found for *Kazol Lota* rice in Magura than BRRIdhan28 cultivated in Barisal. This variation was due to the varietal effect and may be the variations of weather conditions as well as fertility variation of soils. Weight of 1000 grains was higher in BRRIdhan28 than *Kazol Lota* rice but their differences were insignificant. Yield of BRRIdhan28 was also found significantly higher than that of *Kazol Lota* rice. This was due to that BRRIdhan28 is a high yielding variety and *Kazol Lota* rice is local aromatic rice. These experiments were replicated in the year 2012-13 and similar results were found in 2011-12 season.

Table 5. Yield and yield contributing factors of solar irrigated *boro* rice during 2012-13.

Location	Variety	Plant height (cm)	Length of panicle (cm)	Number of grain per panicle	1000 grain weight (g)	Grain yield (t/ha)
Magura	<i>Kazol Lota</i>	102.00	25.00	93.36	21.50	2.50
Barisal	BRR1 dhan28	81.09	24.52	112.34	24.82	3.40
Significance		*	ns	*	ns	*

During 2012-13 cropping season total water requirement for *boro* rice cultivation in Magura was 1024 mm and in Barisal it was 1481 mm. This variation was due to the type of soil and variations of weather and variety of rice. In Magura soil type was clay loam and in Barisal soil type was sandy loam. On the other hand in Magura rice variety was *Kazol Lota* and in Barisal the rice variety was BRR1 dhan28. During the crop season no effective rainfall was obtained in Barisal and Magura. In *boro* rice cultivation 1324 mm water was used in Magura and 1252 mm of water was required in Barisal. During 2011-12 season, average irrigation was applied in *boro* rice cultivation during the *boro* season of 2012-13 was 1288 mm of water.

3.6 Financial analysis of solar irrigation

Financial analyses of submersible solar pump irrigation for vegetable and cereal crops are given in Table 6. Initial cost of the submersible solar pump (Lorentz, PS1200) including installation cost was high (Taka 450,000) but the service life is high (20 years). Estimated command areas of solar pump for tomato, brinjal, wheat and *boro* rice were 1.06, 1.40, 3.75 and 0.58 ha, respectively. The highest gross and net returns were found for brinjal followed by tomato and wheat and the lowest gross and net returns were found for solar irrigated *boro* rice. Net return for solar irrigated *boro* rice was negative due to high invest for irrigation. The reason for high invest was less command area and high water requirement of *boro* rice. The yield of tomato was higher than that of brinjal but total production of solar irrigated brinjal was higher than tomato due to higher command area.

Table 6. Financial analysis of submersible solar pump for surface irrigation of vegetables and cereal crops.

Cost items	Tomato	Brinjal	Wheat	Boro rice
Depreciation (Tk/year)	20250	20250	20250	20250
Interest on investment (14%) (Tk/year)	34650	34650	34650	34650
Repair, maintenance and shelter (Tk/year)	4500	4500	4500	4500
Fixed cost for solar pump (Tk/year)	59400	59400	59400	59400
Water requirement per season (mm)	610	460	430	1288
Command area (ha) at 60% irrigation efficiency	1.06	1.40	3.75	0.58
Land use cost (Tk/year)	23080	34132	43744	6944
Total fixed cost (Tk/year)	82480	93532	103144	94244
Total variable cost	99153	86117	38664	66099
Total cost (Fixed cost + variable cost) (Tk/year)	181633	179649	141808	160343
Yield (ton/ha)	38.00	30.00	3.50	4.25
Total production of crop (ton)	40.28	42.00	13.13	2.47
Price at harvesting season (Tk/ton)	10000	10000	25000	20000
Gross return (Tk)	402800	420000	328250	49400
Net return over total cost (Tk)	22116	240351	186442	-110943
Benefit cost ratio	2.22	2.34	2.31	0.31

Initial cost of solar pump = Taka 450,000, Life of pump and solar panel = 20 years, Average discharge = 100 L/min

Benefit cost ratio for cultivation of solar irrigated wheat was the highest followed by brinjal and tomato. The reason was that the water requirement of wheat was lower than vegetables (tomato and brinjal). So, command area and irrigation intervals of wheat were higher than vegetables. On the other hand, input cost of wheat was lower than

vegetables but price of wheat was higher than vegetable at harvesting season. The benefit cost ratio of brinjal, tomato and wheat over total cost basis were 2.34, 2.22 and 2.31, respectively. So, cultivations of solar irrigated brinjal, tomato and wheat were economically profitable. For cultivation of solar irrigated *boro* rice, net margin was negative and benefit cost ratio was found less than unity (0.31). Therefore irrigation of *boro* rice by solar pump was not economically profitable. But solar pump was found technically suitable for cultivation of *boro* rice.

3.7 Carbon dioxide emissions

Carbon dioxide emissions from irrigation pumps in different years in Bangladesh are shown in Figure 2. It is observed from the figure that carbon dioxide emission from irrigation pumps was increasing with the numbers of irrigation pumps. In 2000, CO₂ emission from irrigation pumps was 3.9 million tons and it was increased sharply to 8.4 million tons in 2011. Solar pump is pollution free and green irrigation technology to mitigate CO₂ emission. If these diesel or electricity powered irrigation pumps may be changed with solar pumps, Bangladesh can mitigate huge quantity of CO₂ emission each year. Therefore, solar pump may be use for irrigation of crops for sustainable green agriculture.

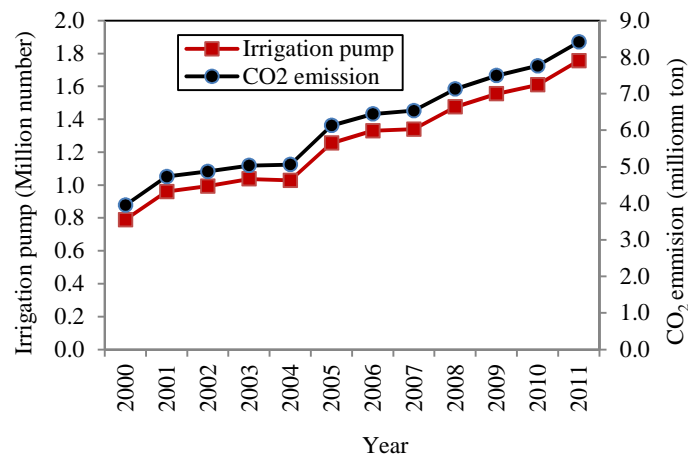


Fig. 2 Carbon dioxide emissions from irrigation pumps in different years in Bangladesh.

4. Conclusions

The field performance of solar pumps tested in different locations of Bangladesh for surface and groundwater lifting was found satisfactory. Solar pump was found technically suitable for irrigation in rice and non-rice crops. Drip irrigation in vegetables saved about 50% water than furrow irrigation method. Vegetables and wheat cultivation by solar pump irrigation was economically profitable. Rice cultivation by solar pump irrigation was not found economically viable under the tested situation. Diesel engine operated irrigation pump emits carbon dioxide and pollutes environment but solar pump is an environment friendly irrigation technology.

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6th BSME International Conference on Thermal Engineering (ICTE 2014)

Performance of an Electricity-Generating Cooking Stove with Pressurized Kerosene Burner

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Abstract

A clean-burning cooking stove that also generates electricity (The Score-Stove™) was modified to enable evaluations to take place in 3 regions of Bangladesh. Using the principle of thermo-acoustics to generate electricity it can supply power for applications such as - LED lighting, mobile phone charging and radios particularly in rural areas without grid electricity. After assessing the needs of the rural communities through a survey, tea-stalls and small restaurants owners were identified as people with the most potential of using the Stove in Bangladesh. The Bangladesh University of Engineering and Technology ((BUET) modified a Score-Stove to use both wood and a pressurised kerosene burner of a design that is widely used for cooking in rural areas of Bangladesh. The design was adapted to meet performance needs such as: heating rate, cooking efficiency, energy distribution, electric power generation, exhaust emissions and time taken to boil water using standardised water boiling tests. Performance was also compared with conventional (non-electrically generating) stoves that use a pressurised kerosene burner. A stove suitable to be demonstrated was developed to obtain feedback from some end-users for evaluation. Effects of the technical changes to the stove required for field trials and laboratory experimental results are presented. Technical deficiencies are documented and recommendations for improvements and future research in order to obtain wider end-user acceptance are made.

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Keywords: Score-Stove; Thermo-acoustics; Clean cooking stove; Small-scale power; Kerosene burner

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1. Introduction

Over three billion people around the world, particularly in Sub-Saharan Africa, Indian subcontinent and South America cook an open fire stoves, and 1.4 billion are deprived of grid electricity. Inefficient burning causes thousands of tons of carbon emission as well as serious health hazards to the users, which causes almost four million people to die prematurely each year due to household air pollution (HAP) [1]. The Lancet [2] states that household air pollution is the leading risk factor for premature deaths in south Asia.

Despite the high death rates, the problem continues to be intractable for a variety of reasons [3]. The World Bank [4] states "... In short, many approaches to introducing improved stoves have been tried, with some successes and many failures...". There is a growing body of opinion that more radical approaches are needed [5]. Riley [6] argues that the addition of electrical generation to cooking stoves increases the affordability and hence social acceptance of clean cooking. Studies in Malawi [7] using thermo-electric technology have made some progress, although the power produced is low, about 3 Watts of electricity. Another thermo-electric stove that is commercially available for use in developed countries and has had trials in Laos, is the Biolite [8] that produces about 2 to 3W. It only take small pieces of wood and so is thought unsuitable for areas where cut wood is about 50 to 70 cm long [9].

In Bangladesh, the per capita energy consumption of 321 kWh is one of the lowest in the world [10], [11] a fact recognised by the Bangladeshi government which is committed to improving the situation. Recent developments in thermo-acoustic technology have shown potential to provide solutions to the problems set out above [12], [13], [14], [15]. This paper describes the use in Bangladesh of the Score-Stove™ [5] that incorporates the thermoacoustic principle to generate electricity whilst cooking by converting excess thermal energy into electrical energy before releasing waste energy to the atmosphere. With the use of a chimney and proper combustion of air-fuel the stove can provide a non-smoky and healthier environment inside the kitchen.

Nomenclature

AHX	ambient heat exchanger	PAB	practical action Bangladesh	TBT	thermal buffer tube
HHX	hot heat exchanger	PVC	poly vinyl chloride	SS	stainless steel
HAP	household air pollution	TAE	thermo-acoustic engine	WBT	water boiling test

2. Background and working principle

Byron Higgins (1777) first documented the thermoacoustic phenomenon [16]. A century later Lord Rayleigh explained the phenomenon qualitatively [18], in the 1960s'. From then until the 1990's others progressed understanding [17,18] until progress became much more rapid through the theoretical work of Swift [19] at Los Alamos laboratories [21] and the practical realisations of deBlok from Aster [22]. Fig 1 below shows the basic components of a dual full wavelength, looped tube travelling wave engine as used in the Score-Stove™.

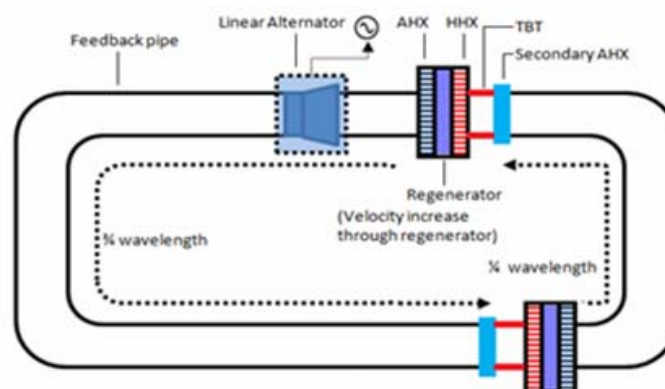


Fig. 1. Functional diagram of SCORE-Stove.

In a thermoacoustic engine, heat is supplied from a source to a gas (air in Score-Stove) via the hot heat exchanger (HHX), heat is removed via the ambient heat exchanger (AHX) and the gas undergoes repetitive thermal expansion and rarefaction to produce acoustic energy. Between the HHX and AHX is a porous material called a regenerator, with a temperature gradient across it, to sustain a resonant acoustic wave and a linear alternator within the closed loop converts the acoustic wave into electricity. In the field trial Score-Stove design the linear alternator was implemented using a low-cost loudspeaker working in reverse.

3. Design of Field Survey

3.1 Methodology

Work in rural Nepal and Uganda [23] has shown that low cost is essential for acceptability by the local people. To meet the low cost target, the Score-Stove requires much more research and is currently too expensive for single household use, although work on affordability [6] and recent trials in Nepal by Kathmandu University [24] have shown that the cost targets are not as onerous as first thought. For the BUET research the objective was to find a solution that was less cost sensitive, more in tune with Bangladesh cooking habits and so could be implemented more quickly. Small tea shops were identified as highly potential users as stall owners typically were found to use small cookers running on kerosene, briquette of sawdust or biomass fuels for long hours. Additionally, they often have to buy electricity from a nearby stall that has a petrol/diesel-driven generator.

Therefore a Score-Stove was modified for use in Bangladesh and tested under laboratory conditions to ensure it was safe and suitable for later field trials undertaken with a field survey (yet to be published) with the help of Practical Action Bangladesh (PAB). This paper describes the preliminary work required for the later field trials.

3.2 Proposed implementation



Fig. 2. Field survey for identification of applications and potential user

Larger shops tend to use pressurised kerosene burners but smaller ones use gravity feed. Often two pots are used side by side, one for boiling and the other for pre-heating even though some burners had limited capacity for doing this. A typical tea stall size is 3 x 5 m, which could spare only 0.5 x 1 m for the stove, imposing restriction on its acceptable physical size. Road side restaurants were also identified as another source of potential users of Score-Stove. They have stronger burners and longer operational hours. Both pressurised kerosene and larger wood burners were found to be in use. However their electrical power requirement was in the order of one kilowatt so they often have a mains electric supply. These premises would not gain enough benefit from a Score-Stove. Fig 2 shows picture of the more potential applications. The right hand-side of the figure is typical of the pressurised kerosene burners used by the traders; two burners can be seen.

4. Construction and Modification of Score-Stove

In order to make the Score-Stove useful to rural people, it was designed and constructed in such a way so that it could be run using kerosene, wood, briquette of sawdust or other biomass as fuel. Flexibility of usage of fuel was considered a key requirement for the targeted remote rural areas. BUET constructed the modified frame in two parts for ease of transportability with two mild steel components bolted together. A 45 degree inclined metal frame was used for supporting the TAE, and another part of the frame housed the cooking pots and chimney for removal of exhaust gas. This arrangement is adaptable for a regular kerosene stove or alternatively a wood/biomass burner placed below the TAE.

Hot gases from the burner pass through a BUET designed combustion chamber passage over the HHX then across the cooking pots. Combustion chamber and gas passages are made of stainless steel which has higher resistance to corrosion. Stainless steel sheets are bolted to the second metal frame and at the centre of the sheets are holes to house cooking or tea pots. After passing under the cooking pot the hot gas moves up the chimney and exhausted outside. Combustion chamber and cooking hob are insulated with a combination of rock and ceramic wool of 75 mm thickness to minimise heat loss. The top surface of the hob was made of stainless steel so that corrosion that is common due to the water from cooking could be avoided.

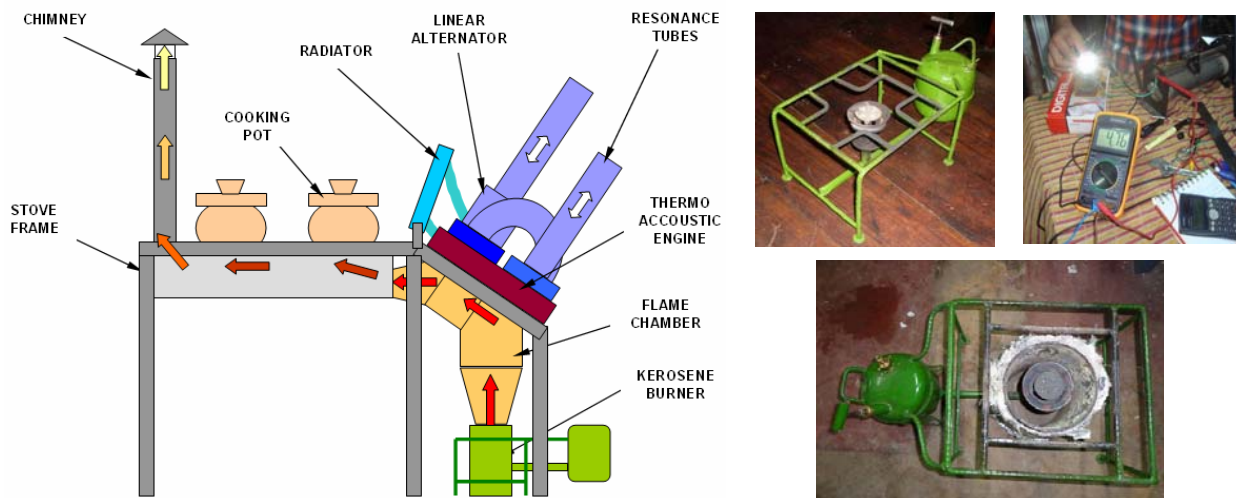


Fig. 3. Score-Stove schematic showing components and flow path of flue gas and typical(top) and modified(bottom) kerosene burner on the right.

To generate the travelling wave, a closed loop of PVC pipes was used with several joints, as shown on the right of Fig 4. For trials outside the laboratory, a car radiator was used for cooling the AHX in a closed loop that used the thermo-siphon effect to circulate the water and natural air convection to cool the radiator and alternatively continuous flow from the mains water for experimental work. A loudspeaker used in reverse converts acoustic energy into electrical energy. Fig 3 shows the schematic diagram of the two frames and a more detailed description of the TAE operation can be found in this reference [25].

For the kerosene option, testing showed that although the flame temperature is almost 1000°C at the burner, the temperature quickly drops as the flame moves away from the burner core due to excess air ingress around the burner; hence the flame burns with a lean air-fuel ratio giving good clean combustion but lower flame temperature. For correct operation the HHX needs to be over 700°C to start thermoacoustic resonance.

A number of options were tried to reduce the excess air and finally a cylindrical replaceable metal shielding with insulation on the outer side as the simplest modification for controlling excess air flow was incorporated. Use of the shield reduced excess air flow and raised the flue gas temperature to the required level. Fig 3 shows a normal kerosene stove on the right at the top and the modified kerosene stove with cylindrical shield at the bottom. The wood option was similar to the kerosene option, but with a BUET designed combustion chamber in place of the kerosene burner, as shown on the left of Fig 4.



Fig. 4. In the wood burning version of Score-Stove (left) the kerosene burner (right) is replaced by a wood burning section.

5. Laboratory testing

Stove performance was tested during typical water boiling tests (WBT) and the heat input rate was calculated from the gravimetric measurement of the fuel consumption rate and the lower heating value. Temperatures of the flue gas, TAE HHX and AHX were recorded using K-type thermocouples and a National Instruments compact data acquisition system. Mass flow rate and temperatures of the cooling water and the exhaust leaving the chimney were recorded to estimate the heat losses. The electric power voltage and current produced from the linear actuator was measured using a watt-metre with either LED lights or a variable resistance as a load in order to check the sensitivity at different loads (fig 3 right top). The major parameters recorded during the laboratory water boiling test are given in Table 1. Field trials later demonstrated the Score-Stove in a number of locations in rural Bangladesh.

Table 1. Performance parameters of Score-Stove in a WBT test

Test Type	WBT
Parameters	Result
Amount of water	2 kg water in each of two pots
Temperature	From 26°C room temperature to 80°C
Fuel	Kerosene
Resonance initiation (onset)	11 min 17 seconds after start-up, Frequency: 64 Hz
Power output	About 3.5 watts (lighting 2 LED lamps)
Maximum current	0.7 Amp at 5 volts
Fuel consumed	0.36 Lit/hr
Temp of TAE hot-end	700°C
Temp at exhaust	175°C
Exhaust condition	clear exhaust, almost invisible

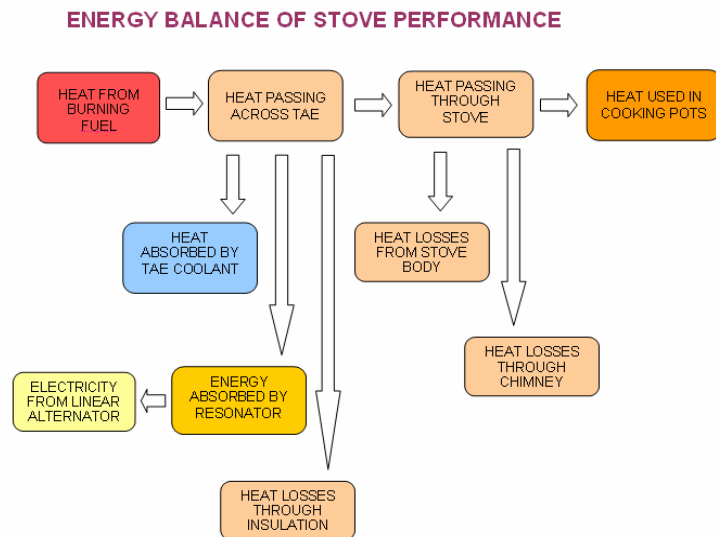


Fig. 5. Flow diagram of heat balance components

For the WBT, two identical water pots each filled with 2 litres of water were placed on the stove. Resonance started after about 11 minutes of heating at about 64 Hz and the lights came on within 12 minutes. The first pot reached a temperature of 80°C after about 39 minutes, while the water in the second pot reached 64°C. It took 15 minutes more to get another pot of hot water at 80°C if the preheated water of the second pot was used to replace the water in the first pot. The burner was needed to be kept on, for the whole time. Resonance and lights would keep on for about 3 minutes when the burner is extinguished due to thermal storage in the system. During testing a number of issues were found that need to be addressed:

- TAE performance was robust as long the air in the resonance tubes was well sealed
- Heat was lost through the stove body (despite the insulation) and it reached about 60°C before stabilising
- The heating rate of the burner was found to vary from run to run, within an order of $\pm 10\%$. Variation of vapour pressure with tank body temperature and poor piston finishing were mainly responsible for such variations
- With the pressurised kerosene burner, reduced air flow increased the flame temperature (to make the TAE more efficient) caused more heat to be conducted to the fuel pipe which increased kerosene temperature. This resulted in gradual overheating and excessive vaporisation of the fuel limiting continuous safe use of the Score-Stove to two hours after which there is risk of fire hazard from fuel escaping due to excessive vapour pressure. In WBT laboratory experiments the fuel tank temperature was monitored to avoid risk of fire hazard and cooking with the Score-Stove. Restricting the air flow also increased the pollution created from combustion in the burner.
- In the interest of safety, excess air needs to be used to ensure that the kerosene is kept to a safe operating temperature. However, this reduces TAE efficiency, electrical output and the amount of heat transferred to the cooking pots.

6. Energy analysis and performance evaluation

Being a heat engine the Score-Stove TAE is limited by the second law of thermodynamics and Carnot's law so TAE efficiency is a function of the temperature difference between HHX and AHX. Fig 5 shows heat flows of the stove under test and Table 2 shows the component shares of energy distribution during a WBT test.

It was noted that the total energy requirements for boiling in the Score-Stove was higher (for about 39 mins) compared to boiling the same pot of water directly using the conventional pressurised kerosene burner (typically for about 10 mins). This is because in the conventional stove the flame directly comes in contact to the pot and the temperature difference across the water in the pot and the flames are higher which facilitated a greater rate of heat transfer and faster heating. In the case of Score-Stove, the flame from the burner first passes by the TAE and then reaches the boiling pots in sequence, which reduces flame temperature thus reducing the temperature gradient and the rate of heat transfer. In the unit tested, waste heat from the AHX is vented to atmosphere and so is not doing useful work.

Higher flame temperatures would have been achieved by restricting the air flow and keeping combustion closer to stoichiometric conditions (less excess air). However, laboratory experiments showed that this higher flame temperature caused gradual overheating of the fuel tank as more heat started to be conducted through the metallic fuel line up to the burner. This increased the vaporisation of kerosene fuel, which increased the fire risk significantly and so was considered unsafe for field trials. The problem also could be solved by reorienting the fuel tank and connecting it with a non-metallic high-temperature withstanding pressure hose. However this would compromise the simplicity of the present design and convenience of directly plugging in the very popular pressurised kerosene stove. So in practice with the common pressurised kerosene burner design there is limitation regarding increasing of flame temperature hence the heat transfer rate decreases causing longer time requirement of the Score-Stove for performing the WBT.

Table 2: Energy Distribution of Score-Stove, first WBT run up to 80°C in Pots after 39 min

INPUT ENERGY COMPONENT	Value
Fuel consumption @ 26°C room	0.194 kg
Assumed Burning efficiency	95%
Input heating Rate	3325W
Total Energy during WBT (100%)	7780 kJ

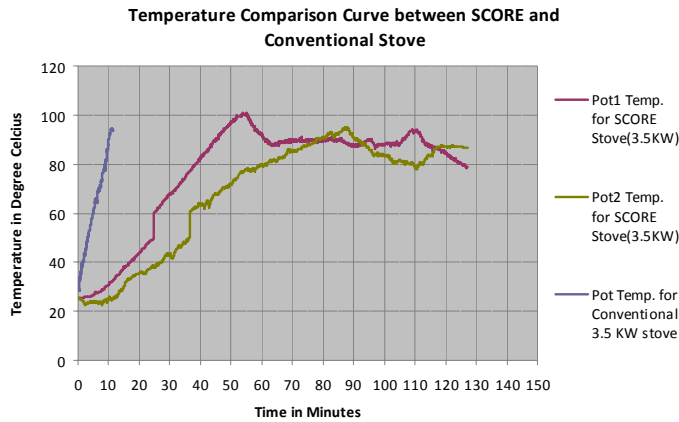


Fig. 6. Thermal lag of heating water in SCORE-Stove compared to conventional stoves.

ENERGY CONSUMPTION	kJ	Share
Pot-1 (conv. 80°C + evap, 50 mg)	565	11.4%
Pot-2 (conv. 64°C + evap, 0 mg)	319	11.4%
Heat absorbed by Cooling Water	1297	16.7%
Heat lost from Exhaust Gases	986	12.7%
Heat loss from Cooking Pot	140	1.8%
Heat loss from Hot Stove surface	1193	15.3%
Heat loss from Chimney surface (open)	387	5%
Radiation loss from Exposed Flame	790	10.2%
Heat absorbed by ~ 90kg Metallic Mass	1377	17.7%
Energy as sound (estimated) Considering 5% alternator efficiency	180	2.3%
Unaccounted Energy losses	555	7.2 %

Table-3: Typical Emission Characteristics from Score-Stove using two fuels

	Kerosene Burner	Wood Burner
Excess Air %	127	23
Flame Temperature °C	900	900
Hot Heat Exch. Surface Temp °C	580	550
Exhaust Temp at Chimney Exit °C	150	122
CO ppm	138	1997
CO ₂ %	6.8	12.6
CO/CO ₂ ratio	0.002	0.262
Remaining Oxygen %	11.7	3.9

Fig 6 shows the time lag of heating water in the Score-Stove compared to the conventional pressurised kerosene stove. Increasing the insulation to improve the heat transfer was tried, and delayed the heat losses. However, eventually the kerosene tank ended up in similar thermal conditions, with very little effect on fuel consumption.

In addition to the WBT cooking was performed; eggs were boiled and vegetables and rice cooked. The food tasted as usual and enough lighting was generated for cooking. Tests were also carried out with a specially designed wood burner replacing kerosene. The smoke was channelled out of the kitchen through a 50mm diameter chimney, ensuring a much healthier atmosphere inside the kitchen. Back pressure from chimney piping was small and natural convection easily exhausted the hot smoke. Updraft created in the chimney assisted the combustion process and enabled healthy cooking conditions compared to conventional stoves. Table 3 shows some comparison of emission measurements from test runs with pressurised kerosene and wood burners.

7. Areas for future research and development

The Score-Stove demonstrated a new way of producing electricity from waste heat, especially from heat lost during cooking. The following describe future work to overcome the limitations described in section 5 and 6:

- The requirements are that cooking time with electrical generation should be the same or better than the time of a conventional stove with the same fuel flow. Fig 6 shows that a 4-5 times improvement is required to achieve the target. This could be achieved by:
 - Decreasing excess air from 127% to 30%, giving a target improvement of 2 times in heat transfer. (This will require a different kerosene/burner arrangement to ensure overall safety.)
 - Utilising the waste heat from the TAE to part heat the water. Target improvement of 2 times.
 - Improved insulation and heat transfer to the pot to bring the overall improvement to target.
 - Alternatives are to redirect the hot gasses so that cooking or electrical generation can take priority.
- After a few test runs some condensation of water vapour was found to be occurring in the resonance tubes. Gradually some of this water vapour gets absorbed in the diaphragm of the linear actuator, dampens it and significantly reduces electrical power from the linear alternator on the next run. The problem was minimised by passing hot air through the resonance tube assembly for a while before each test run. This phenomenon was observed to some degree both in rainy and dry seasons, while the moisture content of ambient air varies significantly. Experience from other Score Centres has shown that this can be caused by sporadic leakage from the secondary AHX into the thermo-acoustic path. This happens under certain temperature profiles when the water pressure is higher than the acoustic gas pressure. Their solution will be applied in future.
- For most of the end-users the current space required by the Score-Stove is still too large. Closer integration of the TAE with the hobs could reduce the overall size as would coiling the resonant stubs. It is not recommended to use flexible corrugated tubes for the resonance air to allow reducing dimensional requirements as this will severely reduce TAE performance and may lead to no resonance at all.
- The TAE core has been designed to withstand 3 to 4 bar gauge pressure and plastic pipes are available up to 16 bar rating at 25°C (They need de-rating for higher temperatures). After suitable pressure compliance testing at an acceptable safety factor, TAE pressure could be increased which will improve electrical output and system efficiency.

8. Conclusion

The Score-Stove provides a unique solution using thermoacoustic technology regarding the use of waste heat during cooking and the potential to produce small-scale electricity, especially for the people who do not have the access to mains electricity. The Score-Stove can use multiple fuels and also provides a healthier cooking environment for the people who use wood and biomass fuels.

The current design is acceptable for limited field trials to obtain end-user feedback. However, performance is lower than that required so expectations should be set accordingly.

Further adaptations are required to improve performance and ensure safety under typical end use. This is a rich area for further research and development and provided the changes give sufficient improvement, the Score-Stove has the potential to make an impact on the target users.

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Electrodeposition and Characterization of Copper Oxide Thin Films for Solar Cell Applications

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Kazi Md. Shorowordi (Bangladesh)*

Abstract

Copper oxide thin films are being considered in thin film solar cells for its unique photovoltaic properties. Electrodeposition is one of the cheapest processes to deposit copper oxide thin films. In this study, copper oxide was electrodeposited on the copper substrate and gold plated glass substrate in an electrolyte bath containing 0.2M CuSO₄·5H₂O, 3M lactic acid and NaOH. A potentiostat/galvanostat with silver chloride electrode (Ag/AgCl) as a reference electrode was used for electrodeposition. During deposition, the bath temperature and pH were maintained 60°C and 12-12.5 respectively. Copper oxide was deposited at different potentials and deposition time. The films deposited at different electrodeposition conditions were characterized by Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS). The optical band gap was determined from the films deposited on gold plated glass substrate using Ultraviolet-Visible Spectroscopy. From visual inspection it was found that copper oxide film was black and adherent on copper substrate. In gold coated glass substrate copper oxide film was also black but bonding between the substrate and copper oxide film was not so strong. The SEM study reveal that the films become more compact and grain sizes of copper oxide films decreases at more negative potentials in deposition potential range. EDS analysis shows that percentage of oxygen in the copper oxide films increases with more negative potentials at the deposition potential range. It was found that with increase of time more adherent and uniform film thickness occurs. The variation of the thickness of copper oxide films with different deposition parameters was analyzed. The optical band gap which represents the optical properties is also correlated with the deposition parameters

Keywords: Copper oxide, Electrodeposition, Solar cell, Optical band gap



6th BSME International Conference on Thermal Engineering (ICTE 2014)

Biofuel: An Australian Perspective in Abating the Fossil Fuel Vulnerability

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Abstract

The fossil fuels are now considered as one of the most environmentally unsustainable energy resources though they are the major energy source for transport sectors and other industries. Increased demand of fuel consumption can lead to the threat of energy supply instability and the consequences of energy uses and emission on both environment and economy are significant concerns of most of the countries. This article reviews the vulnerability of Australian fuel supply chain and a brief description on how biofuels can turn into significant alternative resources of fossil fuel. It has been observed that the prospective applications of biofuel can assist in abating both the greenhouse gas (GHG) emissions and fossil fuel vulnerabilities. Currently, Australia imports about 37% of the total crude oil demand managing a diverse supply chain system. The local refining capacities are not utilized properly. No more technically advanced projects are under consideration to achieve self-sufficiency to make the best use of domestic crudes in order to reduce the fuel imports. Though Australia possesses abundant facility of producing nonedible biofuel feedstocks, high costs for feedstock processing has caused shut down of 68% of the existing biofuel refineries. But, biofuels can reduce over 60% of the GHG emissions caused by the same amount of fossil fuels. Though the Government has granted an excise of flat tax on biofuels until 2021 to promote the commercial growth in this sector, the lack of infrastructure investment from the Government has been slowed the progress of this industry since its inception. Establishment of regional biofuels refineries can reduce both the distribution transport cost and import load of the fossil fuels. Being alternative resources, biofuel production can effectively make the best use of deserted or unused lands, creating employment opportunities and reducing both fossil fuel market instability and environment pollutions.

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Keywords: Biofuel; Fuel Policy; Alternative Fuel; GHG Emission; Fossil Fuel; Low Carbon Emission; Clean Energy Regulation

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1. Introduction

Sustainable biofuels can contribute to the substantial reductions of emissions from transport sectors. They can also play a significant role to convert this sector as a low carbon emission economy. At present, about 5% of the total fuel consumption is contributed by various alternative fuels like biodiesel, bioethanol, gaseous fuels, etc. to the Australian transport sector [1]. Despite of its own production capacity, Australian domestic petroleum market has been inclining towards import of refined petroleum products increasing about threefold within the last decade [2], the vulnerability of supply chain management is aggregating [3-6]. Figure 1 shows the petroleum product supply chain management system of Australia from year 2000 to 2013 where the dependency on imported petroleum products is surely dragging the nation's fuel security into assailable state [7]. The reasons are, shut down of existing refineries and the incapability of refining crude oil as per the domestic fuel standard [8].

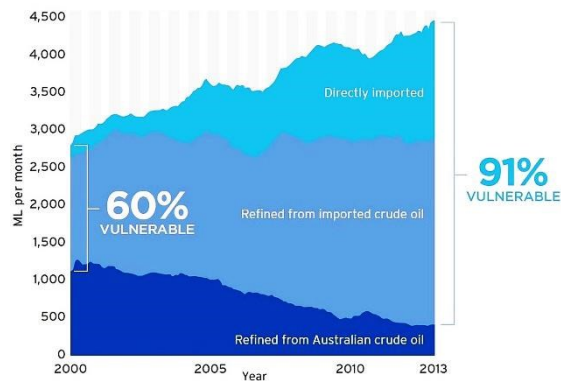


Fig. 1. Vulnerability of Australian Fuel Supply Chain [8]

There is always a threat of declining the overall fossil fuel reserve in worldwide due to increased consumption worldwide and political unrest in the oil producing regions. According to the National Energy Security Assessment (NESA) conducted in the year 2011, the overall domestic fossil fuel security rank will downgrade from high till 2016 in to moderate rank in the year 2035 [9]. That means, there will be some deterring issues which should be resolved prior to meet the local socio-economic requirement in order to sustain on the higher level of energy security. Other than the fossil fuels, there are several alternative resources like electricity, compressed natural gas, Gas-To-Liquid, Liquefied Petroleum Gases, bio-oil, bioethanol and biodiesel, etc. which can be potentially effective in Australia's renewable energy quest due to availability of those feedstocks. It requires developing the market demand of those alternative fuels as a suitable alternative for the vehicles and resolving some other barriers like taxation, regional feedstock production and fuel refining capacity development, etc. Certain effective and time frame based actions to be implemented to develop the biofuel policy in this country so that the feedstock of the respective biofuel can be produced, converted in to crude oil, refining from regional refineries and distributed to meet the demand and environment sustainability issues.

Due to increased population, the overall fuel consumption is increasing with the increased number of vehicle and industrial expansion like electricity generation. Therefore, cost of the fuel is increasing and Australia is facing trading imbalance which has been reported as more than AUD 20 billion [10]. This is evidently an unsustainable supply chain management system and economic burden to the consumers. Biofuel can be a potential source of coping with the local fuel supply deficiency and improve the environment as these are proven clean and renewable fuels. The feedstocks are mainly obtained from agricultural farming or forests. They can be either edible or nonedible, first generation or second generation, etc. based on the feedstocks and technical investigations to avoid any involvement in food vs fuel issues. Though the first generation biofuels, generated from various edible vegetable oils, sugar and starch around the world, differs from the second generation biofuels in terms of sustainability but can be used if demands of food based feedstocks are less than that of total production. Establishment of deep-rooted and nonedible feedstock farming in saline and degraded lands due to mining leftover, grazed and coastal lands can potentially improve the ecological condition and environment by reducing the GHG

emission [11]. To set up a reliable fuel supply market and protect the environment from GHG pollution, a substantial policy implementation and development of biofuel market is essential.

This paper has focused on the requirement of effective policy and framework development to meet the nation's fossil fuel demand for energy production in transport and industrial sectors. Biofuel has been found as potential in this regard which can abate the supply chain management instability created due to fossil fuel reserve attenuation threat in few decades around the world. There is a potential of creating biofuel based industry in this country considering as environment friendly and leading to national economic growth by reducing import load of fossil fuels, GHG emission, unemployment rate, unused and deserted lands, and sudden hike of fuel price due to fossil fuel supply interruption in the world as demanded by Australian market. Such investigation could be beneficial for other countries which are not producing enough fossil fuel for themselves.

2. Fossil Fuel and Refining Vulnerability in Australia

According to the table 1 [4], in 2012-2013, total consumption of Petroleum was 55,083.5ML. Diesel fuel consumption accounted around 40% in the transport sector. Net import was about 37% of total petroleum consumption, whereas, this country exported 75% of its own crude oil produced [12]. Conventional petroleum fuels provided 95% of liquid fuel demand and met about 34% of total energy consumed [4, 13]. Whereas, Natural gas and coal combinedly met about 60% and biomass met 3% of the total energy demand [14].

Table 1. Total gasoline and diesel fuel statistics of Australia between 2010 and 2013 fiscal year

Year	Crude oil & other refinery products (ML)		Automotive gasoline (ML)		Diesel (ML)		Total automotive diesel sales (ML)	Total automotive gasoline sales (ML)	Total petroleum product sales (ML)
	Import	Export	Import	Production	Import	Production			
2012-2013	29519.80	15761.4	3653.1	15602.8	12512.1	12875.6	22618.1	18658.7	55083.5
2011-2012	29494.5	17423.9	3671.1	15573	11224.9	12658.3	21642.6	18761.6	53961.8
2010-2011	31765.5	19619.6	2652.8	16642.8	8832.4	12858.7	20053.9	18725.2	52409.8

Most of the Australian crudes are light, sweet grade, typically low in sulfur and wax, and therefore higher in value than the heavier crudes [14]. Among those the Carnarvon Basin of Northwest Australia accounts for 72% of total Australian petroleum production. Most of this bounty is exported due to the lack of existing refining capacity, the proximity to Asian markets and the ability to demand premium prices for the light, sweet grade of oil produced. Subsequently, the country's North and Northwest regions completely rely on imports of refined liquid fuel products for domestic uses. The amount of total crude refining capacity has been declining for last decade in Australia due to failure in competing with the newer, more efficient, diversified and larger Asian refineries. It is only 17% of the domestically produced crude which is sent to the local refineries. But it was almost 37% a decade ago [7]. Though the domestic refineries are still producing about half of the fuels consumed, the remainder crude being imported covers the refinery input. A large portion of fossil fuels are being imported as refined as well. It has been already presented through figure 1 that the vulnerability of fuel supplying capacity has been increasing day by day in Australia. Moreover, once few more refinery closures are complete by mid-2015, Australia will be left with only four refineries, equating to a reduction in domestic refining capacity of 42% since 2011. Any further rationalisation of domestic refinery capacity will further increase the proportion of refined products sourced from.

The declining trends of refining facilities in Australian refineries will have impact on increased load on liquid fuel import, complications on defence and aviation sectors due to risk of noncompliance from foreign refineries, increased price of refinery by-products which are mostly necessary for other petrochemical industries, etc. despite the capacity of developing more refineries as compliant to the local crude oils. In this way, the world's 9th largest energy producing country, Australia may find itself in a situation like no refineries, a liquid fuel stock of only 20 days and complete dependency on import by 2030 though there is a diversified market based supply chain

management system has been strengthen the confidence of handling any market vulnerability [5, 6, 12, 15]. Therefore, any critical disruption in the foreign supply market will just lead to a run out of publicly consumed fuels within three days.

As long as the domestic refineries are capable, there may be a good relationship with outside refineries. This condition could be changed when there is peak demand of fuels for harvesting and defence uses as Australia is not meeting the obligatory reserve maintenance of at least 90 days equivalent net average fuel import of the prior year or equivalent produced crude oil [13]. As an instance of supply chain vulnerability, there was a scarcity of diesel supply for harvest season in the North-Western Victoria after 2 days of Geelong's refinery operation disruption due to an incident in 2012 [5]. When there is a capacity of producing own crude oil, the technology advancement should get priority to overcome local issues than to overlook it depending on outsourcing. This dependency increases vulnerability in the country's development issues. There is a potential of entrenching into higher crude oil production when the newly developed wells will reach into their peak production capacities. The unavailability of own refineries will be a disadvantage then. Also, lot of uncertainties will arise which may recede the potential exploration of new oil sources, profitable commercialization, and finding other technologies to use the unconventional sources like light tight oil, shale oil, Gas-to-liquid, Coal-to-liquid, bio-oil, etc. which are totally/partially dependent on petroleum refining processes.

Hence, the Australian Government should seek for enhancing the local fuel resourcing to meet any peak demand on transport sector, defence system and harvesting purposes. Table 2 shows the current status of transport fuel stocks in Australia. Australia is still not maintaining the overall stock of crude oil/petroleum for 90 days and the growing demand of consumption may make it harder to deal with it on the basis of refined fuel import process. Moreover, the International Energy Agency (IEA) has projected that the new policy (existing commitments to achieve any target) will require about 35% increase of world primary energy demand by 2035, whereas, Australian liquid fuel demand will rise up to 56.3 GL (about 2.2% more than that of 2012-2013) with reduced locally produced fuel supply [16, 17]. Among total demand of required energy, 59% would be met by fossil fuels and 17.8% by the renewable energy that urges new policy implementation in Australian energy market.

Table 2. Overall Petroleum stocks in Australia in end of months of recent years [16, 17]

Time period	Crude oil and refinery feedstocks (days)	Automotive Gasoline (days)	Aviation Gasoline (days)	Automotive Diesel (days)
May, 2014	26	20	126	13
April, 2014	25	20	132	13
March, 2014	26	20	129	15
February, 2014	22	18	104	14
January, 2014	23	19	141	19
2012-2013	25	19	88	17
2011-2012	25	19	88	18
2010-2011	29	18	104	17

3. Improving Liquid Fuel Security in Australia

With the existing technology in Australia, it is tough to attain 100% energy independence. Also it will not be technically acceptable to be 100% reliable on foreign supplies of refined fuels. Implementation of long term plans and optimizing the refining capacity as per both the produced crude oil quality and emission standards can help protecting the environment pollution and reduce the supply chain vulnerability. Therefore, the import load will not increase with the increased demand of consumptions over the years. Also, the emergency response mechanism of IEA can be beneficial for Australia to meet the temporary supply interruption of large amount of fuel [9]. As an additional issue, due to excessive utilization of fossil fuels for energy supply without significant consumption controlling, the energy based GHG emissions could be more than twice by 2050. Therefore, there is an urge from IEA to contrive attainable and effective technologies as per requirement to reach up to a global CO₂ emission target of reducing 50% by 2050 from the current emission levels [18]. Thus the world would be protected from global warming due to severe GHG emissions [18]. Australia is to cut its GHG emission by 60% by 2020 as per Kyoto

Protocol [19]. Moreover, based on energy content, coal accounts 60% of energy exported from Australia [16]. Also two-third of the electricity production in Australia is dependent upon coal burning. Target of environment pollution reduction policy could affect the export based earning as well as inland consumption. Moreover, economic consumption of the customers and adaptation of alternative energy sources have provoked the price increase (59% since 2009) of per unit electricity uses in order to cover the profit and infrastructure costs [16].

There are many potential renewable and alternative energy resources (solar, wind, natural gas, hydro, geothermal, shale oil, bioenergy, etc.) which are available in this country to meet energy consumption in transport and power productions. Alternative fuels like biofuel can be abundantly produced in this country from local resources. This can reduce the CO₂ emission level caused by the fossil fuel consumption [20]. There are still scopes of conducting effective research on the viability of producing and supplying standardized biofuels as per consumers' demand. Also the risk assessment and mitigation strategies related to both import based supply chain system and domestically produced alternative fuels need to be conducted to overcome any future trouble [5]. Australian Government has taken few initiatives to increase the use of biofuels. For instance, using B5 (i.e. 5% biodiesel blended with diesel) and E10 (10% Ethanol blended with petrol) have been approved for commercial use according to the Australian national fuel standards [21, 22]. Further research and effective supply chain management system can increase the total biofuel consumption. The Australian biofuels market is currently in the development stage with the government and private entities engaging in promotion of the technology across the country [23]. Significant investment and subsidies may establish the market of local fuel supply system which is renewable and cost competitive in comparison to the import cost of that amount of fossil fuel and the price of CO₂ emission.

4. Biofuels in Australia

Evolution of biofuels (i.e. bioethanol and biodiesel) in Australia could be a potential source of supporting the green energy producing quest for improvement of environment, development of national economy, technical advancement and quality life in the society. Biofuel consumption in Australia has been increasing since 2003-04 and with significant support it may contribute in a good share of nation's total fuel consumption in near future.

4.1. Bioethanol

In Australia, E10, 10% ethanol blend with unleaded or premium unleaded petrol can be commercially available to use in petrol engines satisfactorily. Therefore, the energy content of the petrol is reduced by 3% but represents an excise facility of 4 cents per liter [24]. Also it can be detrimental to the older engines occurring the clogging of fuel filter due to solvent properties of ethanol. Ethanol produced from cellulosic materials is highly suitable to abate the GHG emission and food-vs-fuel issues. As per the report from Biofuels Association of Australia [25], total production capacity of ethanol is about 440 ML (0.44 GL) and all are in production. Mainly, the Red Sorghum (80 ML), Waste Starch (300 ML) and Molasses of sugar processing byproduct (60 ML) are the feedstocks contributing this ethanol production. It has been predicted that the demand of petrol (gasoline) will almost remain steady between 18 GL and 19 GL in 2030 [26]. Hence, there is a requirement of increasing the production of ethanol by 5 times of the recent status for an overall input of E10 fuel blend in the consumer market. Analysing the economic production process of feedstocks will be a prime focus to chase this target as the quality of feedstock governs the quality of the ethanol production as well as the blend quality. Due to abundant forest resourcing and land availability, Australian ethanol production quest can be accelerated with the lingo-cellulosic biomass or green wastes feedstock and corresponding efficient technical implementation for optimal output. The local production cost of ethanol is less than that of imported ethanol due to subsidy on fuel excise duty. Such facility should be given to endorse this potential industry. A detail status of biofuel production from ethanol in Australia has been discussed in Puri et al. [23].

Not only Australia is paying attention to develop the ethanol production infrastructure, there are many other countries which have already focused on increasing production of ethanol to cope with the fossil fuel demand, supply vulnerability and environment sustainability. Both USA and Brazil are in global leadership of producing bioethanol from corn, lingo-cellulosic crops and sugarcane, etc. without making food-vs-fuel contradiction. Table 3

[27] demonstrates that production of ethanol in USA has been doubled within 2007-2013 [28]. These countries have also exported more than 6% of the total production. They have shown that the increase of ethanol production enhanced the value of the agro-products and investment for technological development [29].

Table 3. Ethanol Production in Various Countries [27]

World Fuel Ethanol Production by Country or Region from 2007-2013 (Million Gallons)							
Country	2007	2008	2009	2010	2011	2012	2013
USA	6521.00	9309.00	10938.00	13298.00	13948.00	13300.00	13300.00
Brazil	5019.20	6472.20	6578.00	6921.54	5573.24	5577.00	6267.00
Europe	570.30	733.60	1040.00	1208.58	1167.64	1179.00	1371.00
China	486.00	501.90	542.00	541.55	554.76	555.00	696.00
Canada	211.30	237.70	291.00	356.63	462.30	449.00	523.00
Australia	26.40	26.40	56.80	66.04	87.20	71.00	116.23
Rest of World	288.90	363.00	857.00	918.57	610.95	681.00	1272.00
World	13123.10	17643.80	20302.80	23310.91	22404.09	21812.00	23545.23

To gain such developed market stability, there was a substantial support from Government from 1997-2006 (\$9 billion) to keep the corn prices lower than the production expenditure. By that period the bioethanol established its market and farmers/producers could earn the money of total expenditure from the consumer markets than no relying on the Government's financial assistance which reduced to \$2 billion in 2013. Detail techno-economic steps and success statistics can be obtained from the 2014 ethanol industry outlook [30]. Since 2005, USA have been reducing their import load (-20% of earlier level) of fossil fuel and increasing the production of biofuel to meet the gap of total energy requirement at present (Fig. 2). The long term effective plan of reducing foreign dependency has shown growth in job field creation, contributing to the GDP and increasing the household incomes.

On the other hand, Australia, in spite of being one of the top 10 energy producing countries, it is going to increase its import load and trade gaps to avoid the infrastructure investment cost needed to establish self-sufficient biofuel market. The economic reports and the contrived policies have been showing more profits through short term plans than achieving the self-sufficiency. Comprehensive technical analysis and long term plan are required to regain a momentum of increasing self-sufficiency from both fossil fuels and alternative resources. Implementation of E10 bioethanol in overall gasoline consumption demand in Australia will be requiring about 1.9GL of bioethanol production. So, the business development policy taken by USA may turn in to a guide line for Australian renewable fuel market development by 2030 if any effective long term investment infrastructure can be deployed.

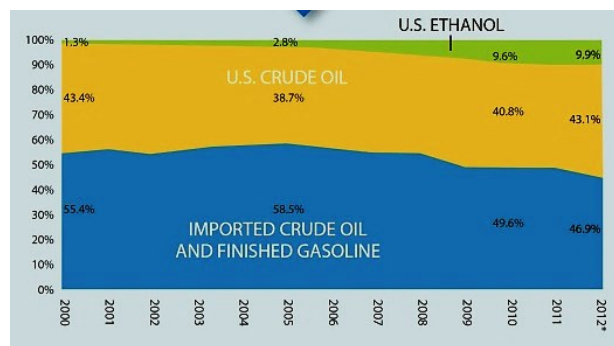


Fig. 2. Fuel supply chain management of USA

4.2. Biodiesel

Biodiesel is mainly a mixture of methyl or ethyl ester of fatty acids which are obtained through the transesterification of vegetable oil/animal fat based triglycerides following some controlled chemical processes [31–38]. This is also known as cleanest renewable fuels that can be used mainly in the diesel engines. The fuel properties of biodiesels are almost similar to the diesel fuel following the ASTM D6751-09 standard and can be blended with it in any proportion [39–41]. Direct use of 100% biodiesel in an unmodified diesel engine is discouraged due to some variation in inherent properties of biodiesel fuels with diesel fuel [42]. But various diesel-biodiesel blends can be used which improves the emission performance of the fuel. Australian transport sector is almost solely dependent on liquid fuel consumption. In Australia, 5% blend of biodiesel with diesel fuel (B5) has been approved to be sold in commercial outlets without any mandatory labelling [43, 44]. With this option, 5% of overall diesel fuel consumption could be replaced by 0.95 GL of biodiesel in 2012–2013. This requirement is also increasing with the increased demand of diesel consumption. But the current production capacity is just insufficient to supply this amount of biodiesel in the market [11, 16, 45]. Moreover, the *Commonwealth Scientific and Industrial Research Organisation* (CSIRO) investigation has revealed that the B26 also can conform to the petroleum quality [43], whereas, a taskforce of the Australian Government has described that the B20 would not have any detrimental effect on engine [22]. It necessitates more research and explorations on suitability of optimal biodiesel blend quantity to be used commercially in Australian states and territories.

One liter diesel fuel can produce about 2.67kg of CO₂ and that of one litre biodiesel can reduce the net CO₂ emission by 67.7% (~1.8kg) [45, 46]. Therefore, the supply assurance of higher blends of biodiesel in Australian diesel fuel market can substantially reduce a lot of CO₂ emission.

Indeed, in terms of production capacity, there is no limitation of land availability in Australia to produce the required amount of biodiesel. Rather, there are some misconceptions that recede in developing a convenient biofuel policy in this country [1, 8, 12, 22, 47]. At present, Australia has a total installation capacity of 360 ML for biodiesel production but only 115 ML biodiesel is commercially produced from the tallow and waste cooking oil [25].

Batten and O'Connell [48] as well as RACQ [43] have referred that B5 blend of canola, waste cooking oil and the tallow based biodiesels can reduce GHG emission by 1.5%, 4.2% and 1.5% and for B20 blends, the GHG emission reduced by 7.6%, 19.3% and 8.7% respectively in comparison to the ultra-low sulfur diesel. The feasibility of commercially utilizing the higher biodiesel blends can significantly contribute to Australian resolution of reducing GHG emission by 60% as per Kyoto protocol within next 6 years [19]. The transport sector consumes most of the share of overall liquid fuels. Thus improving the quality of the fossil fuels by blending with biodiesels can reduce the import load and environment pollution. Therefore, technical investigations on commercializing higher amount of biodiesel blends could be one of the essential targets to increase the supply of biodiesel in the local market to lessen the fossil fuel vulnerability.

Moreover, the Government has granted a fixed tax excise subsidy to cope up with the initial investment cost and market creation phase until 2021 [Energy White paper 2012]. With abundant amount of deserted, grazed, coastal and mined land, it is essential to find out some oil rich and nonedible vegetable oil based plants which would grow in those lands. Ashwath [11] observed about 200 species of vegetable oil based plants for potential use as biodiesel feedstock and he found few feedstocks containing higher amount of oil and conversion rates. He proposed that the feedstocks like *Pongamia pinnata* (Karanja), *Calophyllum inophyllum* (beauty leaf tree), *Cocos nucifera* (coconut), *Syagrus romanzoffiana* (Queen palm), *Aleurites moluccana* (candle nut tree) and *Jagera pseudorhus* (jagera) can be readily grow in Australia to yield higher amount of oil for biodiesel production. There is a requirement of conducting detail analysis for provenance variations in various characteristics of these feedstocks to be considered as good source of biodiesel production. Due to excessive dependence on diversified international fuel market for energy security, both Government and private sectors failed to pay attention in developing biodiesel fuel market as per demand to be created. Moreover, few biodiesel refinery plants have been shut down due to discouragement in development of alternative fuel market. The feedstocks are also dependent on land quality and various environmental factors. Therefore, proper selection of feedstocks can make the business profitable by supplying fuel in the national fuel supply management system.

5. Discussions

As per December quarter of 2013 [4], as a member of the *Organisation for Economic Co-operation and Development* (OECD) countries, Australian Government earned 52.5 cents/liter and 51.5 cents/liter from selling of automotive diesel fuel and gasoline fuel respectively to the consumers. This is about 50% of the fuel price that covers all other expenses including production, refining, transportations and the profit of all the levels who bring it from well to the customers' engines. In the same time, Mexico and USA Governments earned 13.6 and 15.1 cents/liter respectively in Australian currency. The fuel price did not vary as much as the tax varied. Though the customers of this country are paying the price as it require, but the fuel policy and the technical establishment are not improving as it needs to develop the energy production, refining and distribution infrastructure from its own capacity [13]. Instead, the fuel price has to be set according to the international suppliers' policy. Moreover, the energy policy developers in Australia have made a superficial idea that the declining capacity of refineries will not affect the fuel demand in future due to diversified supply chain management with the international market. It infers that the Government will have to increase the price of the fuels if there is any market instability of the exporters and the people will be destined to pay more if there is no subsidy.

Higher operating cost, inadequate rail network and sea network to transport crude oil, shallowness of the berths for which the large crude carriers are unsuitable, increased technological intricacies to refine the locally produced crudes in to standardized petroleum products, etc. have been considered to cease the local refineries and import from outside markets [8, 13]. Such policy cannot build reliable progression of a nation's other interdependent business establishment. It seems the policy makers are totally complacent of showing some money saving in the transition period of essential technical evolution by following a silly term of "cost saving". As Australia is one of the developed countries in the world, it should focus on adopting long term and foreseeable policies to progress and establish its own product based market. It is high time to take plan of actions to build up modern and reliable land based and sea based communication systems for effective commercial purposes, making best use of long coastal areas with the help of convenient sized crude carriers, investing on technical advancement and skill development to cope up with the necessities to provide support local business activities. Otherwise, the increased trade gap is going to create a grievous inflation in the country's economic system.

A local refinery from local raw crude petroleum produces various by products other than gasoline and diesel fuels which are effectively used in various industries like aviation, energy production in the industries, chemical industries for various product development, road construction works, etc. These industries including the refinery expansion can facilitate more local jobs and utilization of skilled people which is now a threat to citizens/residents of this country. Nation's economy is mostly based on mining exploration for skill based job placement. The other industries are still in vulnerable condition due to short term economic analysis and over dependence on foreign suppliers. This dependence is just helping those producer countries to develop further. There is a large share of private investors in existing fuel management system in Australia. Hence, an adjustment cost incentive through primary investment from the government will surely encourage the private sector investors to explore more towards self-sufficient fuel market development.

A developed country should focus on import supply chain management system only after making the optimal use of local capacities and putting effort to deal with the demand gap from potential alternative resources. For instance, the biofuel policy in USA can be a model for other countries who would like to use the import supply chain management to achieve certain development in the alternative fuel development. That is the reason that USA will not face the trouble of fossil fuel scarcity from its exporters after 2035 as the alternative resources will be capable of support substantially (figure 2). If Australian Government targets on local biofuel (B5-B20 by biodiesel and E10 by the bioethanol) production and supply market, there will be a demand of producing about 1.2-4.5GL biodiesel and 1.9GL bioethanol to reduce the fossil fuel load by 15-30% by 2030. At present, only 0.115GL out of 0.360GL biodiesel production capacity is available for production from few feedstocks. Overcoming the techno-economic barriers can contribute significantly in this case. Selection of regional based most economic biofuel feedstocks, refining process and distribution system development, uncertainties in private sector based investment due to higher adjustment cost, consumer level information exchange, lack of infrastructure, etc. are few of the main barriers to adopt and promote biofuel in Australian transport fuel mix [1, 8]. Current excise duty on biodiesel until 30 June, 2021 may potentially contribute to achieve the target of GHG emissions and save AUD1.2 billion within this period.

Moreover, the deserted lands will be utilized economically creating regional work opportunities, reducing fuel transport and distribution loads based on regionally surrounding supply chain system from the commercial outlets. Non edible biofuel feedstocks cultivated in the unused lands will not be a competitor to food. Since the fossil fuel price has been increasing, the price of the commercially available biofuels may receive the appropriate price from customers by 2030 and with technical progress [18]. Information gap with the customers have been making a gap between fuel quality and their using compatibility in the engines.

Besides the evolution and establishment of biofuel based energy industries in Australia, the transport sector will be also depending on hybrid or electrical power based vehicle operation system. Various alternative fuels like GTL (Gas-to-Liquid), CTL (Coal-to-Liquid), LPG (liquefied Petroleum Gas), LNG (liquefied Natural Gas), waste to fuel, etc. can come into the play as a local provider to the fossil fuel demand when the peak oil period will be approaching by 2035. Therefore, diversified fuel development policy with foreseeing technical management and implementation can reduce the net importer vulnerability of fossil fuels in Australia.

Moreover, ceasing domestic refining capacity and depending upon foreign markets will make the industrial investors confused to expand the energy based business in this country. Import of the refinery by products may require more transport costs than the value of the raw materials and overall product cost could be increased.

6. Conclusion

The demand of fossil fuels and other refinery by products will be increasing with the increase of population and required industrial development. Therefore, Government must take steps to invest on long term techno-economic plans than the short term profits. Self-sufficiency with technical evolution to make the best use of domestic assets can reduce the trade gaps. Environment sustainability issues may influence the reduction of coal based export earnings and shut down of power plants. More use of fossil fuel will be responsible for increasing the GHG emissions. Therefore, the bioethanol and biodiesel can potentially contribute about 10-15% and more than 20% respectively of the total liquid fuel demand in the energy sectors. Both the power and transport sectors can utilize these renewable and biodegradable fuels for reducing GHG emission and achieving sustainability. The fuel supply chain management system should facilitate this sector based demands. Australia can depend upon import of fossil fuels and other petroleum by products with the target of achieving self-sufficiency in biofuel production and utilization following the fuel security infrastructure models of USA and Brazil. It has been proved that the non-edible feedstocks can be grown in unused lands giving potential of technology development for small or medium sized fuel processing plants in various regions of the county. Also the quest of technology development to optimize the refining capacity of crudes through government funds can let away the prejudice of surrendering over the establishment of new and efficient refineries in the country. These efforts will help making the best use of lands, people, and money to bring a sustainable national economic condition. Thus, proper and timely endorsement of biofuel industry and its policy can potentially abate the fossil fuel vulnerability in this country.

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Production of Biodiesel Using Alkaline Based Catalysts From Waste Cooking Oil: A Case Study

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Abstract:

Waste cooking oil (WCO) is typically cheaper than diesel so its use as biodiesel can reduce the cost of diesel run operation. Air-conditioned fast food restaurants (FFR) in Bangladesh generate lot of WCO, but due to frequent load shedding they also burn lot of diesel for captive power generation. Recycling part of the waste oils in the form of biodiesel can reduce the need of diesel fuel and increase profitability of the establishment. The techno-economic feasibility of such operation in case of a FFR in Dhaka has been investigated. CH₃OH (methanol) and NaOH (sodium hydroxide, base catalyst) are mostly used in this process because of their lowest costs, higher reaction rates and higher yields. With content of free fatty acids (FFA's) lower than 2.5%, WCO can directly undergo base catalyzed transesterification reaction in order to convert it to biodiesel. The yield for WCO biodiesel production in this study is assumed in the range of 80-90% according to previous research. In addition, the single-stage transesterification (SST) process is the cheapest and the easiest than those of the other different methods. The cost of chemicals will further minimize by recycling of CH₃OH and NaOH in this SST process. The possible CH₃OH and NaOH recoveries are fully depended on the amounts of their uses in the reactions. The best use of methanol in the reactions is either in molar ratio (6:1 or 5:1). In case of 5:1 molar ratio, the possible recovery of CH₃OH (excess methanol) and NaOH is about in the range of 35-40% and 80-90% respectively. It is found from the study that a techno-economic model could be developed with recovery units for minimizing the cost of the production of biodiesel (B5) to run a diesel generator plant successfully with an extra monthly savings equivalent to 4% of the diesel cost for standby power.

Keywords: Waste Cooking Oil; biodiesel; B5; Transesterification; Cost effectiveness; NaOH catalyst; methanol and NaOH recovery



6th BSME International Conference on Thermal Engineering (ICTE 2014)

Thermo-gravimetric and Kinetic Analysis of Different Varieties of Rice Husk

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Abstract

Rice husk is source of renewable biomass and it contributes to supply solid and gaseous fuel through the process of thermo-chemical conversion. A clear understanding is required about the kinetic parameters of rice husk for design and operation of industrial systems. A significant difference is observed in kinetic parameters of rice husk for different varieties which indicates that design parameters for industrial processes of rice husk would be different. © 2015 The Authors. Published by Elsevier Ltd. Peer-review under responsibility of organizing committee of the 6th BSME International Conference on Thermal Engineering (ICTE 2014).

Keywords: Rice husk, Thermogravimetric analysis, Kinetic analysis, Decomposition rate, Activation energy, Frequency factor.

Nomenclature

A	Frequency factor (min^{-1})
DTG	Differential thermogravimetric
E	Activation energy of the decomposition reaction (KJ mol^{-1})
n	Order of reaction
R	Universal gas constant ($\text{kJ mol}^{-1}\text{K}^{-1}$)
T	Absolute temperature (K)
TGA	Thermogravimetric analysis
X	Weight of sample undergoing reaction (kg)

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1. Introduction

There is increasing concern in biomass fuels and raw materials due to the problems associated with environment and climate change. Several efforts have been made for conversion of rice husk into higher value fuels through combustion and/or gasification processes [1-4]. The thermal decomposition reactions are playing an important role during different processes of the biomass utilization. Thermogravimetric analysis (TGA) is a quite precision method for the study of pyrolysis at control heating rates, under well-defined conditions in the kinetic system. It also provides information about the partial processes and reaction kinetics. The thermal degradation patterns of lignocellulosic biomass are strongly affected by their chemical composition such as cellulose, hemicellulose and lignin [5-6]. A physical and thermo-chemical property of rice husk varies depending on the types of variety and geographical location of cultivation of crop. Physical properties such as particle size, moisture content and bulk density are important factors of any biomass. Transportability, flow ability and combustion characteristics are dependent on the physical properties. Physical properties also play an important role to design the energy conversion technologies such as boiler, furnace, gasifier etc. In Bangladesh there exist about 65 modern varieties of rice. The varieties are different in terms of their growing season (January-May, August-November), weather condition, yield productivity (4-9 tonne/hectare), duration of growth phase, grain size (3.9-7.4 millimeter) and aroma etc [7-11]. Chandra [12] and Bridgwater [13] reported that the bulk density of rice husk to be 90-150 kg/m³ and 100 kg/m³, respectively. The physical properties of rice husks show that there is a distinct difference in the linear dimension of husk from variety to variety. These parameters help to plan boiler combustion chamber design. Rice husk can be used as a source of fuel in the rice milling industry or in the thermal power plant through the thermo-chemical conversion technologies suggested by Beagle [1], Kaupp [2], Bridgwater [3] and Boateng et al. [4]. However, adequate knowledge about the physical and thermal properties of different varieties of rice husk pertaining to thermo-chemical conversion processes is deficient. In order to examine the characteristics of few varieties of rice husk related to energy use are investigated in this study.

2. Objective

The main objective of this study is to analyze the kinetic parameters from thermogravimetric data of six varieties of rice husk and to compare the kinetic parameter of one raw rice husk and alkali treated rice husk.

3. Theoretical consideration

The kinetics of thermal decomposition reactions of biomass materials is complicated manner in a sense that there is a large number of reactions simultaneously occurred during decomposition process of these materials. However, TGA provides general information on the overall kinetics of the reaction, rather than individual reactions, it is a tool for providing comparison kinetic data of various reaction parameters such as temperature and heating rate. The advantages TGA usages for determining kinetic parameters are that fewer data from a single sample are required for calculating the kinetic parameters over an entire temperature range in a continuous manner. Kinetic parameters from TG data are determined based on the following Arrhenius rate equation [14-15].

$$\frac{dX}{dt} = -Ae^{-\frac{E}{RT}} X^n \quad (1)$$

Where, X = Weight of sample undergoing reaction (kg)

t = Time (min)

A = Pre-exponential or frequency factor (min⁻¹)

E = Activation energy of the decomposition reaction (kJ mol⁻¹)

R = Universal gas constant (kJ mol⁻¹ K⁻¹)

T = Absolute temperature (K)

n = Order of reaction

Arrhenius equation technique proposed by Goldfarb et al. [16] was used to determine the kinetic parameters from TGA data. The linearized form of the Arrhenius equation was used to determine A, E and n by applying least squares (multiple linear regressions) technique. The simplified form of the linearized rate equation is as follows:

$$y = B + Cx + Dz. \quad (2)$$

The parameters y , x , z , B , C and D are defined as follows:

$$y = \ln \left\{ - \frac{1}{w_0 - w_f} \cdot \frac{dw}{dt} \right\} \quad (3)$$

$$x = \frac{1}{RT} \quad (4)$$

$$z = \ln \left\{ \frac{w - w_f}{w_0 - w_f} \right\} \quad (5)$$

$$B = \ln(A)$$

$$C = -E$$

$$D = n$$

w = weight of sample at time t

w_0 = initial weight of sample

w_f = final weight of sample after decomposition

4. Materials and methods

Six types of rice husk are selected to investigate the characteristics. The types of husk were chosen based on the popularity to the farmers for cultivation and readily availability from the rice mills. The names of the varieties are BR16, BRRIdhan 28 (BR28), BRRIdhan 29 (BR29), BRRIdhan 34 (BR34), BRRIdhan 50 (BR50) and BRRIdhan hybrid rice 3 (Hybrid3). The moisture content of the rice husk is ranged from 9 to 11%, the length of the rice husk varies from 5.45 mm - 9.90 mm. The breadth of the husk varies from 0.67 mm for BR 50 and 2.17 mm for Hybrid 3 variety. The thickness of the husk varies from 0.35 mm for BR 50 to 1.1 mm for Hybrid 3. The bulk density of the husk varies from 88.72 kg/m³ for BR 50 and 123.62 kg/m³ for Hybrid 3 [17].

Thermogravimetric (TG) analysis is an important tool for obtaining weight loss of the biomass sample versus temperature or time. Differential TG (DTG) curve is first derivative of TG curve. TG curve conveys information on thermal behaviour of solid fuels in pyrolytic conditions. While the DTG results highlight the zone of reaction where various reaction steps are taking place over the entire temperature range. Modern thermal analyses suggest that activation energy as the predominant factor in the reactivity equation. Activation energy, essentially, affects the temperature sensitivity of the reaction rate. In TG analysis, the weight of the rice husk sample is determined as a function of time and temperature as it is subjected to a controlled temperature program. TG/DTG analysis is conducted using equipment TG/DTA6300 Exstar6000 at BCSIR, Dhaka. Six rice husk varieties were taken for this analysis. The heating rate was fixed at 20°C/min in nitrogen medium.

5. Results and discussion

5.1. Thermal decomposition analysis

The TG and DTG curves of the different varieties of rice husk at a heating rate 20°C/min are shown in Fig.1. From the results of TG and DTG analysis it is observed that the moisture removal peak takes places at about the temperature in the range of 63°C to 77°C for all the six varieties considered. There is a variation in moisture removal rate in the range of 0.038 to 0.06 mg/min from variety to variety. The moisture removal took place up to 200°C followed by pyrolysis. After moisture removal and higher degree in temperature, the major weight loss due to the main decomposition of volatiles starts at around 200°C for all types of rice husk considered. The major weight loss occurred up to a temperature range of 384°C to 390°C. The weight loss was about in the range of 60 to 63% for all types of husk except BR50 (55% weight loss) in inert media. The char was formed after removal of volatile matters. Weight fraction of the char including ash to the total weights of the rice husks were 37%, 40%, 39%, 37%, 45% and 40% for BR16, BR28, BR29, BR34, BR50 and Hybrid3 respectively. The values of char remained after heating up to 800°C correspond with the results of the proximate analysis (values of fixed carbon and ash combined equal to char) of the husk. The main components of biomass are hemicelluloses, cellulose and lignin. These components are decomposed at different temperature ranges. Hemicellulose, cellulose and lignin are decomposed at 150-380, 250-380, and 250-500°C, respectively [18-21]. In the present study the decomposition is divided into two main zones,

one is in the range of 200–390°C in which region the major decomposition is occurred and the second zone in the range of 390–600°C in which region the lignin portion of the husk is decomposed.

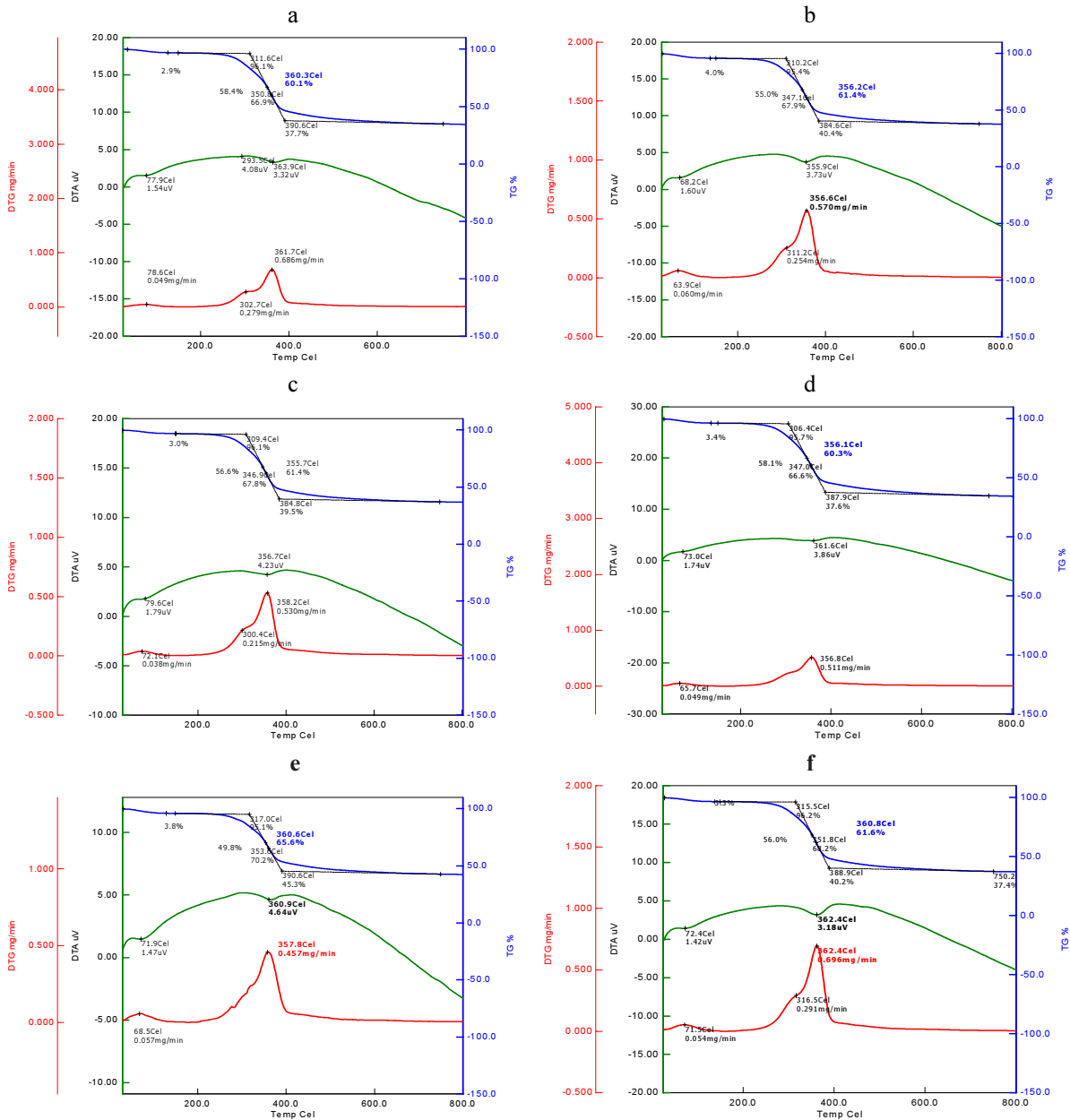


Fig. 1. TG, DTG and DTA curves for (a) BR16, (b) BR28, (c) BR29, (d) BR34, (e) BR50 and (f) Hybrid3 rice husks at 20°C/min heating rate in inert media

Three main stages of decomposition were observed in the TG curve. The first stage is from ambient temperature to near about up to 200°C. The second stage is limited on the TG curve in interval 200 to near about 400°C. During this stage rapid decomposition occurred and the main portion of rice husk biomass was lost. The steps were clearly shaped, and the processes determined the thermal stability of the rice husks. For these reasons, the second zone of thermal decomposition was the object of kinetic studies. The third stage of decomposition from 400 to 650°C was clearly observed a very slow decomposition and DTG curve showed the rate of degradation was almost zero.

The TG curves for the rice husk are similar in shape and nature and they follow the same path of residual percentage up to the major destruction of mass (up to 400°C). After the major destruction there is an insignificant variation of TG curves observed. The similar pathway of TG curve expressed that the similar type of composition of rice husk exists in different varieties of husk. DTG curves showed the maximum rate of destruction of husk biomass (mass loss) occurred at temperature with very little variation. The maximum destruction rate at closer temperature indicates the similar type of biomass composition in different husks. However, the maximum rate of destruction varied significantly among the varieties ranged from 0.457 $\mu\text{g}/\text{min}$ (BR50) to 0.696 $\mu\text{g}/\text{min}$ (Hybrid3). This variation may be due to physiological divergence of rice varieties wherein the nature of silica deposition at outer layer of rice husk may be one of the factors affecting the destruction of rate of biomass.

Rice husk from BR50 was treated with alkali (sodium hydroxide) to remove the mineral content silica. The objective of this study was to observe the changes of thermo-chemical properties of rice husk whether that could enhance combustion efficiency as well as increase energy density of rice husk. To compare the raw husk and alkali treated husk TG/DTG analysis was done for treated husk and the TG/DTG curve is presented in Fig.2. The TG/DTG results clearly indicate higher decomposition of biomass for treated husk compared to raw husk. The residual content reduced to 17% for treated husk compared to 45% for untreated husk from BR50. Similar nature of comparison results also reported recently by Markovska et al. [22] and Ndazi et al. [23].

The variation of maximum destruction rate between raw and treated husk was observed in the DTG analysis. The value of maximum degradation occurred at the same temperature however, the destruction rate increased from 0.457 $\mu\text{g}/\text{min}$ for raw husk to 0.693 $\mu\text{g}/\text{min}$ for treated husk (Fig.2). Similar variation of maximum destruction for raw and sodium hydroxide treated husk was reported by Markovska et al. [22]. Differential thermal analysis (DTA) shows that there are two endothermic peaks for each sample. One peak is observed in the temperature range of 63.9 to 79.6°C due to moisture removal. Another peak is observed in the temperature range of 355.9°C to 363.9°C due to the thermal degradation of samples.

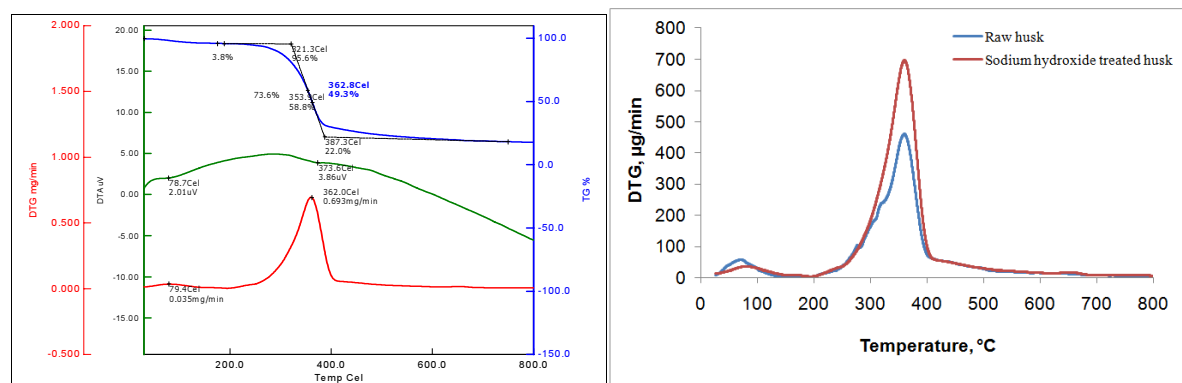


Fig.2. TG, DTG and DTA curve for sodium hydroxide treated BR50 rice husk at 20°C/min heating rate in inert media (left) and comparison of TG curves of raw husk and alkali treated husk

5.2 Determination of kinetic parameters of thermal decomposition

The kinetics of thermal decomposition reactions of biomass materials is much complex. TG analysis provides general information on the overall reaction kinetics, rather than individual reactions. By using the TGA data in the linearized Arrhenius rate equation the kinetic parameters were determined and presented in Table 1. The results of the kinetic parameters has a correlation coefficient of 0.958 to 0.996. A relatively higher activation energy was obtained for the rice husk variety BR28 (98.03 kJ/mol) as compared to those of the rice husk varieties BR16 (86.23 kJ/mol), BR29 (84.84 kJ/mol), BR34 (84.72 kJ/mol), BR50 (77.28 kJ/mol) and Hybrid3 (84.32 kJ/mol). These activation energy values correspond to a good agreement with those reported by Ozawa [24] 82.9 kJ/mol, and Coats and Redfern [25] 77.4 kJ/mol. The pre-exponential factors for different types of husk ranged from 1.45×10^7 to $2.22 \times 10^9 \text{ min}^{-1}$. The order of reactions determined in this investigation was in the range of 1.36 to 4.07 depending on rice husk varieties. A comparatively low order of reaction order of 0.02 was observed for alkali treated rice husk.

Table 1. Thermal and kinetic characteristics of rice husk in nitrogen media

Sample	Temp. interval °C	Max. decomposition rate % min ⁻¹	Activation energy, E kJ mol ⁻¹	Frequency factor min ⁻¹	Order n	Correlation coefficient R ²
BR16	227-387	15.38	86.23	2.74x10 ⁸	1.36	0.958
BR28	212-390	14.83	98.03	2.22x10 ⁹	4.07	0.965
BR29	229-356	14.96	84.84	1.07x10 ⁸	2.04	0.984
BR34	220-356	14.56	84.72	1.17x10 ⁸	2.28	0.993
BR50	210-358	11.76	77.28	1.45x10 ⁷	1.96	0.995
Hybrid 3	220-362	15.58	84.32	5.88x10 ⁷	1.60	0.993
NaOH treated husk (BR50)	210-362	19.30	73.84	7.57x10 ⁶	0.02	0.996
Ozawa [24]			82.9	6.2x10 ⁶	-	
Coats & Redfern [24]			77.4	1.1x10 ⁶	-	

6. Conclusion

It is clear from nature of the TGA curves that the decomposition is divided into two main zones, one is in the range of 200-390°C in which region the major decomposition is occurred and the second zone in the range of 390-600°C in which region the lignin portion of the husk is decomposed. The maximum rate of destruction varied significantly among the varieties ranged from 0.457 to 0.696 µg/min. This variation may be due to physiological divergence of rice varieties wherein the nature of silica deposition at outer layer of rice husk may be one of the factors affecting the destruction of rate of biomass. Kinetic parameters show distinct difference among the varieties of rice husk. A comparatively high degradation and low order of reaction are observed for alkali treated rice husk.

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6th BSME International Conference on Thermal Engineering (ICTE 2014)

Biogas from Mesophilic Anaerobic Digestion of Cow Dung Using Silica Gel as Catalyst

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Abstract

Biogas originates from bacteria in the process of biological breakdown of organic material under anaerobic conditions. A research work was conducted to investigate the production ability of biogas from mesophilic anaerobic digestions of cow dung (CD) using silica gel as catalyst. Two laboratory scale digesters were constructed to digest cow dung, where one set-up was used for digestion of cow dung without catalyst and the other set-up was used for digestion with catalyst. The digesters were made of glass conical flask of 1-liter capacity each. Cow dung was used 390 gm and water was used 310 gm in each experiment. In the slurry, total solid content was maintained 8% (wt.) for all the observations. The digesters were fed on batch basis. The digesters were operated at ambient temperatures of 27 – 31°C. The total gas yield was obtained about 27.3 L/kg CD for digestion without catalyst and about 30.5 L/kg of CD for digestion with catalyst. The retention time was about 76 days for both the digestions. The gas yields were compared with the previous work of mesophilic digestions of cow dung without catalyst of operating temperatures 18 – 28°C.

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Keywords: Biogas; anaerobic; mesophilic; cow dung; catalyst.

1. Introduction

Anaerobic digestion is a biological process that happens naturally in which anaerobic bacteria decompose organic matter in environments with little or no oxygen and produces biogas. Biogas can be used for cooking, heating, cooling,

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lighting, generating electricity etc. [1]. The key by-product of anaerobic digestion is digested solid which is rich in nitrogen and can be used as a fertilizer. The composition of biogas mainly depends on feed materials and biogas generally composes of 55-65% methane, 35-45% carbon dioxide, 0-3% nitrogen, 0-1% hydrogen, and 0-1% hydrogen sulfide [2]. By anaerobic digestion process the significant methane emission resulting from the uncontrolled anaerobic decomposition of organic waste into atmosphere would be stopped, where methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide [3]. Moreover, production of biogas will reduce the use of fossil fuels, thereby reducing the carbon dioxide emission. This is thus in accord with Kyoto Summit agreement [4]. Anaerobic digestion is in principle possible between 3°C and approximately 70°C. Differentiation is generally made between three temperature ranges: the psychrophilic temperature range lies below 20°C, the mesophilic temperature range between 20°C and 40°C, and the thermophilic temperature range above 40°C [5]. Patel et al. [6] studied the effect of silica gel as one of the adsorbents in an effort to improve the anaerobic codigestion of water hyacinth and cattle dung. Desai and Madamwar [7] used silica gel as one of the adsorbents for improving the efficiency of anaerobic digestion of a mixture of cheese whey, poultry waste and cattle dung. For improving anaerobic digestion of water hyacinth and cattle dung temperature was optimized in the range 20 to 65°C by Madamwar et al. [8]. Desai et al. [9] reported that with the increase of temperature from 20 to 40°C gas production from anaerobic digestion of cattle dung, poultry waste and cheese whey was increased with a higher methane percentage. Patel and Madamwar [10] studied the effect of temperature in the range of 25 to 55°C on total gas production from acidic petrochemical waste water. Salam et al. [11] investigated the production ability of biogas from cow dung at ambient temperatures in the range 18–28°C. Ukpai and Nnabuchi [12] investigated the anaerobic digestion of cow dung for generating biogas while slurry temperature was maintained between 22 and 36°C.

The scope of this investigation was to conduct research in the laboratory scale to produce biogas from mesophilic anaerobic digestion of cow dung using silica gel as a catalyst.

2. Materials and methods

2.1. Source of cow dung and slurry preparation

The cow dung (CD) for this research work was collected from the area inside Chittagong University of Engineering and Technology campus. The total solid content of cow dung was determined by heating cow dung at 115°C in oven for 42 hours. And the total solid (TS) content was found to be 14.38%. Normally total solid content of fresh cow dung varies between 15 – 19% [13]. For preparing the slurry 8% of total solid content was maintained by adding water. Solid contents in the range 7 – 9% were considered to be optimum by many researchers [8, 14–16]. For each experiment 700 gm slurry was prepared from 390 gm of cow dung and 310 gm of water. For anaerobic digestion with silica gel 2.8 gm silica gel was added into the slurry.

2.2. Experimental set-up and procedure

Two experimental set-ups were made to investigate the production of biogas from the anaerobic digestion of cow dung using silica gel as catalyst. Where one set-up was used for anaerobic digestion with silica gel (WSG) as catalyst and the other was used for anaerobic digestion without silica gel (WOSG). The set-ups were placed in the Heat Engine Laboratory of Mechanical Engineering department of CUET. The digesters made of glass conical flask of 1 liter capacity was used for each set-up. The schematic diagram of the set-up is shown in Fig.1. The digesters were connected with displacement tank / gas collector and water collector. As methanogenic micro-organisms are very sensitive to temperature fluctuation the digesters were kept in the containers and covered with rice husk to keep the digesters temperature stable. Plastic pipes were used to connect the digesters and the displacement tanks. The gas produced in the digester passed through the pipe to the displacement tank. Another plastic pipe was used to take the displaced water from the displacement tank to the water collector which fitted air tight in the displacement tank and inserted up to bottom part of it. Digestion was done at ambient temperature. During the investigation the volume of the produced gas was measured with the help of water displacement method [11], considering the volume of the produced biogas was equivalent to the displaced water in the water collector. The digesters were operated in batch mode and fed manually. At the time of experiments, these were ensured that the digesters were fully gas tightened.

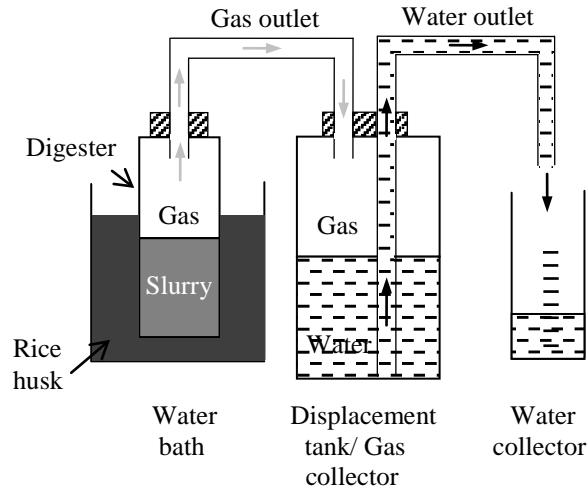


Fig. 1. Schematic diagram of the experimental set-up for anaerobic digestion of cow dung.

3. Results and discussions

Data were taken for collected gas and room temperature for the digestion set-ups between 18/05/2011 and 02/08/2011. Figure 2 shows the total gas yields for both anaerobic digestions of cow dung with (WSG) and without silica gel (WOSG) catalyst. The ambient temperatures during the data taking period varied between 27 and 31°C,

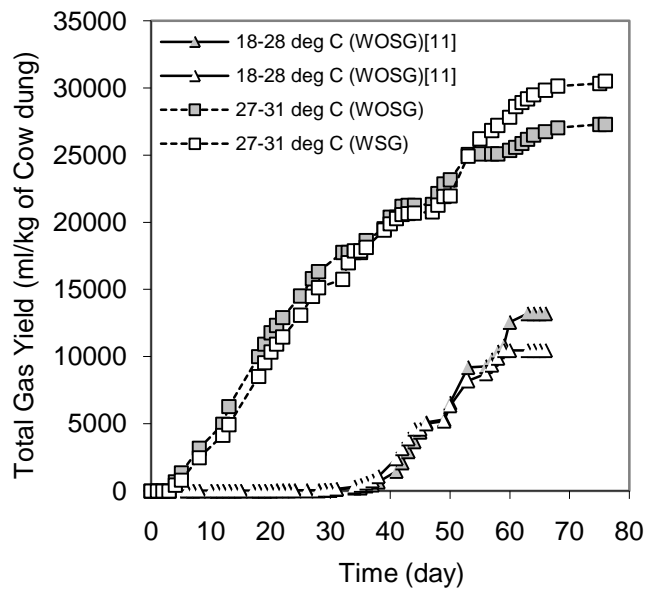


Fig. 2. Total gas yield from anaerobic digestion of cow dung.

Fig. 3. For both the cases the gas productions were found to be started from the 5th day. The gas production continued up to 76th and 77th days for WOSG and WSG respectively. The total gas yield for digestion without silica gel catalyst was found to be 27272 ml/kg CD and for digestion with silica gel catalyst was found to be 30528

ml/kg CD. An increase of 11.94% total gas production for using silica gel catalyst was observed. Patel et al. [6] used up to 6 gm/liter of silica gel for anaerobic digestion of mixture of water hyacinth and cow dung and reported increase of gas production for digestion with silica gel. The authors found maximum gas production of 1.35 l/l of digester/day for 1 gm/liter silica gel compared to 1 l/l of digester/day gas production from digestion without silica gel. Desai and Madamwar [7] also reported increase of gas production from digestion of mixture of cow dung, poultry waste and cheese whey with silica gel. They found 4 l/l of digester/day gas production from 4 gm/liter silica gel compared to gas production of 2.2 l/l of digester/day from digestion without silica gel. Fig. 2 also shows total gas production from anaerobic digestion of cow dung from earlier work where ambient temperatures varied between

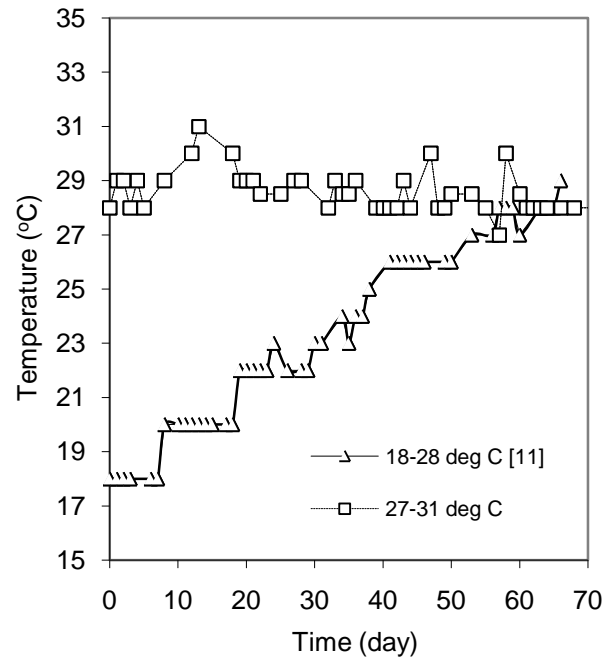


Fig. 3. Ambient temperatures during anaerobic digestion of cow dung.

18 and 28°C, Fig. 3 [11]. Total gas productions at lower range of ambient temperatures were reported to be significantly lower. At 18 to 28°C ambient temperature range total gas productions from two digesters were reported to be 10447 and 13139 ml/kg CD [11]. Ukpai and Nnabuchi [12] reported total gas generation of 7312 ml/kg CD from anaerobic digestion of cow dung while slurry temperature was maintained between 22 and 36°C. The optimum mesophilic temperature at which the micro-organisms which take part in methane fermentation lies between 35 – 40°C [17]. Figure 4 shows the daily gas production for both digestions of without silica gel and with silica gel. No significant differences were shown from the two digestions for daily gas production. For digestion without silica gel maximum daily gas production of 1346 ml/kg of CD was obtained on the 14th day. For digestion with silica gel the maximum daily gas production of 1244 ml/kg CD was obtained on the 34th day. In the last part of the digestion processes daily gas production from WSG were found to be more than those from WOSG. For WOSG digestion the daily gas production from 56th to 76th days varied between 0 to 308 ml/kg CD. Whereas for digestion WSG the daily gas production from 56th to 77th days varied between 27 to 769 ml/kg CD.

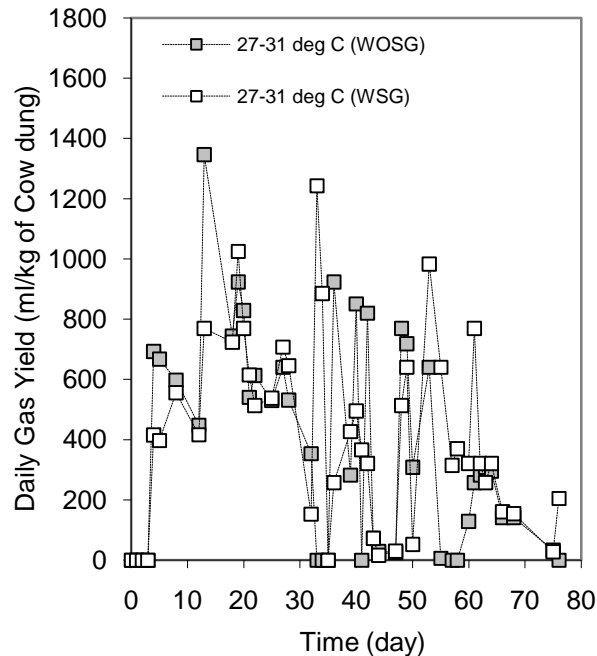


Fig. 4. Daily gas yields from anaerobic digestion of cow dung.

4. Conclusions

The effect of silica gel catalyst on anaerobic mesophilic digestion of cow dung was investigated using batch type 1 liter digesters. Digestions were done at ambient conditions of temperature 27 – 31°C. An increase of 11.94% total gas production for using silica gel catalyst was observed. Total gas productions at higher range of ambient temperatures were reported to be significantly higher.

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Recent Developments on Internal Combustion Engine Performance and Emissions Fuelled With Biodiesel-Diesel-Ethanol Blends

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Abstract

Ever increasing drift of energy consumption due to growth of population, transportation and luxurious lifestyle has motivated researchers to carry out research on biofuel as a sustainable alternative fuel for diesel engine. Biofuel such as biodiesel and ethanol, produced from renewable feedstocks, are the most appropriate alternative of petroleum fuels. However, direct using of ethanol in diesel fuel face some technical problem especially in cold weather, due to low cetane number, lower flash point and poor solubility. Biodiesel can be blended with both ethanol and diesel fuel and biodiesel–alcohol–diesel blends can be used in diesel engines. The aim of this review paper is to discuss the effect of mixed blends of biodiesel alcohol and diesel on engine performance and emission parameters of a diesel engine. Most of the researchers reported that adding ethanol into biodiesel-diesel blend in diesel engines significantly reduce HC, PM, NO_x and smoke emissions but slightly increase fuel consumption. The study concluded that biodiesel-diesel-ethanol blend can be used as a substitute of petro-diesel fuel to reduce dependency on fossil fuel as well as the exhaust emissions of the engine.

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Keywords: Global energy consumption; emission; diesel engine; ethanol; biodiesel

1. Introduction

The demand for energy, specifically the demand for petroleum fuels around the world is increasing every day [1]. From 2012 to 2015, 41% increase in global energy consumption is forecasted, 30% and 52% increase over last ten and last twenty years respectively. Non-OECD economies will account for 95% of this growth, half of which is expected to come from China and India. Compared to 2012, 69% higher energy will be used in 2035 in the non-OECD economics. Due to having benefits such as adaptability, high combustion efficiency, availability,

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reliability as well as the handling facilities, fossil fuels results in most energy consumption. Shares of the major fossil fuels are converging, with natural gas, oil and coal each contributing 27% of the total mix by 2035 and the remaining share supplied by nuclear and renewable energy. **Table 1** shows the primary energy consumption by fuel type between 2012 and 2035 [2]. Burning of fossil fuels produces emissions that have serious effect on both the environment as well as human health. Fuel, coal and gas each contributes 38% of the increase in emissions and 24% increase is coming from oil. It is predicted that by 2035 global CO₂ emissions from energy use will increase 29%. Compared to 1990, global emissions will be nearly double in 2035. Price hiking of the petroleum products, world-wide environmental concerns as well as the rapid depletion of fossil diesel fuel have encouraged researcher to search for alternative fuel sources which will provide cleaner combustion of diesel engines. Therefore, it has become a global agenda to develop clean alternative fuels which are domestically available, environmentally acceptable and technically feasible. According to the Energy Policy Act of 1992 (EPACT, US), natural gas, biofuel, electricity and methanol are the most suitable substitute to fossil fuels that can reduce global warming, fossil fuels consumption and exhaust emissions [3]. As an alternative fuel, biofuel such as ethanol, biodiesel are the best choices due to having properties such as environment friendly behaviour and similar functional properties with diesel fuel. In both developing and developed countries biofuel are at the top of their agendas and thus it is predicted that world biofuel production will be quadruple by 2020 [4].

Table 1: Global primary energy consumption by source [2]

Sources	2012		2035*	
	Mtoe	Share (%)	Mtoe	Share (%)
Oil	4130.5	33.10	4967.3	28.27
Natural gas	2987.1	23.94	4631.0	26.36
Coal	3730.1	29.89	4743.0	27
Nuclear	560.4	5.00	859.9	4.89
Hydropower	831.1	6.66	1245.8	7.09
Renewable	237.4	1.90	1118.9	6.36
Total	12476.6	100	17566.0	100

*Prediction

Biofuel such as biodiesel and ethanol are produced from renewable feedstocks. Especially, compared to fossil fuels, biodiesels, made from various crops and animal fat, are non-toxic, bio-degradable, eco-friendly and renewable. Biodiesel can be used in its pure form (B100) or may be blended with petroleum diesel in modern diesel engines. Using only alcoholic fermentation process, ethanol can be produced from agricultural products. Significant particulate matter (PM) emission reduction can be achieved by using ethanol in diesel fuel [5]. However, due to having properties such as low cetane number, lower flash point and poor solubility the direct use of ethanol in diesel engine faces some technical barriers. Biodiesel can be mixed with both alcohols and diesel; using biodiesel as an emulsifier with alcohols and diesel can be used as biodiesel–alcohol– diesel blends in diesel engines [6, 7]. Thus this review aims to investigate different fuel properties of diesel– biodiesel-ethanol/bioethanol blends and the performance of an internal combustion engine fuelled with these blends, investigated by many researchers.

Table 2: Physical and chemical properties of ethanol-biodiesel-diesel blend [7, 11, 14, 18]

D:BD:EtoH	Density [kg/m ³]	Viscosity [mm ² /s]	Flash point [°C]	Calorific value [MJ/kg]	Cetane number	Pour point [°C]	CFPP [°C]	Cloud Point [°C]
80:5:15 ROME 99.8%	823.5 ^b	1.843	-	40.28	45.1	-	-	-
70:10:20 JBD 99.7%	832.87 ^a	2.380 ^c	14	39.93	50	-3	-	-
50:20:30 JBD 99.7%	834.55 ^a	2.401 ^c	12.5	38.96	50	-9	-	-
50:10:40 JBD 99.7%	820.42 ^a	2.018 ^c	12	36.33	41	-12	-	-
85:12:3 SBD 99.7%	840 ^b	3.01 ^c	-	41.50	-	-	-	-
80:16:4 SBD 99.7%	840 ^b	3.03 ^c	-	41.20	-	-	-	-
75:20:5 SBD	845 ^b	3.04 ^b	-	40.90	45	-	-	-
60:30:10 WCOBD 99.9%	826 ^d	2.44 ^d	18.5	39.10	47.3	-3	-	-1
50:40:10 WCOBD 99.9%	831 ^d	2.60 ^d	19	38.70	47.2	-3	-	3
50:30:20 WCOBD 99.9%	821 ^d	2.14 ^d	15	37.85	47.2	-6	-	4
90:5:5 RBD 99.3%	843.7 ^a	2.435 ^c	17.5	41.70	51.04	-	-18	-
85:10:5 RBD 99.3%	845 ^a	2.421 ^c	14	41.56	51.20	-	-17	-

80:15:5 RBD 99.3%	847.2 ^a	2.527 ^c	16	41.41	51.36	–	–13	–
75:20:5 RBD 99.3%	849.6 ^a	2.645 ^c	17	41.26	51.52	–	–17	–
70:25:5 RBD 99.3%	851.9 ^a	2.756 ^c	18	41.12	51.68	–	–16	–
75:15:10 RBD 99.3%	844.7 ^a	2.374 ^c	15.5	40.66	49.24	–	–4	–
70:20:10 RBD 99.3%	846.8 ^a	2.480 ^c	16	40.52	49.41	–	–7	–
80:15:5 PBD(PME) 99.5%	838.3 ^a	2.63 ^c	17	43.80	53.2	3	–	–
80:15:5 PBD(PEE) 99.5%	837.8 ^a	2.72 ^c	15.7	39.30	–	3	–	–
80:15:5 PBD(PBE) 99.5%	837 ^a	2.73 ^c	15	43.70	–	3	–	–
85:10:5 PBD(PME) 99.5%	836.1 ^a	2.57 ^c	15	43.70	52	3	–	–
85:10:5 PBD(PEE) 99.5%	835.9 ^a	2.63 ^c	15	43.90	–	3	–	–
85:10:5 PBD(PBE) 99.5%	835.4 ^a	2.65 ^c	16	44.00	–	3	–	–

2. Production and properties of diesel-ethanol-biodiesel blends

Using transesterification process biodiesel can be obtained from vegetable oils, animal fats, used cooking oil and waste grease from restaurants. Currently, the sources of biodiesel include soybean oil, sunflower oil, corn oil, used fried oil, olive oil, rapeseed oil, castor oil, lesquerella oil, milkweed (*Asclepias*) seed oil, *Jatropha curcas*, *Pongamia glabra* (karanja), *Madhuca indica* (Mahua) and *Salvadora oleoides* (Pilu), *Calophyllum inophyllum*, palm oil, linseed oil, algae etc [8]. Ethanol is a low cost oxygenates which contains 34% higher oxygen content by weight. Using fermentation process ethanol can be made biologically from a variety of biomass sources such as sugarcane, corn, sugar beet, molasses, cassava root etc. Rural economy can be boosted significantly by the use of ethanol in diesel engines. The large-scale production steps of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration and denaturing. Some crops require saccharification or hydrolysis of carbohydrates such as cellulose and starch into sugars prior to fermentation process [5]. Ethanol and biodiesel both has several different chemical and physical properties. Several factors influences the quality of biofuel, such as: the quality of feedstock, fatty acid composition of the feedstock, type of production and refining process employed and post production parameters [9]. Modification of properties is achieved when biodiesel-diesel or diesel-ethanol or biodiesel-diesel-ethanol is blended. **Table 2** shows the properties of diesel- biodiesel-ethanol blends.

3. Performance and emission characteristics of biodiesel-diesel-ethanol blends in diesel engines

In many countries researchers have investigated the performance and emission characteristics of diesel engines fuelled with ethanol-biodiesel-diesel blends. It has been reported that performance of ethanol-biodiesel-diesel fuelled engine are in influenced by many factors such as engine type, operating condition, properties and fuel concentration. Fig.1 shows the CO (Carbon monoxide), NO (Nitric oxide) and HC (Hydrocarbon) of diesel engines using different percentages of biodiesel-diesel-ethanol blends. A study conducted by Labeckas et al. [10] studied the effect of ethanol-diesel and rapeseed biodiesel blends (15 vol% of ethanol and 5 vol% of biodiesel to 80 vol% diesel fuels) on performance and emission characteristics of a diesel engine at different loads and speed condition. The test results showed that engine running with composite blend BDE15 developed similar brake thermal efficiency as a straight diesel operating on slightly richer air–fuel mixture $\lambda = 1.5$ at rated 2200 rpm speed. The tertiary blend BDE15 showed a significant reduction of NO_x and the HC emissions by 6.3%, 11.9%, 9.5% and 24.6%, 14.6%, 15.1% compared to that of normal diesel fuel at 1400, 1800, 2200 rpm speeds. At 1400 rpm the emission of CO was 3.9% lower, but 14.7% and 1.0% higher at 1800 and 2200 rpm respectively. They also found that smoke opacity was 26.1% lower at 1400 rpm and 8.4% higher at 1800 rpm, and again 15.6% lower at 2200-rpm speeds. The lower NO_x revealed exclusive role of fuel bound oxygen, HC emissions along with positive changes in the CO emissions and opacities of the exhaust. The authors concluded that the ethanol (15 vol %), diesel (80 vol %) and biodiesel (5 vol %) blend is the suitable blend and significantly can be used in diesel engines. The addition of anhydrous ethanol and RME to petro-diesel fuel suggests ecological advantages and increases the renewable biofuel concentration in the blend that is one of the targets recommended by the EU Directive 2009/28/EC. Yilmaz et al. [11] investigated the emission of biodiesel-diesel- ethanol (BDE3, BDE5, BDE15 and BDE25) blends in a diesel engine at different engine load condition. Experimental results indicate that emissions are strongly depended on engine operating conditions and biofuel concentration in the blend. Ethanol blended fuels increased CO emissions compared to that of diesel fuel for all

operating conditions but the blended fuels reduced NO emissions for all concentrations. Overall, lower percentages of ethanol in the blend decreased HC emissions and vice versa. But ethanol blended fuel reduced HC emissions at over 50% load conditions. Fang et al. [12] studied the performance and emission of ethanol-diesel-biodiesel blend in a diesel engine at low combustion temperature condition. They found that ethanol-diesel-biodiesel blended fuel produce lower NO_x emissions and higher HC and CO emissions due to higher latent heat of vaporization which causes lower combustion temperature. In case of smoke emission blended fuel (ethanol-diesel-biodiesel) lowered it compared to that of diesel and biodiesel-diesel fuel. The peaks of smoke emissions were reduced in a large extent with the increase of percentage of ethanol in blended fuels. Finally, they concluded that ethanol-diesel-biodiesel is suitable alternative to reduce NO_x and smoke emissions in premixed lower temperature condition. Ferreira et al. [13] studied the performance and emission characteristics of a diesel engine connected to an electric generator operating with diesel-biodiesel-ethanol (D70B30-E5, D70B30-E9 and D70B30-E15) blend at 1800 rpm. They found that the use of ethanol in the biodiesel diesel blend is perfect to reduce NO_x emissions of compression ignition engines. But the CO and THC emissions increased as the ethanol content increased in the blend. However, contradictory to the traditional inverse relationship between NO_x and particulate matter emissions (PM), NO_x emissions reduction was reported with a slight reduction in opacity. They concluded that the ethanol fumigation could be an effective method for controlling the emission of NO_x from diesel engines when higher concentration of biodiesel is used in the blends. It also helps to preserves the natural resources and reduces the dependency on petro- diesel. Zhu et al. [14] studied the effect of ethanol-diesel-biodiesel blend on particulate and unregulated emission of a diesel engine at 1800 rpm and different engine load condition. The test results showed that adding ethanol into the biodiesel-diesel blend lowered particle number concentration and particulate mass emission as well. However, other than regulated emissions, blended fuels gives higher formaldehyde and acetaldehyde emissions, due to different H-abstraction reaction of ethanol, compared with biodiesel and diesel fuel. Armas et al. [15] investigated the effect of using ethanol-biodiesel-diesel in a city bus at real driving condition on particle size distribution and reported reduction of both the number and size of the accumulation-mode particles with the use of oxygenated fuel blends, with less proportion of aromatic hydrocarbons and sulphur in their composition. However the nuclei diameter remains constant as these fuels increase the nuclei concentration. Yilmaz et al. [16] studied the performance and emission of biodiesel-diesel-ethanol blends (B45E10D45, B40E20D40) in a diesel engine at different load conditions. They found that the use of ethanol in the biodiesel-diesel blend showed higher fuel consumption than that of diesel fuel. The blended fuel increased CO and HC emissions but reduced NO emissions. They concluded that adding ethanol in the blends would be the perfect choice to reduce NO emissions for the concentrations presented in this study. Pícol et al. [17] studied the performance and emission characteristics of a turbocharged diesel engine fuelled with diesel-biodiesel-ethanol (B40E10D40) blends at different speed and load conditions. They found that the main advantage of adding ethanol into the blend lowered smoke levels due to the presence of higher oxygen, higher volatility and reduction of soot precursor's concentration of ethanol- blended fuel. Hulwan and Joshi [6] used higher concentration of ethanol in diesel-ethanol- biodiesel blends to study the performance and emission characteristics of a direct injection diesel engine. The blends consisted of D70/E20/B10, D50/E30/B20 and D50/E40/B10 and the result compared with pure diesel fuel. They found that the blended fuel gives higher brake specific fuel consumption, slight improvement of thermal efficiency and reduction of smoke opacity at high loads. The variation of NO emission depends on operating conditions and at lower load condition CO emissions increased as compared to diesel fuel. Zhu et al. [18] tested Euro V diesel fuel and ethanol-biodiesel blends in a four-cylinder direct injection diesel engine and found that the addition of 5% ethanol in biodiesel improves engine performance slightly. It also reduces NO_x, PM, CO and HC emissions compared to diesel fuel. In exception, higher concentration of ethanol in blend could increase CO and HC emissions, while significantly reducing NO_x and PM emissions. Chhenkachorn and Fungtammasan [20] studied the performance and emission of a light duty truck using ethanol-diesel-biodiesel-bioethanol blends (84% diesel, 0.25% hydrous ethanol, 4.75% anhydrous ethanol, and 11% biodiesel by volume).

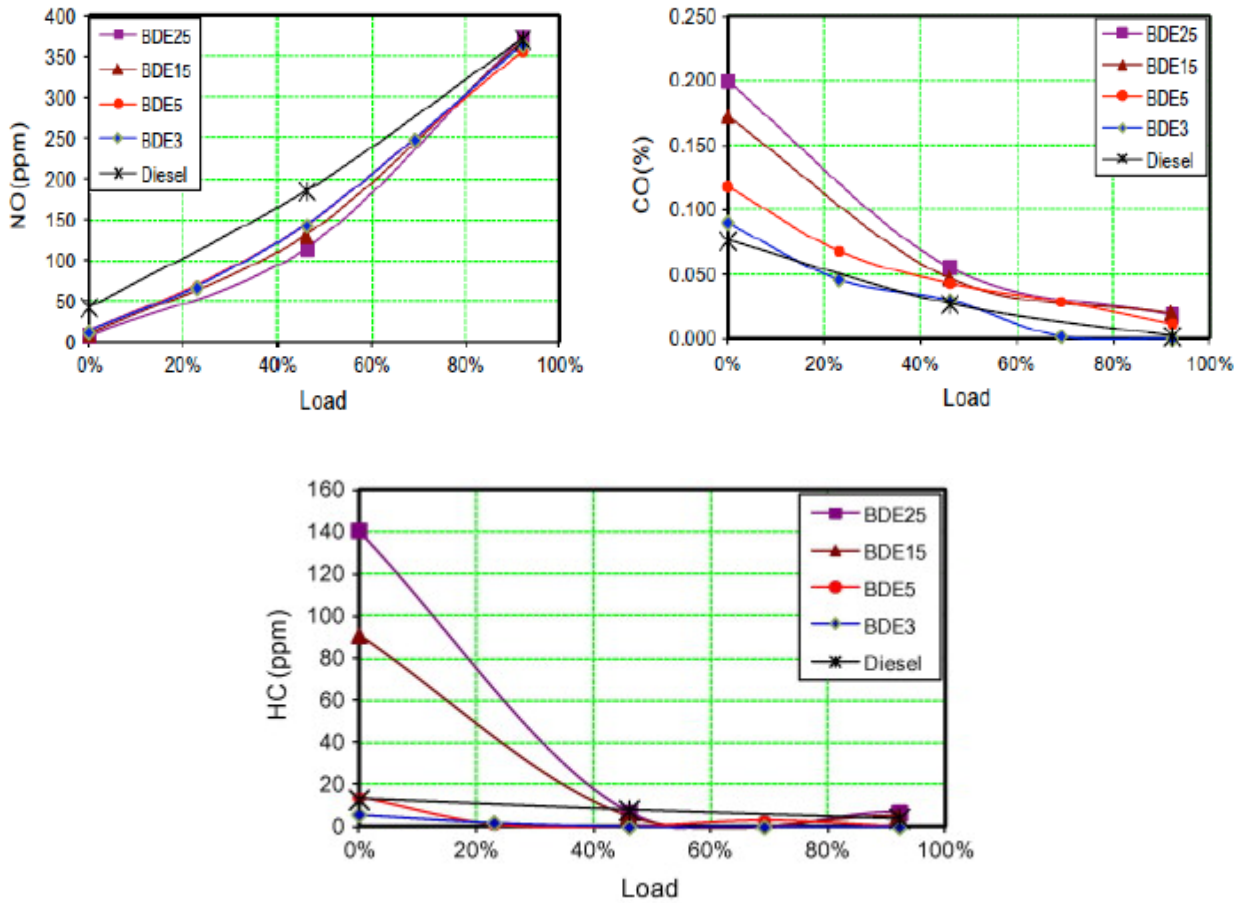


Fig. 1: Effect of diesel-biodiesel-ethanol blends on NO, CO and HC [11]

Both the blend and diesel fuel showed almost similar NO_x emission result and fuel consumption. However, biodiesel–ethanol–diesel fuel indicated lower PM and CO emissions compared to that of baseline petro-diesel fuel. Barabas et al. [21] studied the performance and emission of diesel-biodiesel-ethanol (D85/B10/E5 D80/B10/E10 and D70/B25/E5) blends in a diesel engine and compared to diesel fuel. The test result indicated that, at all operating condition HC and PM emissions decreased for blended fuel. The emission of CO decreased and CO₂ emissions increased at low engine loads due to a prolonged oxidation process including the exhaust. Authors also found that blended fuel increased NO_x due to the presence of higher oxygen that leads to complete combustion. Aydin and Ilkiliç [22] investigated the performance of a diesel engine using a blend containing 20% of ethanol in sunflower biodiesel (B80E20). They found that ethanol blended fuel produced lower specific fuel consumption than biodiesel-diesel blend (B20), and almost the same specific fuel consumption as diesel oil.

4. Discussions

Due to increase in petroleum price and adverse effect on environment of petroleum fuel, biofuel is taking its position every day over fossil fuel. Biofuel offer a sustainable source of energy and can play a significant role to reduce dependency on petro-diesel and green house gas emission. Although there have always been inconsistent trends for engine performances and its emissions fuelled with biofuel due to different factors such as the different tested engines, the different operating conditions or driving cycles, the different used biodiesel or reference diesel, the different measurement techniques or instruments, etc as shown in Fig.1.

5. Conclusions

This paper critically reviews on fuel properties, performance and emission of biodiesel-diesel- ethanol blends. Following findings can be summarized from the review:

- 1) Emissions are strongly depended on engine operating conditions and biofuel concentration in the blend.
- 2) Combined blends of biodiesel-diesel-alcohol reduce NO_x and HC significantly.
- 3) The peaks of smoke emissions were reduced in a large extent with the increase of percentage of ethanol in blended fuels.
- 4) Contrary to traditional belief, NO_x and PM emission both reduced due to the use of mixed blends.
- 5) Addition of ethanol into the biodiesel-diesel blend lowered particle number concentration and particulate mass emission as well.
- 6) The use of ethanol in the biodiesel-diesel blend showed higher fuel consumption than that of diesel fuel.

This review indicate that maximum of 20–25% biodiesel and 5% ethanol can be added effectively and efficiently with the fossil diesel fuel to reduce engine emission with a small fuel consumption penalty. Finally, biodiesel-diesel-ethanol blend can be suggested for especially medium and small load engines.

Future work

The authors of this paper will do investigation on engine performance and regulated exhaust emissions such as CO_2 , HC and NO_x , and unregulated emissions such as PAH, formaldehyde and dioxin emissions, etc from ethanol, Calophyllum oil based biofuels as there is not enough research on the emission of ethanol-Calophyllum biodiesel-diesel blend in diesel engines.

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Effect of Biodiesel-Diesel Blending on Physico-Chemical Properties of Biodiesel Fuel

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Abstract

The aim of this paper is to study the physical and chemical properties of *Moringa oleifera* biodiesel and its blends of 10%-90% by volume with petro-diesel according to the American society for testing and materials (ASTM D6751) standards and European standards (EN 14214). It was found that when *Moringa* biodiesel is blended with diesel fuel, all its fuel properties such as kinematic viscosity (KV), density (D), calorific value (CV), flash point (FP), cloud point (CP), pour point (PP), and cold filter plugging point (CFPP). For example, B10 reduce the viscosity of B100 from 5.05 mm²/s to 3.54 mm²/s (1.4:1). Then developed empirical models of properties are show high regression value (R²) between properties and MOME-diesel blend. It is believed that the results obtained and empirical model proposed in this study will help the researchers to predict the properties of biodiesel-diesel blend which are important parameters to design the fuel system of biodiesel engine.

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Keywords: Fossil fuel; *Moringa oleifera*; Biodiesel production; Characterization; Blending.

1. Introduction

As the reserves of fossil energy resources are limited and decreasing day by day, discovering alternative energy sources has become one of the global agenda now a day. Biodiesel has gained popularity among the researchers as

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one of the alternative energy sources due to potential possession of reducing dependency on fossil diesel fuel, environmental pollutants, etc. [1-4]. Biodiesel can be obtained by employing the transesterification process of vegetable oils, animal fats, waste cooking oil and waste restaurant greases. The most common biodiesel sources from edible oils are palm oil, rapeseed oil, sunflower oil, coconut oil, peanut oil, *Jatropha curcas*, neem, cotton, jojoba, rubber, *Moringa oleifera*, Mahua, castor and animal tallow [5-7].

Recently, investigations have been carried out by numerous researchers [3, 8, 9] regarding the potential of biodiesel production from edible oil and non-edible oil sources and their utilization in a diesel engine. A few authors [9-13] have reported on the potential of biodiesel production from *Moringa oleifera*, a non-edible oil source but there is no extensive report on the characterization of *Moringa oleifera* biodiesel blend. *Moringa oleifera* is a member of the *Moringaceae* family, mainly grows in tropical countries. It is drought-tolerant pioneer species. The *Moringa oleifera* are most available in northwest India, Malaysia, Bangladesh, Africa, South America and Arabia, etc. [14]. It can grow up to 5 to 10 m. The plant starts bearing Pods 6-8 months after planting and reaches an average of 3 t of seed per hectare per year [15, 16]. The seeds of *Moringa oleifera* are triangular in shape which contains about 40% of oil by weight. The oil produced from the seed kernel of *Moringa oleifera* is golden yellow in color. It has been reported that *Moringa oleifera* oil contains higher amount of oleic acid and it is almost 74.41% of the entire fatty acid profile. Among all feedstocks, *Moringa oleifera* oil has a good potential to be converted into biodiesel and being non-edible oil source, it will not create the food versus fuel conflict. Thus the aim of this paper is to study the physical and chemical properties of *Moringa oleifera* biodiesel and its blends of 10%-90% by volume with petrodiesel according to the American society for testing and materials (ASTM D6751) standards and European standards (EN 14214).

Table 1: List of equipment used for properties test

Property	Equipment	Manufacturer	Test method
Kinematic viscosity	SVM 3000	(Anton Paar, UK)	ASTM D445
Density	SVM 3000	(Anton Paar, UK)	ASTM D1298
Oxidation stability	873 Rancimat	(Metrohm, Switzerland)	EN ISO 14112
Flash Point	Pensky-martens flash point - automatic NPM 440	(Norma lab, France)	ASTM D93
Cloud and Pour point	Cloud and Pour point tester - automatic NTE 450	(Norma lab, France)	ASTMD2500, ASTM D97
Cold filter plugging point	Cold filter plugging point tester - automatic NTL 450	(Norma lab, France)	ASTM D6371
Caloric value	C2000 basic calorimeter	(IKA, UK)	ASTM D240

2. Materials and methods

2.1 Materials

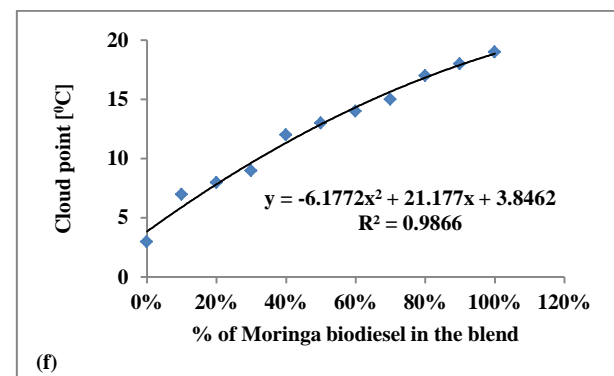
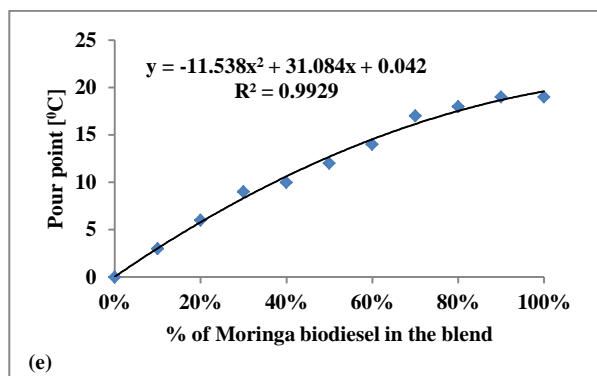
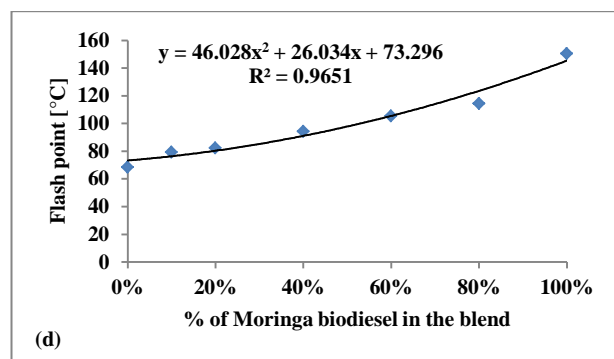
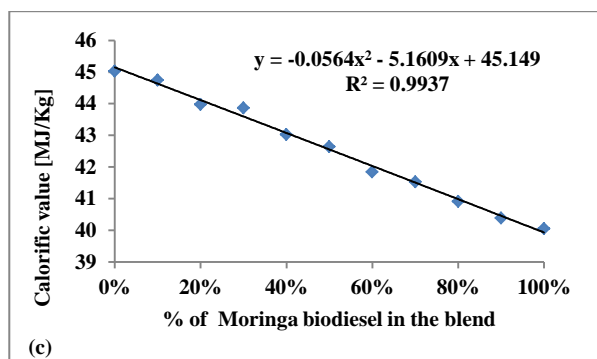
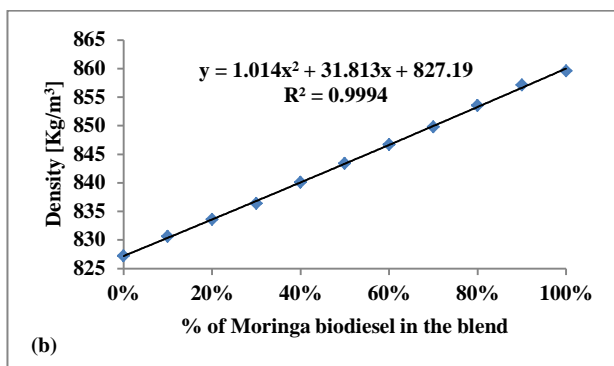
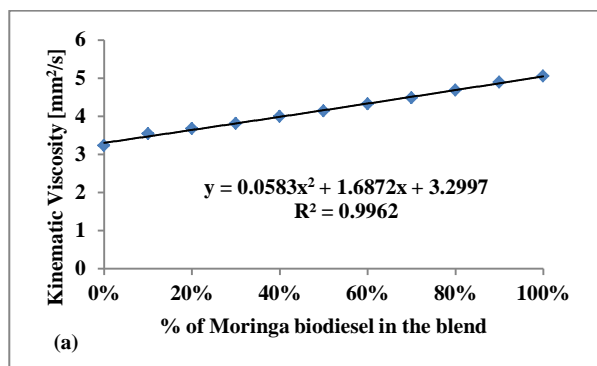
Crude *Moringa oleifera* oil (CMOO) was collected through a personal communication. All other chemicals, reagents and accessories were purchased from LGC Scientific Sdn Bhd. Table 1 shows the list of equipment that used for properties test.

Table 2 Physico-chemical properties of CMOO

Properties	Unit	CMOO	MOME	Diesel
Kinematic viscosity at 40 °C	mm ² /s	43.33	5.05	3.23
Flash point	°C	268.5	150.5	68
CFPP	°C	18	18	5
Pour Point	°C	11	19	0
Cloud point	°C	10	19	0
Density	kg/m ³	897.5	869.6	827.2
Acid value	mg KOH/g oil	8.62	0.22	-
Calorific value	MJ/kg	38.05	40.05	45.30

2.2 Production of MOME

Biodiesel was produced using 1L batch reactor, a reflux condenser, magnetic stirrer, and thermometer and sampling outlet. Before starting the esterification process the crude oil was heated to 60°C inside the control rotary evaporator (IKA) under vacuum conditions to remove moisture. For esterification of the crude oil, a molar ratio of 12:1 of methanol to crude *Moringa oleifera* oil (CMOO) and 1% (v/v oil of sulphuric acid (H₂SO₄)) were added to the preheated oil and stirred at 600 rpm and at 60°C temperature for 3 hours. Later, the esterified oil was separated from the excess alcohol, sulphuric acid, and impurities by using separating funnel. Again the separated esterified oil was



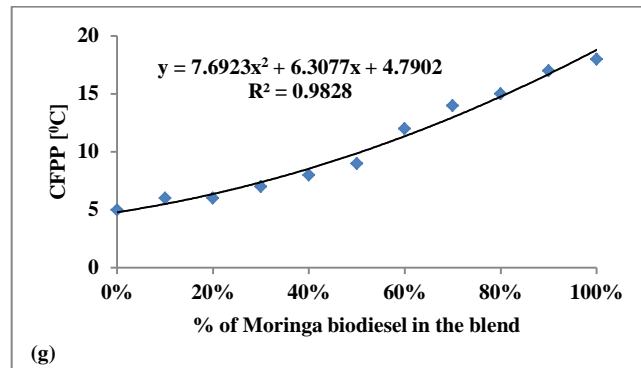


Fig.1 MOME-diesel blending effect on (a) KV (b) density (c) CV (d) FP (e) PP (f) CP (g) CFPP

heated to 60°C inside the control rotary evaporator for 1 hour to remove methanol and water. Then for transesterification purpose, a molar ratio 6:1 methanol to oil and 1% (m/m oil) of potassium hydroxide (KOH) were mixed with the preheated esterified *Moringa oleifera* oil (EMOO) and stirred at constant 600 rpm and at 60°C temperature for 2 hours. Once the reaction is finished, the produced methyl ester was kept in a separation funnel for 16 hours. Then the separated glycerol was drained out and methyl ester was filtered using qualitative filter paper to get final product.

3. Results and discussion

The physico-chemical properties of the produced methyl ester were characterized according to the ASTM D6751 and EN 14214 standards. The major fuel properties of CMOO and MOME are analyzed and presented in **Table 2**. It is found that the KV, FP, CFPP, PP, CP, D, acid value (AV) and CV of CMOO are 43.33 mm²/s, 268.5°C, 18°C, 11°C, 10°C, 897.5 kg/m³, 8.62 mg KOH/g oil and 38.05 MJ/kg respectively. The main findings from properties test is that MOME possesses the better fuel properties such as KV, FP, D, CV and AV but worse cold flow properties (CP, PP and CFPP) compared to CMOO.

Biodiesel can be blended with petro-diesel at any ratios [17]. Then the key fuel properties such as viscosity, density (D), calorific value (CV), flash point (FP), cloud point (CP), pour point (PP), and cold filter plugging point (CFPP) of different blend samples were determined. The effect of MOME-diesel blending on fuel properties are shown in Figs. 2a-g.

The following empirical equations have been developed from Figs.1a-g to predict the viscosity, density, calorific value, flash point, cloud point, pour point and CFPP of any MOME-diesel blend. Where, (x denotes % of MOME in the blend).

KV	= 0.0583x ² + 1.6872x + 3.2997	0 ≤ x ≤ 100	R ² =0.9962	(1)
D	= 1.014x ² + 31.813x + 827.19	0 ≤ x ≤ 100	R ² =0.9994	(2)
CV	= -0.0564x ² - 5.1609x + 45.149	0 ≤ x ≤ 100	R ² =0.9937	(3)
FP	= 46.028x ² + 26.034x + 73.296	0 ≤ x ≤ 100	R ² =0.9651	(4)
PP	= -11.538x ² + 31.084x + 0.042	0 ≤ x ≤ 100	R ² =0.9929	(5)
CP	= -6.1772x ² + 21.177x + 3.8462	0 ≤ x ≤ 100	R ² =0.9866	(6)
CFPP	= 7.6923x ² + 6.3077x + 4.7902	0 ≤ x ≤ 100	R ² =0.9828	(7)

It is seen that the D, KV, FP, CP, PP and CFPP increases as the percentages of biodiesel in the blends increases but the CV decreases as the percentages of biodiesel increases in the blends as expected. It is clear that MOME-diesel blend improves the KV, D, CV, CP, PP and CFPP of biodiesel.

Conclusions

In this paper biodiesel from CMOO was produced through transesterification process. Then the physico-chemical properties of biodiesel-diesel blending of 10-90% by volume are determined. It was found that the fuel properties such as KV, D, CV, CP, PP, CFPP and FP increases with blending ratio either linearly or exponentially as applicable & CV decreases with blending ratio. Finally, the empirical models of fuel properties are proposed. The outcome of the study will help to predict the properties of biodiesel-diesel blend at any blend ration which will be a substantial assistance to design the fuel system of biodiesel engine.

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Comparison of Oil Yield by Solvent Extraction in Conventional and Modified Soxhlet Apparatus from Seeds of *Pongamia pinnata*

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Abstract

In the present paper a comparative study of process parameters on oil yield from non-edible plant oil seeds was made using a conventional soxhlet apparatus and a modified soxhlet apparatus. The conventional soxhlet apparatus was modified to enhance its performance in oil extraction. *Pongamia pinnata* oil seeds were taken for the analysis in both the setups. It was observed that oil yield was more and the process time was less in the modified soxhlet apparatus in comparison to the conventional soxhlet apparatus. Effect of seed to solvent ratio, extraction time, particle size, moisture, solvent type etc. on plant oil yield was studied with the modified setup. The improved set up gave the best results in terms of oil yield (31%).

Keywords: soxhlet, moisture, extraction, oil
