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Mr. Priyabrata Pradhan

Contact Information

PhD student
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Education

Ph.D. – Bio-energy (GPA 8.81/10.0)
Indian Institute of Technology Bombay, Mumbai, India Jul 2014 – present

Thesis – Pelletization and gasification of biomass for energy applications in small enterprises

M.Tech. – Agricultural Engineering (Farm Machinery and Power) (GPA 8.53/10.0)
Indian Institute of Technology Kharagpur, Kharagpur, India Jul 2010 – Jun 2012

Thesis – Performance of a diesel engine fueled with preheated Jatropha oil by recovering heat from exhaust gas

B.Tech. – Agricultural Engineering (First class with Honours, GPA 8.31/10.0)
Orissa University of Agriculture and Technology, Bhubaneswar, India Aug 2006 – Jun 2010

Employment

Senior Research Fellow (SRF) Jul 2016 – Present
Indian Institute of Technology Bombay, Mumbai, India

Junior Research Fellow (JRF) Jul 2014 – Jul 2016
Indian Institute of Technology Bombay, Mumbai, India

Lecturer in Mechanical Engineering Jul 2012 – Jul 2014
Rajiv Gandhi University of Knowledge Technologies (RGUKT), Hyderabad, India

Research Interests

Biofuels and sustainable energy

- Feedstock improvement and solid biofuel production
- Experiments and simulation in biomass gasification
- Alternative fuels for diesel engines
- Techno-economic analysis
- Statistical analysis

Publications

Total research publications – 12 (List attached) **(Scopus: h-index – 3, Citations – 53)**

Papers in SCI journals – **6**; Papers in conference proceedings – **6**

Best 3 publications:

- **Pradhan, P.**, Gadkari P., Mahajani, S.M., Arora, A., 2019. A conceptual framework and techno-economic analysis of a pelletization-gasification based bioenergy system. *Applied Energy*; 249, 1–13. (Impact Factor: **7.9**)
- **Pradhan, P.**, Arora, A., Mahajani, S. M., 2019. A semi-empirical approach towards predicting producer gas composition in biomass gasification. *Bioresource Technology*; 272, 535–544. (Impact Factor: **5.8**)
- **Pradhan, P.**, Mahajani, S. M., Arora, A., 2018. Production and utilization of fuel pellets from biomass: A review. *Fuel Processing Technology*; 181, 215–232. (Most downloaded article) (Impact Factor: **3.9**)

Awards and Fellowships

- **Best Presentation Award**(First, Oral), National Environmental Conference, IIT Bombay 2019
- **International Travel Support**, Science and Engineering Research Board, India 2018
- **Institute Teaching Assistantship**, Ministry of Human Resource Development 2014 – 2019
- **National Eligibility Test (NET)**, Agricultural Scientists Recruitment Board, India 2014
- **Assistantship** during M.Tech, Ministry of Human Resource Development 2010 – 2012
- **Graduate Aptitude Test in Engineering (GATE)**, Indian Insititutes of Technology 2010
- **University Merit Scholarship**, Orissa University of Agriculture and Technology 2006 – 2010

Journal Peer Reviewer

- Fuel, Elsevier
- Energy Procedia, Elsevier
- IOP Conference Series Earth and Environmental Science
- Plant Science: Current Research, Herald Scholarly Open Access

Research guidance

- Guided five undergraduate B.Tech. projects during my tenure as a Lecturer at RGUKT, India

Technical Skills

- **Programming languages**: Advance C, MATLAB
- **Tools**: Minitab 17, Satistica 10.0, R, Latex, OriginPro, Vensim, openLCA, AutoCAD, QGIS

Extra Academic Activities

- **Convocation Volunteer**, IIT Bombay. 2018
- **Led a team** to participate at Make in India 'Hackathon' 2016, IIT Bombay. 2016
- **Judge** in National Children's Science Congress, Kendriya Vidyalaya, IIT Bombay. 2016
- **Department Representative**, Research Scholar's Forum, IIT Bombay. 2015 – 2016
- **Organizer**, Finance Team, Research Scholar's Confluence, 2015, IIT Bombay. 2014 – 2015

References

- Prof. Amit Arora (My Ph.D. supervisor)
  Associate Professor, Centre for Technology Alternatives for Rural Areas (CTARA)
  Indian Institute of Technology Bombay, India–400076
  Email: aarora@iitb.ac.in

- Prof. Sanjay M. Mahajani (My Ph.D. Co-supervisor)
  Professor, Chemical Engineering Department
  Professor-in-Charge, Tata Centre for Technology and Design
  Indian Institute of Technology Bombay, India–400076
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- Prof. Hifjur Raheman (My M.Tech. supervisor)
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PUBLICATIONS

Papers in SCI journals

1. **Pradhan, P.**, Gadkari P., Mahajani, S.M., Arora, A., 2019. A conceptual framework and techno-economic analysis of a pelletization-gasification based bioenergy system. *Applied Energy*; 249, 1–13. [doi] (Impact Factor: **7.9**)

2. **Pradhan, P.**, Arora, A., Mahajani, S.M., 2019. A semi-empirical approach towards predicting producer gas composition in biomass gasification. *Bioresource Technology*; 272, 535–544. [doi] (Impact Factor: **5.8**, Citation: **1**)

3. **Pradhan, P.**, Mahajani, S.M., Arora, A., 2018. Production and utilization of fuel pellets from biomass: A review. *Fuel Processing Technology*; 181, 215–232. [doi](Most downloaded article) (Impact Factor: **3.9**, Citations: **8**)

4. **Pradhan, P.**, Arora, A., Mahajani, S.M., 2018. Pilot scale evaluation of fuel pellets production from garden waste biomass. *Energy for Sustainable Development*; 43, 1–14. [doi] (Impact Factor: **2.6**, Citations: **13**)

5. **Pradhan, P.**, Raheman, H., Padhee, D., 2014. Combustion and performance of a diesel engine with preheated Jatropha curcas oil using waste heat from exhaust gas. *Fuel*; 115, 527–533. [doi] (Impact Factor: **4.6**, Citations: **29**)

6. Raheman, H., **Pradhan, P.**, 2013. Fuel properties improvement of jatropha oil using exhaust heat of diesel engine.*Journal of The Institution of Engineers (India): Series A*; 93 (4), 233-239. [doi] (Citation: **1**)

Papers in conference proceedings

1. **Pradhan, P.**, Gadkari P., Arora, A., Mahajani, S.M., 2018. Economic feasibility of agro waste pelletization as an energy option in rural India. *10th International Conference on Applied Energy (ICAE2018)*; August 22-25, **Hong Kong, China**. (Travel support by IIT Bombay) [doi] (Oral presentation)

2. **Pradhan, P.**, Mahajani, S.M., Arora, A., 2018. Energy requirement for biomass densification via mechanical compression and an integrated pelletization unit. *26th European Biomass Conference and Exhibition (EUBCE-2018)*; May 14-17, **Copenhagen, Denmark**. (Travel support by SERB, DST) [doi] (Poster presentation)

3. **Pradhan, P.**, Mahajani, S.M., Arora, A., 2017. Evaluating the sensitivity of biomass feedstocks to producer gas composition using stoichiometric equilibrium model. *6th International Conference on Advances in Energy Research (ICAER-2017)*; Dec 12-14, **IIT Bombay, Mumbai, India**. (Oral presentation)

4. **Pradhan, P.**, Mahajani, S.M., Arora, A., 2016. An economic analysis of a pilot scale biomass pelletisation plant. *International Conference on Emerging Technologies in Agricultural and Food Engineering (ETAE-2016)*; Dec 27-30, **IIT Kharagpur, West Bengal, India**. (Oral presentation)

5. **Pradhan, P.**, Arora, A., 2015. Biofuel generation technologies: A global perspective. *International Conference on Renewable Energy and Sustainable Environment (RESE-2015)*; Aug 10–13, **Coimbatore, Tamil Nadu, India**. (Oral presentation)

6. **Pradhan, P.**, 2014. Rice husk: A sustainable biomass for rural electrification. *International Conference on Energy Technology, Power Engineering and Environmental Sustainablility (ETPEES-2014)*; Jun 21–22, **New Delhi, India**. (Oral presentation)

Abstracts presented at conferences

1. **Pradhan, P.**, Gadkari, P., Mahajani, S.M., Arora, A., 2019. Energy recovery from waste – Gasification of biomass pellets for thermal energy production. *National Environmental Conference*; Jan 31–Feb 2, **IIT Bombay, Mumbai, India**. (Received best presentation award, First prize) (Oral presentation)

2. Patil, V.V., **Pradhan, P.**, Mahajani, S.M., 2016. Thermal energy from urban garden waste. *4th International Conference on Sustainable Municipal Solid Waste Processing Technology for Developing Nations*; Feb 18–19, **Surat, Gujarat, India**. (Poster presentation)

3. Kate, H., Rao, B., Kumar, A. and **Pradhan, P.**, 2016. CSR and indian development: From what we know to what we need to know. *International Conference on Rural Development (ICRD-2016)*; Feb 04–05, **Jabalpur, Madhya Pradhesh, India**. (Oral presentation)

4. **Pradhan, P.**, Patil, V.V., 2016. Biomass briquetting: A technology for sustainable rural development. *International Conference on Agribusiness in Emerging Economies*; Jan 06–07, **Anand, Gujarat, India**. (Oral presentation)

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A conceptual framework and techno-economic analysis of a pelletization-gasification based bioenergy system

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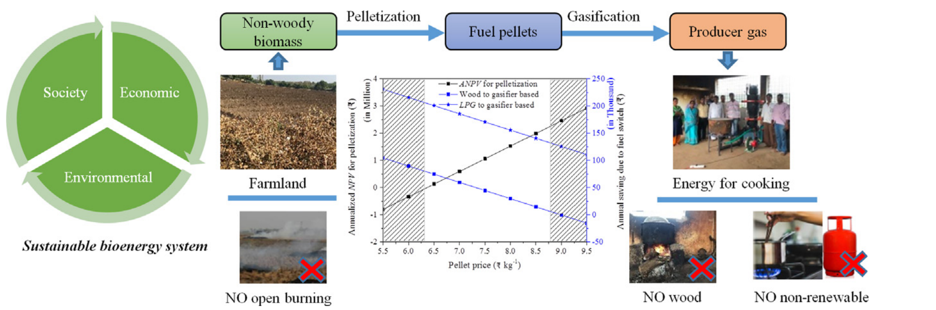
HIGHLIGHTS

- A conceptual framework was designed for a bioenergy system for rural India.
- Agro waste potential was estimated through survey.
- Techno-economic analysis of an integrated system was conducted.
- Uncertainty was assessed through Monte-Carlo simulation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Bioenergy system
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Rural India

ABSTRACT

This paper presents a holistic approach to promote bioenergy in India by designing a conceptual framework that combines resource, technology and market. The proposed concept is an attempt to integrate pelletization and gasification technology for bioenergy system development through an end-to-end approach. The potential of bioenergy resource (i.e. agro waste) was estimated based on survey. The study further assessed the economic feasibility of agro waste pelletization. The economic evaluation was made using indicators such as net present value (*NPV*), internal rate of return (*IRR*), discounted payback period (*DPBP*) *etc.* Pellet plant capacity of 0.5 ton h^{-1} showed acceptable economics and the *NPV*, *IRR* and *DPBP* were ₹9.35 million ($0.13 million), 41% and 2.8 years, respectively. Moreover, the larger capacity plants (> 2 ton h^{-1}) were subjected to more risk under low pellet prices (< ₹5 kg^{-1} or $71.4 ton^{-1}). The cash flow statement showed a strong debt paying ability for the project. Pellet price was the most sensitive factor followed by annual operating days on pellet plant economics. Monte Carlo simulation predicted an average *NPV* of ₹9.3 ± 2.0 million ($133.2 ± 29.1 thousand). The economics of fuel pellets utilization in a gasifier for energy applications was also evaluated. The pellet fed gasifier system appeared to be cost competitive with commercial liquefied petroleum gas (*LPG*) and wood at a pellet price range of ₹6.3–8.8 kg^{-1} ($90–126 ton^{-1}) in a select scenario. Overall, the designed framework appears to reduce over-dependency on wood or fossil sources, and facilitate bioenergy promotion in rural areas.

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A semi-empirical approach towards predicting producer gas composition in biomass gasification

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Keywords:
Equilibrium model
Biomass feedstock
Gasification
Producer gas
Correlations

ABSTRACT

The paper provides a comparison of five distinct models, often used in thermodynamic equilibrium modeling that allows the study of feedstock effect on gasification process. The five models were thus formulated and solved using MATLAB software. The results were compared with published experimental data. The model based on equilibrium constant derived using methane formation reaction and water gas shift reaction showed comparatively better performance. Once the model was selected, the response surface analysis was employed to predict the parameters, such as reactor temperature and feedstock moisture content, for a maximum heating value of the producer gas. Simulations were performed for 50 different biomass feedstocks and simplified correlations were developed from simulated producer gas composition using multiple linear regression. These correlations may be suited for the quick comparison of different feedstocks in gasification process.

1. Introduction

Utilization of alternate sources of energy is important because of the energy crisis problem in the developing world and the drive to reduce dependency on the use of fossil fuels to mitigate the challenges like global warming and climate change (Slade et al., 2014). This paper focuses on issues related to energy generation *via* biomass gasification technology. Biomass gasification involves thermo-chemical conversion of biomass in which solid biomass coverts into gaseous fuel for energy generation or for the production of value-added products (Pradhan et al., 2018b).

Biomass feedstocks contain cellulose, hemicellulose, lignin, and inorganic component in different proportions. The relative fractions of cellulose, hemicellulose, and lignin in biomass plays an important role in the decomposition and energy conversion while undergoing gasification (Sikarwar et al., 2016). The inorganic content is one of the major influencing factors in gasification rate of different lignocellulosic feedstocks (Gupta et al., 2018). Therefore, gasification chemistry is complex which is influenced by the type of feedstock and inherent moisture content, process design and operating parameters (e.g. gasifying agent, equivalence ratio etc.). It is thus difficult to assess whether the variations in product gas output are caused due to change in biomass feedstock, type of gasifier or its operating parameters. Moreover, experimental investigation to study the variability of biomass feedstock in a given gasifier is time consuming and expensive. The mathematical modeling is thus found to be an important tool to study the gasifier behaviour. It helps in optimizing the operation and reduces the load on physical experimentation with different feedstocks. In order to evaluate the effect of gasification parameters on producer gas composition and thus gas heating value, various mathematical models have been developed, *viz.* thermodynamic equilibrium model, kinetic model, computational fluid dynamic model, and artificial neural network model and a comparison of these models can be found in literature (Mikulandric et al., 2014; La Villetta et al., 2017). Among all, the thermodynamic equilibrium models are independent of the gasifier design and thus can be used to analyze the influence of feedstock type and other process parameters on product gas quality (Zainal et al., 2001). Here, the aim of our study is to identify and compare alternate feedstocks for gasification based on the producer gas compositions. In this context, simulation is essential, and the thermodynamic modeling approach is one of the convenient and useful options among all the models. The basic underlying assumptions for equilibrium modeling can be found elsewhere (Gautam et al., 2010; La Villetta et al., 2017).

There are two approaches to the equilibrium modeling i.e. stoichiometric and non-stoichiometric equilibrium modeling. Stoichiometric models are based on the determination of equilibrium constants of an independent set of reactions whereas, non-stoichiometric model involves minimisation of the Gibbs free energy. La Villetta

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Review

Production and utilization of fuel pellets from biomass: A review

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ARTICLE INFO

Keywords:
Bioenergy
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Pelletization
Fuel pellets
Energy utilization

ABSTRACT

Bioenergy is the largest contributor of global renewables, simultaneously providing energy security to billions and stimulates rural development. The growing industrial demand of wood pellets for bioenergy coupled with sustainability issue have encouraged many to produce fuel pellets from non-woody biomass. The production and utilization of fuel pellets from varied feedstocks have therefore opened up opportunities and challenges for the existing technologies. The paper presents a state-of-the-art review on production and utilization of fuel pellets from biomass. This includes different aspects of pellet making process including pre-possessing of biomass for pelletization, influence of process parameters on pellet quality and various ways to utilize pellets. Finally the review ends with a discussion on the economic feasibility of fuel pellets for energy utilization.

1. Introduction

In the year 2017, the world primary energy consumption increased to 13.5 billion tons of oil equivalent which is about 565 EJ (exajoules), along with a decadal average growth rate of 1.7% per year [1]. Therefore, renewable energy is becoming inevitable in the view of ever-increasing energy need, depleting fossil fuel reserves, and environmental concerns. It is expected that the renewable energy market will gain momentum in near future, after the Paris agreement-2015, a commitment to fight climate change. This is a first worldwide climate agreement, a binding treaty that aims to limit climate change to a temperate increase of under 2 °C compared to pre-industrial level [2]. The sustainable development goals of the United Nations also underline the importance of energy. 'Affordable and clean energy' in Goal 7 and 'Climate action' in Goal 13, highlight the significance of new and renewable energy to transform the world [3]. So, the energy sustainability goes hand-in-hand with the sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4]. It is expected that renewable energy will play a significant role in the world's future energy mix. Furthermore, renewables are non-depleting, clean and thus sustainable.

Till date, the renewable energy is contributing of about 19.3% to global final energy consumption as per REN21's 2017 report (Fig. 1) [5]. Solar, wind, hydro, biomass, geothermal are the important sources of renewable energy. Among renewables, biomass energy shares the largest, which accounts for 9% (~51 EJ) of total primary energy supply in the world, out of which 55.4% relates to traditional use (cooking and heating) of biomass and waste resources in developing countries [6]. Slade et al. [7] estimated with reasonable assumptions that biomass has the potential to contribute up to ~100 EJ (~70 EJ from energy crops and ~30 EJ from wastes) in global energy supply. Moreover, biomass is referred to as a carbon neutral fuel because there is no net addition of carbon dioxide in the atmosphere unlike fossil fuels [8]. The use of agricultural residues and organic wastes as fuel substitutes will reduce emissions due to open burning and landfill disposal, respectively and thus, become a source of income for all stakeholders. In this context, biomass has significant potential to be used as a renewable and sustainable source for bioenergy production.

Biomass can be transformed into solid, liquid and gaseous form using modern technologies, and thus becomes an efficient and clean energy supplier for all sectors such as heat, power and transport fuel [9]. There are two routes for biomass conversion, namely the biochemical route and the thermochemical route. The biochemical conversion process uses enzymes, bacteria or other microorganism to convert lignocellulosic biomass into liquid biofuels. In the thermochemical conversion process, biomass converts to any form of energy in presence of heat and with control supply of oxygen. In comparison to biochemical route, thermochemical route has certain advantages, such as utilization of entire biomass, faster kinetics, and flexibility in the feedstock [10]. We focus only on thermochemical route for biomass conversion in the present review (Fig. 2). There are three main thermochemical pathways, such as direct combustion, gasification, and pyrolysis. Direct combustion of firewood is the main energy source among rural areas of developing countries in Asia and Africa for

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Energy for Sustainable Development

Pilot scale evaluation of fuel pellets production from garden waste biomass

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Biomass feedstock
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Pelletization
Pellet quality
Sustainable energy

ABSTRACT

Pelletization of garden waste, without additional binder, was investigated to produce high quality fuel pellets for energy utilization. The influence of pelletization parameters viz. feedstock moisture content (5, 15, 25, and 35%), milling size (25.4 and 6.25 mm) and die size (12 and 15 mm) on pellet quality and pelletization process was studied. The results showed that the studied parameters had significant effect on pellet quality. A reduction in average durability value (95.0% to 92.5%) was observed when moisture content of garden waste increased from 5% to 15%. Appropriate regression models were also developed for each quality attribute by using multiple linear regressions. Eventually, a feedstock moisture content of 5 ± 1%, milling size of 6.35 mm and die size of 15 mm were found to offer standard quality pellets with optimum throughput capacity. Scanning electron microscopy image analysis showed a closer agglomeration of biomass particles when feed materials were pelletized at low moisture content. The equilibrium moisture content due to adsorption for garden waste pellet was found to be 14.6% which was quite low as compared to other feedstocks. Furthermore, we deduced from the combustion test that garden waste pellets may be conveniently used in a residential cookstove. In a nutshell, pelletization of garden waste biomass has been demonstrated at pilot scale in this study.

Introduction

Densification of biomass through pelletization allows one to use carbon neutral fuel with higher energy density thereby reducing the transportation, handling and storage costs (Tumuluru, Wright, Hess, & Kenney, 2011; Miao, Grift, & Ting, 2014). Fuel pellets have various applications, ranging from residential stoves to full-scale power plants (Holm, Henriksen, Hustad, & Sørensen, 2006; Moya, Rodríguez-Zúñiga, Tenorio, Valdez, & Valaert, 2015; Chen et al., 2016). The commonly used biomass feedstock is wood and the market of wood biomass pellets has shown an exponential rise of 0.5 million tonnes (8.5 Peta Joule) to 6.6 million tonnes (120 Peta Joule) between 2000 and 2010 (Lamers, Junginger, Hamelinck, & Faaij, 2012); further the production is projected to increase to 45.2 million tonnes in 2020 (Guo, Song, & Buhain, 2015). The growing demand of fuel pellets has stimulated search for alternate lignocellulosic biomass. After wood wastes, agricultural residues are being considered as potential feedstock available in substantial quantities. Several researchers have investigated pelletization of agricultural residues using binders such as starch, wood powder, lignosulphate etc. to produce highly durable pellets (Serrano, Monedero, Lapuerta, & Portero, 2011; Mediavilla, Esteban, & Fernández, 2012; Said, Abdel Daiem, Garcia-Maraver, & Zamorano, 2015; Stasiak et al., 2017). However, external binder may add to the production cost of the pellets (Jiang et al., 2016). In contrast, garden waste i.e. leaf litters from various tree species, has natural binder such as lignin (Kaliyan & Morey, 2010) which favours solid bridge formation during the pelletization process and hence, the additional cost of binder can be avoided.

In recent times, garden waste is disposed off in open dumps and landfills, which raises socio-environment problems. According to an estimate, the cities in China namely, Beijing and Shanghai, generate about 2.5 million tons of garden waste per year (Shi, Ge, Chang, Shao, & Tang, 2013) and in New Delhi, India, the garden waste shares up to 23% of total landfill waste i.e. 1150 tonnes per day (Chakraborty, Sharma, Pandey, & Gupta, 2013). Thus, garden waste, a potentially huge underutilised biomass can be considered as an alternate guaranteed biomass feedstock to pellet manufacturers relying on wood and agricultural residues (Lamers et al., 2012). Therefore, there is a need to study the pelletizer performance and quality of pellets produced using garden waste which in itself is a unique raw material when its chemical composition is compared with standard pellets made from wood sawdust or homogeneous agricultural residues such as wheat straw, and corn stover (Theerarattananoon et al., 2011).

Various pellet quality standards have been prescribed to maintain homogeneity of pellets both at national and international markets (Table A.1). These pellet properties depend on the type of feedstock, type and quantity of additives, machine specific parameters and expertise

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Combustion and performance of a diesel engine with preheated *Jatropha curcas* oil using waste heat from exhaust gas

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HIGHLIGHTS

- Improvement in fuel properties by preheating.
- Utilization of heat from exhaust gas.
- Performance of preheated Jatropha oil vis-à-vis diesel.
- Lowered ignition delay for preheated Jatropha oil as compared to diesel.
- Lower emissions with preheated Jatropha oil as compared to dieses1.

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Heat exchanger
Performance
Preheated Jatropha Oil
Reduced emissions

ABSTRACT

The viscosity and density of CJO (crude Jatropha oil) were reduced by heating it using the heat from exhaust gas of a diesel engine with an appropriately designed helical coil heat exchanger. Experiments were conducted to evaluate the combustion characteristics of a DI (direct injection) diesel engine using PJO (preheated Jatropha oil). It exhibited a marginally higher cylinder gas pressure, rate of pressure rise and heat release rate as compared to HSD (high speed diesel) during the initial stages of combustion for all engine loadings. Ignition delay was shorter for PJO as compared to HSD. The results also indicated that BSFC (brake specific fuel consumption) and EGT (exhaust gas temperature) increased while BTE (brake thermal efficiency) decreased with PJO as compared to HSD for all engine loadings. The reductions in CO_2 (carbon dioxide), HC (hydrocarbon) and NO_x (nitrous oxide) emissions were observed for PJO along with increased CO (carbon monoxide) emission as compared to those of HSD.

1. Introduction

The rapid depletion of conventional fuel and fluctuation of diesel price in the global market have promoted research for alternative fuels for diesel engine. Among the different alternative fuels, vegetable oil having fuel properties similar to diesel has an acceptable engine performance for short-term operation only [1]. However, long term endurance tests with vegetable oil reported some engine durability issues such as severe engine deposits, piston ring sticking, injector choking, gum formation and lubricating oil thickening [2]. These problems are primarily attributed to high viscosity and poor volatility of straight vegetable oils due to large molecular weight and bulky molecular structure. Higher viscosity of vegetable oil (30–200 cSt at 40 °C) as compared to mineral diesel (4 cSt at 40 °C) leads to unsuitable pumping and fuel spray characteristics. For long running, straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI (compression ignition) engine but this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs. The other alternative could be use of heated vegetable oils as petroleum fuel substitute. Further, heating of oil using exhaust gas from a diesel engine is an attractive proposition.

The viscosity of Jatropha oil was decreased remarkably with increase in temperature and it became close to diesel at temperature above 75 °C [3]. The density of Jatropha oil was reduced from 900.21 kg/m^3 to 883.97 kg/m^3 by raising the temperature of oil from 15 °C to 90 °C [4]. Heating the Jatropha oil between 90 °C and 100 °C was adequate to bring down the viscosity in close range to diesel [5]. Chauhan et al. [6] reduced the viscosity of oil by heating from exhaust gases before feeding to the engine with an appropriately designed shell and tube heat exchanger with exhaust bypass arrangement. Further, optimal fuel inlet temperature was found to be 80 °C considering the BTE and BSEC (brake specific energy consumption). However, combustion characteristics of

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