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Effects of Agro-Industrial Residues on Dual Fuel Mode in CI Engine

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Key words: Agro-industries residues, producer gas, fluidized bed, CI engine, equivalence ratio

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Abstract: In this study, a fluidized bed gasifier with a capacity of 20 kg h^{-1} was designed and developed to use agro-industries residues such as Rice Husk (RH) and Sugarcane Bagasse (SB) as a feed stock are used in this investigation. The objective of this work was to generate better gas efficiency based on equivalence ratio, particle size by optimum parameters such as a reactor temperature (t), equivalence ratio (e), pressure (p), feed size (f_s) and fuel consumption rate (f_c) with the help of design matrix to find the optimum condition and by performing the experimental work for generating Producer Gas (PG) use to drive the CI engine on dual fuel mode with minor modification in engine inlet manifold. This report also reveals the performance of CI engine coupled with gasifier to operate in dual-fuel mode. The full potentiality of biomass for gasification was successfully investigated furthermore, the producer gas from two feed materials used as dual fuel mode with diesel to run single cylinder four stroke water cooled engine with a rated power and speed of 3.75 kW and 1500 rpm, respectively. By considered variables performance such as break thermal efficiency and specific fuel consumption. This study also includes the feasibility of producer gas used as secondary fuel with diesel for different feed materials, considered in this work for the optimum process parameters.

INTRODUCTION

Alternative energy sources to meet the rural area, producer gas from biomass from Agro- industry residues appear to have the greatest potential. It is estimated that about 60% of agriculture residues are not used properly or put to inefficient use[1]. Thermo-chemically technology has been especially developed for woody residues and industrial residues[2]. Gasification as a process converting carbon rich biomass material in to gaseous products using gasifying agent such as air and steam for combustion of low density materials[3]. The sugarcane by product such as bagasse with the energy content (<18 MJ kg^{-1}). Thermodynamically efficient in converting into fuel gas mixture containing CO_2, CO, CH_4, H_2 and also N_2. SB used to generate power as co-generation process by conversion of bagasse into heat, steam or gasses products as producer gas used in generation of power and sales of surplus electricity[4, 5]. Agriculture based residues such RH and SB are rich in sulphur and nickel contents is appreciated for gasification as a commercial scale[6]. Besides, the gasification yields a clean fuel gas can be utilized to generate producer gas using Agro-industrial by products. The potentiality of RH and SB for a pilot scale fluidized bed gasifier has been developed and investigated using two different feed materials. The literature review, reveals the effects of operating parameters on fluidized bed gasification efficiency some investigations shows the quality of producer gas with respect to process parameters such as reactor temperature, pressure, rate of feeding, equivalence ratio and effect of particle size of biomass[7]. This researches also consists the conversion of diesel engine running on diesel-cum producer gas as dual fuel mode.

Gasification process generate clean gas using Agro-industries residues such as RH and SB to run a diesel engine with minor modification in inlet manifold can be made to operate on dual fuel efficiency[8]. Performance of the four stroke diesel engine single cylinder 3.75 kW with respect to its brake thermal efficiency, specific fuel consumption and substitution by use of diesel alone first and producer gas cum-diesel as a secondary fuel through a fluidized bed gasifier. The brake thermal efficiency of engine reported 16-20%[9]. When the gasifier efficiency >70% when engine run with producer cum-diesel fuel.

There is insufficient data on the use of different biomass types and conditions to generate producer gas as a supplementary fuel for diesel engine. Therefore an effort was made to generate producer gas using Agro-industrial residues by studied and evaluating the process parameters with the help of mathematical models using design matrix. The major objectives in this study were as follows:

- To generate producer gas from Agro-industrial residues by the optimization process parameters with help of design matrix
- To fabricate the different components of gas produces and minor modification an engine manifold to operate on a dual fuel mode
- To evaluate the performance of diesel engine for brake thermal efficiency, specific fuel consumption

MATERIALS AND METHODS

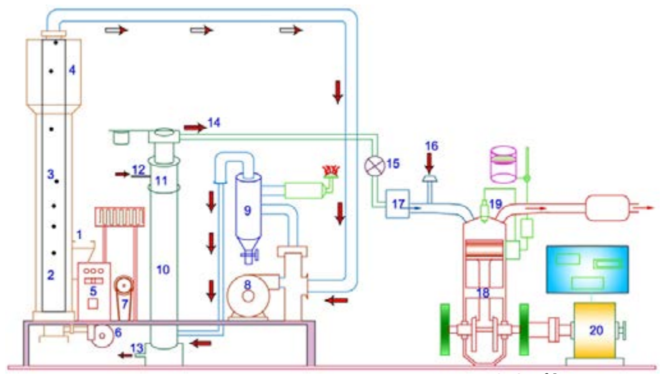
The agro-industry biomass selected to study the optimum condition values to incorporated by fluidized parameters such as temperature (t), equivalence ratio (e), pressure (p), feed size (f_s) and fuel consumption rate (f_c). These residues were collected from agro-industries located near Chidambaram village in India. The physio-chemical properties are analyses as shown in Table 1. The bed material used as silica material and specific gravity of the selected materials were measured by bottle methods, particle size were determined by sieve analysis to reduce the complexities results from different in particle size[10]. The proximate component such as volatile matter and fixed carbon was found out by ASTM procedures. The pressure drop in the distributor plate was determined by 'U' tube manometer. The air velocity with respect to pressure drop, predict the experimental value for minimum fluidized velocity[11] with the help of orifice and flow rate measured by the anemometer experiments.

A 20 kg h^{-1} capacity fluidized bed gasifier has been developed to carry out the investigation as shown in Fig. 1. Table 2 shows the design and specification of gasifier, the inside of the gasifier refractory lining of thickness 0.1 m, filled with distributor plate of multiple holes. The gasifier provided with silica sands bed and air was blower at the downwards of gasifier and maintained fluidized state. During the experiment gasifier was allowed to run to achieve the bed temperature of 650°C the feed materials and feed rate was controlled by the screw feeder and air supply was then regulated to have derived equivalence ratio[12]. The cyclone separator, the bag filter used to cleaned up the gas to for remove dust and core particle from producer gas mixture. The tar separation through condensation with the help of water cooler and an ice trap system.

Factors influences the gasification process: Previous study reveals[13, 20] various factors influence the quality of the producer gas efficiency have been discussed such as reactor bed temperature was less than 650°C required some catalyst hence gasifier is stable around 650°C as lower limits and was 950°C as upper limit expected the gas composition[13]. Pressure less than 1bar, reported in purity of produced gas and greater than 5 bars may be unstable the process control due to hydrogen yield at higher pressure[15]. Feed rate depends on feed materials, feeding rate if <5 kg h^{-1} exposure to melting inside, hence, 20 kg h^{-1} biomass feed rate prevent, forming of feed material on the bottom of a solid bed[16].

Table 1: Ultimate and proximate analysis of agro-industries residues

	Ultimate analysis (%)		Proximate analysis (%)		
Components	Rice husk	Sugarcane bagasse	Components	Rice husk	Sugarcane bagasse
Carbon	50.48	42.51	Volatile matter	70.60	81.32
Hydrogen	6.51	5.94	Fixed carbon	2.97	14.51
Sulphur	0.20	0.09	Moisture	9.45	11.10
Nitrogen	1.49	0.41	Ash	17.09	4.17
Oxygen	41.40	37.54	Calorific value (MJ kg^{-1})	19.81	17.91



1 . Biomass hopper
2. Fluidized bed
3. Thermocouple
4. Free bard
5. Contorl panel
6. Heating coil
7. Screw feeder
8. Blower motor
9. Cyclone
10. Water scrubber
11. Dry filter
12. Water in
13. Water out
14. Gas out
15. Gas control value
16. Air filter
17. Gas to engine
18. Diesel engine
19. Diesel injector
20. Mechanical dynamomete

Fig. 1: Schematic view of experimental setup

Table 2: Specification of gasifier unit

Parameters	Range
Gasifier	Fluidized Bed Gasifier
Gasifier specifications	Diameter (Inner) : 108 mm Total height : 1400 mm
Heating	Electric heating
Coolant	Water
Biomass capacity	20 kg h^{-1}
Feeding method	Screw feeder
Gasifying agents	Air
Temperature	650-950°C
Operating parameters	Bed temperature, pressure, feed rate, equivalence ratio and particle size
Purification	Cyclone, water scrubber, dry filter

Equivalence ratio is an important factors determine the burnt of fuel fraction controlled by bed temperature may be affects the fluidization state equivalent ratio less than 0.2 is insensitive to temperature and >0.5, reported higher heating value of gas was reduced[13]. The feed materials size is implied higher conversion if the particle size <70 µm as lower combustion richness[18] and particle size >500 µm leads to de volatilization time and gasifier size showed increases but reduce the pre-treatment costs[19, 20]. Table shows the physiochemical characteristics of agro-industries residues.

Applying design matrix on gasification to evaluate the optimum condition: Agro-industries residues such as RH and SB are used as the present investigation the predominant factors such as temperature, pressure, feed rate, equivalent ratio, particle size and on the quality of the producer gas efficiency have been identified by different studies. Reactor bed temperature between 650-950°C, pressure 1-5 bar, feed rate 5-20 kg h^{-1}, particle size 70-500 µm, equivalence ratio 0.2-0.5. The use of five important factors out wide range of factors with Central Composite Rotatable Design matrix (CCRD). The number test identified includes with standard 2 k factorial with its origin at the center by fixed axially the 2 k points at a distance α from the center to generate the quadratic terms by replicate the tests at the center points. To maintain rotability the axial points chosen and ensures variance of the model prediction is constant at all points equidistant from the center design.

The design will provide productions against the curvature from twisting by adding axial points and extended up to ±α (axial point). To have rotability the α value depend on the number of experimental runs in the factorial portion of the CCRD given by Eq. 1 and 2:

$$\alpha = [\text{no of factorial point}]^{1/4} \quad (1)$$

$$\alpha = [23]^{1/4} = \pm 1.682 \text{ is for full factorial} \quad (2)$$

When α>1, for factor run at five levels (-α, -1, 0, +1, +α), hence, to achieve rotatable design for CCRD with α>1, however, the factorial design of resolution the center value for the variables were carried out at least six values for the variables were carried out at least six time for the estimation of error and single runs for each tests. Replicates of their test at the center provide an independent and uniform data of the prediction variance over the design data and the important factors influence of the gasification levels are shown in Table 3. The upper and lower levels of the factors are coded as +1.682 and -1.682, respectively for recording and processing the experimental data, using Eq. 3 calculating the coded value of any intermediate value:

$$Xi = 1.682\left[2x\text{-}(Xmax\text{-}Xmin)/(Xmax\text{-}Xmin)\right) \quad (3)$$

Where:

Xi = Coded value of a variable X
X = The value of the variable from X min to X max
Xmin = The lower level of the variable
Xmax = The upper level of the variable

Table 3: Important factors and its levels

Factors	Units	Notation	Factors levels -1.682	-1	0	1	1.682
Bed temperature	Celsius	t	650	725	800	875	950
Pressure	MPa	p	1	2	3	4	5
Fuel consumption rate	kg h^{-1}	f_c	5	8.75	12.5	16.25	20
Feed size	µm	f_s	70	142.5	215	357.5	500
Equivalence ratio		e	0.2	0.275	0.35	0.425	0.5

Table 4: Design matrix and experimental test results for agro- industries residues

Agro-industries residues	Input parameters Bed temperature (°C)	Pressure (MPa)	Feed rate (kg h^1)	Equivalence ratio	Particle size (µm)	Gas composition (%) Gas efficiency
Rice husk	875	4	16.25	0.275	270	61.63
Sugarcane bagasse	950	3	12.5	0.35	285	65.95

Design matrix consisting of 20 sets of coded conditions with full replication, 8 factorial points, 6 corner points and 6 center points was taken in this investigation to optimize the process parameters (Table 3).

Experimental testing done by selected Agro-industries feed stock such as RH and SB used to operate the gasifier with the reactor bed temperature kept in the range of 650-950°C When the experiments were carried out with equivalent pressure 1-5 bar; feed rate 5-20 kg h^{-1}; particle size 70-500 µm; Equivalence ratio 0.2-0.5 with a gas efficiency of rice husk 61.63% and sugarcane bagasse 65.95%, respectively. Table 4 shows the optimum experimental test results using design matrix out of 20 runs each for agro-industries residues such as RH and SB, respectively.

Experimental work in CI engine on dual fuel mode: This report particularly uncovers the use of producer gas in compression ignition engine with diesel on dual fuel mode. Diesel engine with some minor modification at the inlet manifold can be made to operate on dual fuels. Gasification is one process where clean gases could generated using agro-industries such as RH and SB as the feed stock and in turn use the producer gas for power generation. The dual fuel mode diesel engine operation may save diesel up to 85%[8].

Experiments investigation have been conducted on four stroke water cooled CI direct injection system performance evaluation of both the engine and the gasification process is reported[21] the performance of a diesel engine coupled to a biomass fluidized bed gasifier in the dual fuel operation with proper purification of producer gas. Engine performance evaluations have been established the feasibility of producer gas engine after investigation the performance of brake thermal efficiency and specific fuel consumption for producer gas generate from two different agro-industries residues.

Evaluation of engine: Experimental investigation on kirloskar make single cylinder water cooled engine was used for the investigations producer gas from fluidized bed gasifier using agro-industries residues such as RH and SB. The producer gas generate from the gasifier is send along with air into a diesel engine with diesel as the primary and producer gas as secondary fuel the performance characteristics such as brake thermal efficiency, specific fuel consumption of the engine was studied along with and without of producer gas. The intake manifold of the engine was modified using a T-joint to introduce the mixture of air and gas into the engine during suction stroke. The quantity of gas and air flowing to the engine was measured separately with help of orifice provided in the T-section. The fuel supply of the engine from its fuel tank was operated on dual fuel mode and the diesel fuel was provided with a fuel measuring set-up.

Table 5: Engine specification

Parameters	Specifications
Type/model	Vertical/kirloskar
Fuel diesel	
No.of.cylinder	One
Brake power (kW)	3.7
Speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Combustion	Compression ignition
Cooling system	Water cooled

In order to measure the load applied to the engine coupled with mechanical dynamometer (rope brake friction type) was used when the engine reached the operating temperature, the test was conducted by varying the load from no load, 20, 40 and 60% with respect to full load conditions by properly filled loading arrangement as shown in figure were engine coupled with fluidized bed gasifier. The various load conditions with respect to rated brake power by maintained rated speed from no load to full load condition of the engine was calculated given in Eq. 4-11 as specimen calculation for diesel alone and dual fuel mode. Table 5 shows the specifications of the engine.

For diesel alone:

$$\text{Brake power} = \text{Torque}\times\text{Angular velocity} = (\text{T1-T2})\,\text{Re}\times 2\pi\text{N} \quad (4)$$

Where:
N = About 1500 rpm
Re = Torque arm length = 0.305 m

$$\text{Fuel consumption} = \frac{10}{\text{Tavg}} \times \text{Specific gravity of fuel} \times \text{density of water} \quad (5)$$

Assume:

$$\begin{aligned}&\text{Frictional power} = 30\% \text{ rated power}\\&\text{Indicated power} = \text{Brakepower+Fuel power}\end{aligned} \quad (6)$$

$$\text{Mechanical efficiency} = \frac{\text{Brake power}}{\text{Indicated power}} \quad (7)$$

$$\text{Specific fuel consumption} = \frac{\text{Frictional power}}{\text{Brake power}} \quad (8)$$

$$\text{Fuel power} = \frac{\text{Fuel consumption}}{\text{Heating value of fuel}} \quad (9)$$

Brake thermal efficiency:

$$\eta\text{bth} = \frac{\text{Brake power}}{\text{mf+Heating value of fuel}} \times 100 \quad (10)$$

For dual fuel engine:

$$\eta\text{th} = \frac{\text{Brake power}}{\text{mf+Heating value of fuel+ mg} \times \text{Heating value of gas}} \times 100 \quad (11)$$

where, mf and mg mass flow rate of diesel and producer gas respectively, heating value of combustion of diesel and producer gas respectively diesel saving means quality of diesel which is substituted by producer gas during the experiment can be calculated by Eq. 12.

$$\text{Diesel saving(\%)} = \frac{\text{Mass of diesel-Mass of diesel in dual mode}}{\text{Mass of diesel}} \times 100 \quad (12)$$

RESULTS AND DISCUSSION

In this research, the performances of load tests were conducted on dual fuel mode with diesel as primary source and producer gas from gasifier as secondary fuel. The ratio of the power developed to the rated, power and speed of the engine specification with respect to different load conditions is called as load test. The relationship with brake thermal efficiency and specific fuel consumption for various load condition at constant speed will give the economical load condition at the specific brake power.

The specific fuel intake depends on load and speed of the engine and mechanical work available at the shaft of engine terms as brake power. The producer gas from the two different Agro-industries residues, operated at optimum condition was send to the diesel engine and comparison takes place with and without the addition of producer gas for two biomasses such as RH and SB as raw materials after cooling and purification with filters and directed to the diesel engine. The diesel engine is first operated with diesel and air along with producer gas is send to the engine at no load, 20, 40 and 60% load conditions.

Determining the various process parameters by using design matrix to generate the producer gas from agro industries residues as secondary fuel and diesel as primary fuel to drive the diesel engine on dual fuel mode for investigating the performance characteristics of the engine for mass of diesel consumption, brake thermal efficiency and specific fuel consumption.

Table 6 and Fig. 2 shows amount of diesel consumption with and without producer gas for different load condition. The amount of diesel consumption was reported as 2650 mL h^{-1} at 60% load condition when the engine operated at the diesel alone for the same load condition saving of diesel reported as 780 and 600 mL h^{-1}, respectively for engine operating with the diesel and producer gas generated in the case of RH and SB, respectively when used as the feed materials.

Table 7 shows the variation of brake thermal efficiency with various engine loads as diesel along and dual fuel mode using producer gas from different biomasses. Table 8 shows the specific fuel

Table 6: Amount of diesel consumption with and without producer gas for different loads

			Rice husk	Sugarcane bagasse
Load (%)	Brake Power, BP (kW)	Diesel (mLh^{-1})	Diesel+producer gas (mL h^{-1})	Diesel+producer gas (mL h^{-1})
0	0	1440	1090	1210
20	1	1210	1210	890
40	2	1930	1690	1550
60	3	2650	2170	2050

Table 7: Brake thermal efficiency for different loads with and without producer gas in (%)

			Rice husk	Sugarcane bagasse
Load (%)	Brake Power, BP (kW)	Diesel (mL h^{-1})	Diesel+producer gas (%)	Diesel+producer gas (%)
0	0	-	-	-
20	1	11.55	7.97	8.68
40	2	15.71	10.83	12.36
60	3	18.17	11.91	14.41

Table 8: Specific fuel consumption for different loads with and without producer gas in (MJ kWh^{-1})

			Rice husk	Sugarcane bagasse
Load (%)	Brake Power, BP (kW)	Diesel (mL h^{-1})	Diesel+producer gas (MJ kWh^{-1})	Diesel+producer gas (MJ k Wh^{-1})
0	0	-	-	-
20	1	42.03	42.03	30.85
40	2	33.65	29.45	27.01
60	3	30.85	25.26	23.28

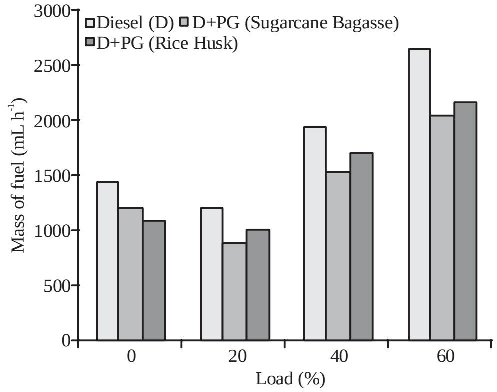


Fig. 2: Mass of diesel consumption in dual fuel mode

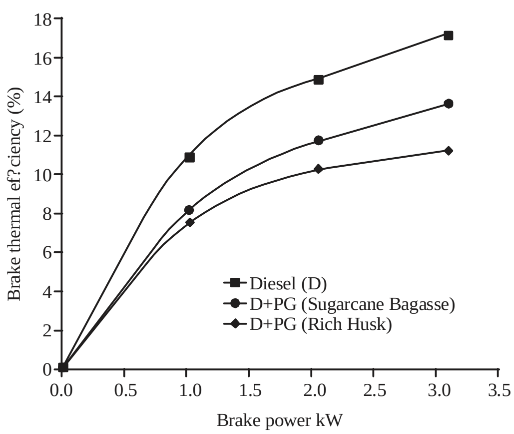


Fig. 3: Brake thermal efficiency Vs. Brake power

consumption per unit brake power with respect to mass of the fuel consumed per unit time.

Brake thermal efficiency: It is ratio of brake power in input fuel power with respect to output power generated by the engine as heat energy supplied to the engine as a result of burning the fuel. The brake thermal efficiency for diesel engine and dual fuel mode as calculated by Eq. 11. The quantity of diesel saving by substituting producer gas during the experiment work is calculated by the Eq. 12.

The results showed that there was a drop in the thermal efficiency of the diesel engine on dual fuel mode when compared with diesel alone. In general the specific fuel consumption decreased with increase in engine load at different load condition in all the cases.

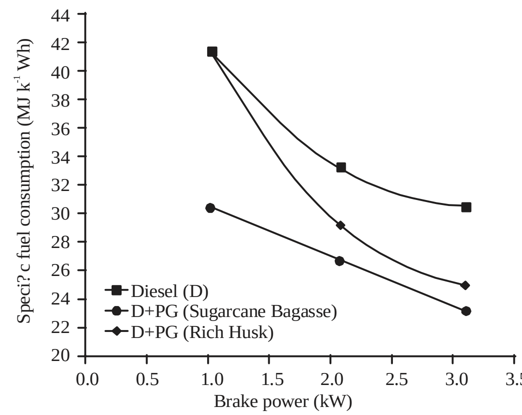


Fig. 4: Specific fuel consumption vs. brake power

The maximum efficiency reported by diesel alone was 18.17% where as in dual fuel mode maximum efficiency was achieved was 11.91 and 14.41%, respectively for D+PG (RH) and D+PG (SB), respectively as shown in Fig. 3. The reduction in thermal efficiency in the case of dual fuel mode is due to the lower calorific value of producer gas. When the combusted mixture enters the engine at higher temperature may reduce in density which results in reduction of mass flow rate of the producer gas and air for the combustion process, hence insufficient O_2 in the combustion process cause incomplete combustion[22]. The optimum brake thermal efficiency is 16.77 and 15.25% on dual combustion for 60% load condition with sugarcane bagasse and rice husk, respectively.

Specific fuel consumption: The relationship between specific fuel consumption and brake power is shown in Fig. 4. The specific fuel consumption in dual fuel mode was found to be higher than that of diesel fuel alone for all the load condition and also in all cases of biomasses. The specific fuel consumption for dual fuel mode was calculated from fuel consumption plus heating value of diesel and producer gas. In general specific fuel consumption is inversely proportional to brake thermal efficiency. The specific fuel consumption decreases with respect to the flow rate of producer gas results reduction in brake thermal efficiency the results shows the producer gas from sugarcane bagasse plus diesel reports 21.77 MJ kWh^{-1} for a brake power of 3 kW and minimum diesel fuel consumption of 30.85 mL h^{-1}. As shown in Fig. 4 specific fuel consumption for different loads with and without producer gas.

CONCLUSION

The performance characteristics are experimentally investigated using diesel engine in a single cylinder four stroke water cooled engine operating with diesel and producer gas from fluidized bed gasifier with two different agro-industries residues by operating at optimum condition the following conclusion are made on the basis of this studies.

Fluidized bed gas producer designed and developed with a 20 kg h^{-1} capacity for run a 3.7 kW diesel engine was found to perform satisfactorily by using two different Agro- industries biomasses such as RH and SB. Maximum gas efficiency with influence of process parameters achieved for experimental investigation using design matrix.

The brake thermal efficiency of engine was found to be slightly dropped on dual fuel mode for all the biomass fuel. However the efficiency for 60% load condition in diesel 18.17% and on dual fuel mode as 11.91 and 14.41%, respectively was comparable to the diesel mode.

The brake thermal efficiency for all cases and loads condition was found to be lower when producer gas used on dual fuel mode however it gives maximum saving of diesel fuel up to 29.43 at 60% load condition using producer gas in comparison with running the engine with diesel alone.

The experimental results show 2% reduction in brake thermal efficiency for the maximum value of dual fuel mode operate at 60% load condition due to the heating value of producer gas.

REFERENCES

01. Ghosal, M.K., D.K. Das and S.P. Dash, 2011. Performance study of a diesel engine by using producer gas from selected agricultural residues on dual-fuel mode of diesel-cum-producer gas. Proceedings of the World Renewable Energy Congress-Sweden, May 8-13, 2011, Linkoping University Electronic Press, Sweden, pp: 3541-3548.
02. Ahmed, I.I. and A.K. Gupta, 2010. Kinetics of woodchips char gasification with steam and carbon dioxide. Applied Energy, 88: 1613-1619.
03. Ghaly, A.E. and A.M. Al-Taweel, 1986. Mackay: GDM project report renewable energy division. Energy Mines and Resources, Canada, Ottawa.
04. Nguyen, V.H. and V.S. Nguyen, 2006. Clean Development Mechanism Project Design Documents (CDM-PDD) for pilot grid connected rice husk fueled bio-power development projects in Mekong Delta, Vietnam: Second technical report. EEPSEA, Hanoi, VietNam.
05. Nguyen, N.T. and M. Ha-Duong, 2009. Economic potential of renewable energy in Vietnam's power sector. Energy Policy, 37: 1601-1613.
06. Hernandez, J.J., G. Aranda-Almansa and C. Serrano, 2010. Co-gasification of biomass wastes and coal-coke blends in an entrained flow gasifier: An experimental study. Energy Fuels, 24: 2479-2488.
07. Altafini, C.R., P.R. Wander and R.M. Barreto, 2003. Prediction of the working parameters of a wood waste gasifier through an equilibrium model. Energy Convers. Manage., 44: 2763-2777.
08. Ali, S., S. Upadhyay and D. Kumar, 2015. Experimental evaluation of performance variables and emissions for producer gas-diesel engine. Int. J. Technol. Res. Eng., 2: 3122-3125.
09. Tiwari, G.N. and M.K. Ghosal, 2007. Fundamentals of Renewable Energy Sources: Basic Principles and Applications. Narosa Publishing House, New Delhi, India,.
10. Lin, C.L., M.Y. Wey and S.D. You, 2002. The effect of particle size distribution on minimum fluidization velocity at high temperature. Powder Technol., 126: 297-301.
11. Filippis, P.D., C. Borgianni, M. Paolucci and F. Pochetti, 2004. Gasification process of Cuban bagasse in a two-stage reactor. Biomass Bioenergy, 27: 247-252.
12. Alauddin, Z.A.B.Z., P. Lahijani, M. Mohammadi and A.R. Mohamed, 2010. Gasification of lignocellulosic biomass in fluidized beds for renewable energy development: A review. Renew. Sustain. Energy Rev., 14: 2852-2862.
13. Van der Drift, A., J. Van Doorn and J.W. Vermeulen, 2002. Ten residual biomass fuels for circulating fluidized-bed gasification. Biomass Bioenergy, 20: 45-56.
14. Luo, S., B. Xiao, Z. Hu, S. Liu, Y. Guan and L. Cai, 2010. Influence of particle size on pyrolysis and gasification performance of municipal solid waste in a fixed bed reactor. Bioresour. Technol., 101: 6517-6520.
15. Martinez-Lera, S., J. Torrico, J. Pallares and A. Gil, 2013. Design and first experimental results of a bubbling fluidized bed for air gasification of plastic waste. J. Mater. Cycles Waste Manage., 15: 370-380.
16. Risberg, M., O.G.W. Ohrman, B.R. Gebart, P.T. Nilsson, A. Gudmundsson and M. Sanati, 2014. Influence from fuel type on the performance of an air-blown cyclone gasifier. Fuel, 116: 751-759.
17. Mansaray, K.G., A.E. Ghaly, A.M. Al-Taweel, F. Hamdullahpur and V.I. Ugursal, 2002. Air gasification of rice husk in a dual distributor type fluidized bed gasifier. Biomass Bioenergy, 17: 315-332.
18. Schiefelbein, G.F., 2003. Biomass thermal gasification research: Recent results from the United States DOE's research program. Biomass, 19: 145-159.

19. Alauddin, Z.A.B.Z., P. Lahijani, M. Mohammadi and A.R. Mohamed, 2010. Gasification of lignocellulosic biomass in fluidized beds for renewable energy development: A review. Renew. Sustain. Energy Rev., 14: 2852-2862.
20. Han, J., H. Kim, W. Minami, T. Shimizu and G. Wang, 2007. The effect of the particle size of alumina sand on the combustion and emission behavior of cedar pellets in a fluidized bed combustor. Bioresour. Technol., 99: 3782-3786.
21. Dasappa, S. and H.V. Sridhar, 2011. Performance of a diesel engine in a dual fuel mode using producer gas for electricity power generation. Int. J. Sustainable Energy, 32: 153-168.
22. Deshmukh, S.J., L.B. Bhuyar and S.B. Thakre, 2008. Investigation on performance and emission characteristics of CI engine fuelled with producer gas and esters of Hingan (Balanites) oil in dual fuel mode. Int. J. Aerosp. Mech. Eng., Vol. 2.