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RESEARCH ARTICLE

Design, Fabrication and Performance Evaluation of Updraft Gasifier for Small Sized Internal Combustion Engines

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ABSTRACT

Energy is necessary for the existence of human beings and to support the modernization of the community. Biomass has been one of the main energy sources of mankind ever since the dawn of civilization, though its significance subsided after the Second World War due to the cheaper and easily useable fossil fuels (oil and gas). In developing countries, biomass is a main source of energy in rural areas. In Pakistan, agriculture sector suffered very badly due to unavailability and high cost of energy. Diesel engines and tractors are major sources of farm power, which increase the cost of production due to higher fuel prices, therefore, gasification could be the most reliable and best alternate to get the energy from the biomass. Gasifiers are the reactors which convert the solid fuels into the gaseous fuels. In this study, an updraft gasifier was designed, fabricated and evaluated to run 15 to 18.6 kW (20-25 hp) diesel engine for irrigation tube well to reduce the cost of operation. The gasifier was evaluated by using different biomass fuels and Completely Randomized Design (CRD) was used to statistically analyze the collected data. The average gas produced by burning of rice husk, rice husk + saw dust and saw dust produced 2.13 m^3/kg, 2.30 m^3/kg and 2.54 m^3/kg producer gas, respectively in updraft gasifier. The engine running times (hours) recorded for rice husk, rice husk + sawdust and with sawdust were 1.66, 1.78 and 1.90, respectively. The gas produced was used to run a 15 kW single cylinder diesel engine with dual fuel (25% diesel and 75% producer gas) at rated rpm successfully.

INTRODUCTION

Energy is essential need for our lives. At present, we rely entirely on abundant and continuous supply of energy for living and working. It is a key factor in all sectors of modern economies. It is clear that the energy demand will increase dramatically in the future. How can we meet this huge environmentally friendly energy requirement? The answer to this question is alternate/renewable energy. At present only a small proportion of the world's energy needs come from alternative and renewable energy sources. These exist in many forms including solar thermal, photovoltaic, wind, hydro, tidal/wave and bioenergy (including biomass, biogas and biofuels).

For countries like Pakistan (rich in natural resources and a population of more than 180 millions), the importance of alternate/renewable energy grows into even more demanding due to the fact of limited hydro potential. Moreover, an increasing gap between energy demands and supply in Pakistan over a period of time, further poses threat to our long term survivability and existence at national level (Nawaz, 2013).

In Pakistan, the shortage of electricity and natural gas is up to 5,300 MW and 17 million m^3/day, respectively (Asif, 2011). The electricity generated by sources such as hydropower, oil, coal and gas and nuclear were used 33.60, 35.10, 0.10, 27 and 3.90%, respectively in years 2010 to 2011. Hydropower is the only sustainable energy source for large scale power production in Pakistan (Mirza et al., 2011).

In many parts of the world, biomass is used as energy source especially for remote areas where supply of high quality fossil fuels is not possible or costly. Biomass is a central substitute energy basis. Energy generated from biomass act as main alternative energy source to luxurious energy assets. By use of burning and cleaning techniques it can be converted into an economical fuel.

Gasification is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion. The resulting gas, known as producer gas, is more versatile in its use than the original solid biomass (Sheth and Babu, 2009). Producer gas consists of carbon monoxide, hydrogen, carbon dioxide, methane, traces of higher hydrocarbons such as ethane and ethylene, water vapor, nitrogen (if air is the oxidizing agent) and various contaminants such as small char particles, ash, tar and oil (Basu, 2013).

In the updraft fixed bed gasifiers, the air, oxygen or steam flows through the bed upwards. The volumetric percentage of methane in the producer gas is significant which facilitates the methanation for SNG (Synthetic Natural Gas) production (Anonymous, 2008).

The first commercial updraft gasifier for continuous gasification of solid fuels with air was developed and installed in 1839 at Paris, France (Chopra and Jain, 2007). Updraft gasifiers were subsequently further developed for different fuels and were widely used in specific industrial power and heat applications up to the 1920's, when their function was gradually taken over by oil fueled engines and furnaces. The internal combustion engine operation would be possible by using wood, charcoal and coal gasifiers. Almost 9 million vehicles were fueled by gasifiers all over the world during Second World War (Breag and Chittenden, 1979).

In this study, an updraft gasifier was designed, fabricated and evaluated for its performance in the Workshop of Department of Farm Machinery and Power, University of Agriculture, Faisalabad, Pakistan to run 15 to 18.6 kW (20-25 hp) four stroke diesel engine (on dual fuel mode) for irrigation tube well operation.

MATERIALS AND METHODS

The sizes of components used for this gasifier design were chosen based on the conversion rate desired for the gasification system (gas required to operate IC engine) and the desire to use off-the-shelf sizes for components. The conversion rate of biomass to producer gas per square inch of cross-sectional area in the gasification chamber was estimated based on the conversion rate used in the updraft gasifier (Bowser et al., 2005). This gasifier (Figure 1) is an updraft and batch type with the basic design inspired by the work of Patil and Rao (1993). Bowser et al. (2005) made improvements to the Patil and Rao gasifier including a motorized scraper blade, improved sensors, off-the shelf pipe and pipe fittings for body components, portability and quick disassembly.

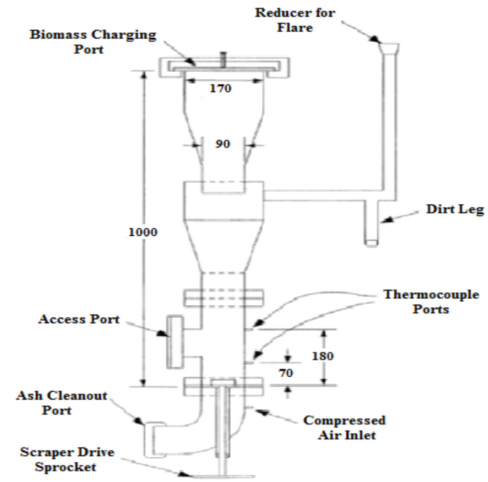

Fig. 1: Schematic diagram of batch type updraft gasifier designed by Bowser et al. (2005)

The body of the gasifier was made of mild steel, 200 mm and 100 mm diameter, schedule-40 pipe, with pipe fittings welded or bolted together and insulated with a calcium silica insulation blanket. The upper section of the gasifier body provided storage for feedstock, which was loaded through the biomass charging port. The body diameter had a reduction from 200 mm to 100 mm intended to reduce pressure on the lower column during operation and to provide some headspace where the flue pipe attached to the gasifier body. However, this reduction acts as a bottleneck to feedstock during operation, compressing the biomass as it moves down and stopping flow. The midsection of the gasifier body included the combustion chamber, thermocouple ports, producer gas exhaust pipe, and access port. The combustion chamber was fabricated from a 10 cm (4 inch) Tee with flange ends. The projecting end of the Tee was used as an access port. The lower portion of the gasifier included an ash grate, rotating motorized scraper assembly, ash receptacle, compressed gas inlet, and ash cleanout port. Ash particles fell through the grate and accumulated in the ash receptacle. This gasifier was also designed and fabricated with some modifications for using eastern red cedar wood as fuel by Sarah Rowland during her master's degree research work (Rowland, 2010).

Notable changes were made in this design to make it convenient for low bulk density fuels i.e. rice husk, sawdust etc. These include:

- An air-tight hopper and screw conveyor to deliver feedstock and make the system capable of operating as a continuous system for short periods of time rather than batch.
- A larger diameter 254 mm rather than 100 mm inner diameter combustion chamber to reduce the effects of the walls on biomass movement.

- No bottlenecks in the gasification chamber. Removal of the bottlenecks allows material to move downward through the system more freely.
- An insulation provides around the combustion chamber to avoid heat loss.
- The producer gas outlet is straight, allowing tar to drip back into the gasifier rather than collecting in the elbow and causing pressure build-up when producer gas cannot escape. Also, there is no “dirt leg” on the producer gas arm.
- There is no side access port on the gasifier. This port was difficult to insulate to avoid any leakage. The combustion zone is initially lit through the ash port.

In this study, the updraft gasifier was constructed using mild steel (MS) sheet having 1.519 mm thickness (16 Gauge) having specific weight of 11.9 kg/m^3.

The complete gasifier unit developed was divided into six different parts viz. i) Reaction chamber with insulation cover ii) Gas collection/outlet unit iii) Ash collection unit with grate iv) Fuel hopper for fuel storage v) Fuel conveying screw auger vi) Stand for supporting the complete unit. The description of different parts is as follows:

i. Reaction chamber with insulation cover

The main body of the gasifier was manufactured by bending mild steel sheets in 250 mm diameter cylindrical shape and 610 mm high. The reaction or gasification chamber was designed and developed to provide favorable environment for the production of producer gas. This reaction chamber was surrounded by another 400 mm diameter cylindrical shell in which a layer of 76 mm thick glass wool was used as insulation material with average thermal conductivity of 0.04 W/m°C and temperature resistance above 1000 °C (Anonymous, 2014). The front and top view of reaction chamber and insulation cover have been presented in Figure 2.

ii. Gas collection/outlet unit

The gas collection unit (Figure 3) was also made in cylindrical shape having 130 mm diameter. This section was 468 mm high for providing the space for the produced gas to stay in this chamber for a short period of time to cool it a little bit. The gas collection unit was fastened with gasification chamber with a bolted flange which can be attached and detached easily for cleaning and maintenances purposes of the gasifier.

The producer gas outlet pipe was fabricated from mild steel and a gas shut off valve and gas sampling port were sealed with the dead end cork for taking samples of the produced gas.

iii. **Ash pit with grate**

After combustion of biomass, ash fall in ash pit that was located at the bottom of the gasifier. A grate was provided in the reduction zone for the air entry in to the reduction section and for the ash to fall into the ash chamber (Figure 4).

v. Fuel hopper for fuel storage

A fuel hopper was designed for the feeding of the biomass to the updraft gasifier (Figure 5a). This section was attached to the gasifier to convert it from batch type to continuous feeding type gasifier. This was necessary to make the gasifier for continuous operation because in batch type it would be refiled with biomass after shutting it down completely. This hopper was connected to the updraft gasifier through gas collection chamber with a fuel delivery pipe (Figure 5b).

vi. Fuel conveying screw auger

A fuel conveying screw auger (Figure 6) was designed and fabricated for the easy feeding of biomass from hopper to the gasifier. This auger conveyor has been found necessary to provide the system in terms of stopping any leakage through this unit. The auger was mounted in the pipe connecting hopper with gasifier with the help of ball bearings for easy rotation.

vii. Stand for supporting the complete unit

The stands were fabricated **(Figure 7a and 7b)** with the angle iron for the support to the hopper and the gasifier. They were made strong enough to support the complete system.

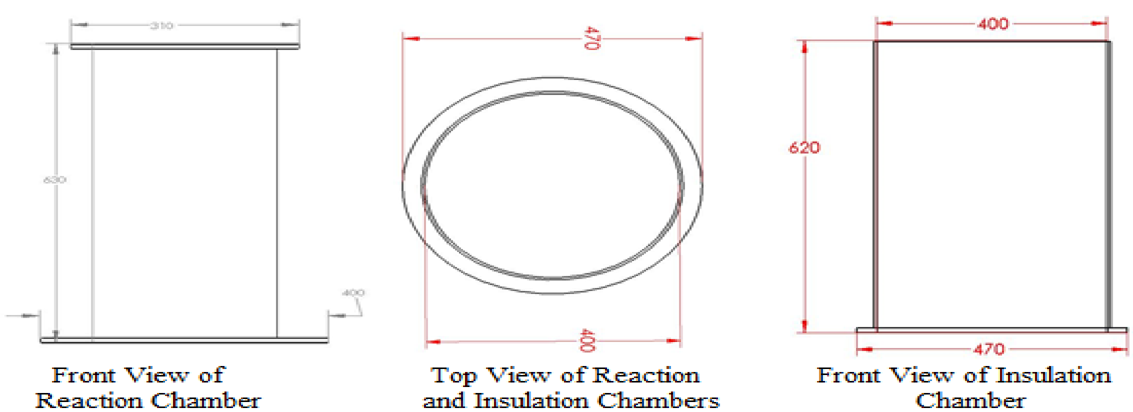

Fig. 2: View of reaction and insulation chambers (All dimensions in mm)

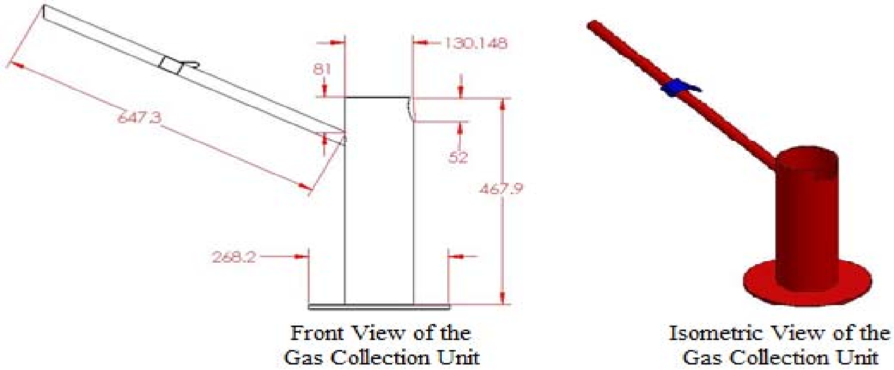

Fig. 3: Gas collection chamber (All dimensions in mm)

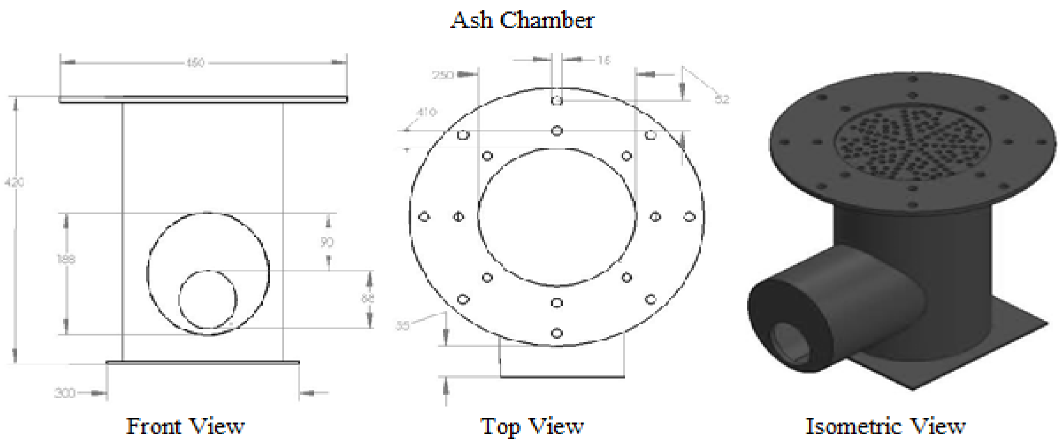

Fig. 4: Ash chamber (All dimensions in mm)

Evaluation of the Gasifier

After complete fabrication of the gasification system was evaluated for its performance. The gasifier was evaluated with different types of biomass feed stock and carried out the analyses of their effects on the production of producer gas, engine running time and the composition of different gases present in the producer gas by using different instruments (IMR2800P Gas Analyzer and digital anemometer). The gas sampling was done during the complete run of gasifier and the average value was taken for analysis. The data was collected for the following treatments and then statistically analyzed by using CRD.

$\mathbf{T_1}$ = Rice husk, $\mathbf{T_2}$ = A mixture of rice husk and saw dust, $\mathbf{T_3}$ = Sawdust

All the treatments were replicated 4 times to get the accuracy in the results obtained.

RESULTS AND DISCUSSION

The updraft gasifier was evaluated for its performance by observing different parameters such as quantity of gas (Volume), time for engine running and the composition of different gases like CO and hydrocarbons (C_xH_x) produced in the gasifier with the same quantity of different fuels i.e. 30 kg. The data recorded were statistically analyzed with PROG GLM (General Linear Model) procedures of the SAS systems (Steel and Torrie, 1984).

1. Engine Running Time

The running time of the updraft gasifier was recorded in minutes. Figure 8 shows that the working time of all treatments were significantly different from each other at 5% level of significance. The graph revealed that the operation time of the updraft gasifier employing rice husk, mixture of rice husk and sawdust and using saw dust as fuel was 5979.3, 6400.8 and 6847.5 seconds respectively and the standard error for the treatment comparison was calculated as 128.91. The difference in operation time could be due to the higher calorific value and bulk density of sawdust as compared to the rice husk.

2. Volume of gas produced with different biomass in updraft gasifier

The volume of gas produced through the gasification of biomass in the gasifier was calculated by using the relationship described by Mandwe et al. (2006).

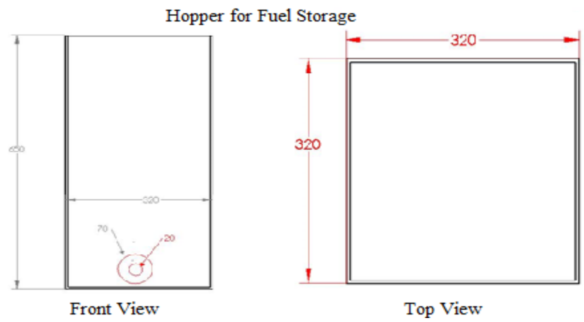

Fig. 5a: view of the fuel hopper (All dimensions in mm)

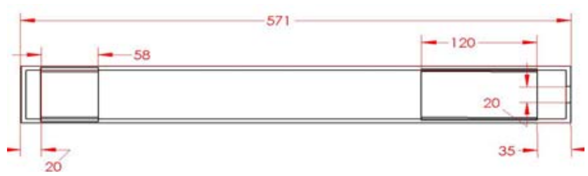

Fig. 5b: Front view of pipe connecting the fuel hopper with gasifier assembly (All dimensions in mm).

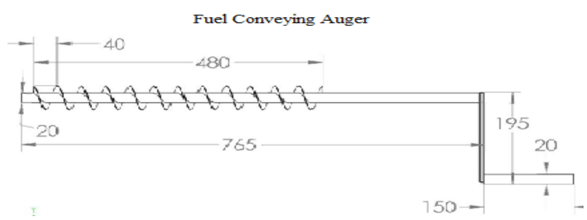

Fig. 6: Front view of the screw auger conveyor (All dimensions in mm)

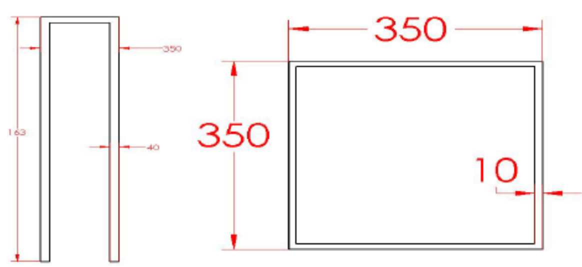

Figure 7a: Front (left) and top (right) view of stand for supporting fuel hopper (All dimensions in mm)

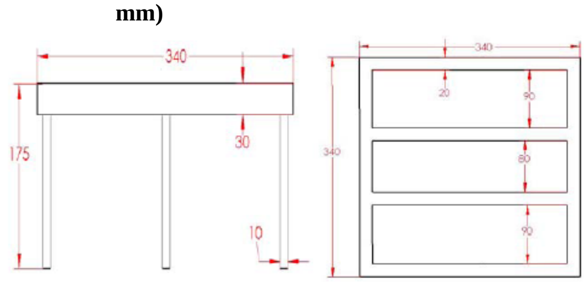

Figure 7b: Front (left) and top (right) view of stand for supporting updraft gasifier (All dimensions in mm).

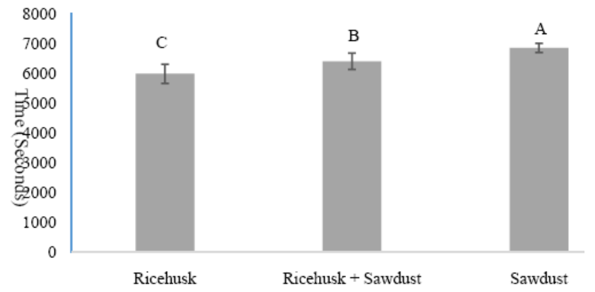

Fig. 8: Effect of treatments on engine running time of gasifier (Error bars show standard deviation)

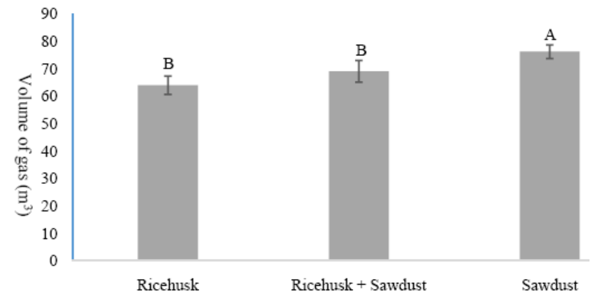

Fig. 9: Effect of treatments on volume of gas produced (Error bars show standard deviation)

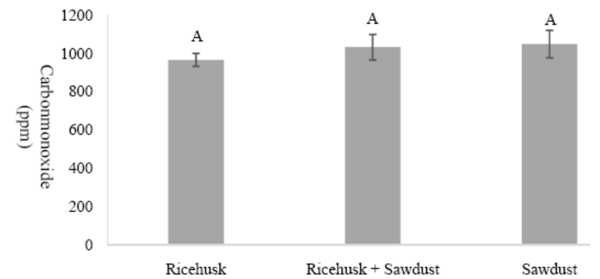

Fig. 10: Effect of treatments on carbon monoxide (CO) (Error bars show standard deviation)

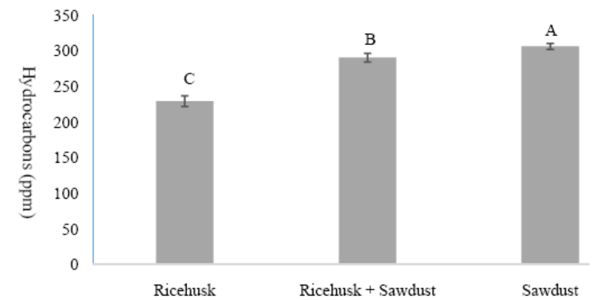

Fig. 11: Effect of treatments on hydrocarbons (C_xH_x) (Error bars show standard deviation)

Volume of gas produced (m^3) = Time (s) x area of pipe (m^2) x velocity of gas (m/s)

Figure 9 showed that the treatments T_1 and T_2 were not significantly different from each other while the treatment T_3 was significantly different from other treatments at given level of significance. The treatment rice husk only produced 63.94 m^3 of producer gas while the rice husk + sawdust and sawdust produced 69.05 m^3 and 76.18 m^3 of producer gas in the updraft gasifier respectively. The grand mean for all treatments was 69.723 m^3 and standard error for the treatment comparison was calculated as 1.654. The standard deviation in the data was found to be 3.349, 3.939 and 2.467 for treatments T_1, T_2 and T_3 respectively. From the data it could safely be concluded that treatment T_1 produced 2.13 m^3, treatment T_2 produced 2.30 m^3 and the treatment T_3 produced 2.54 m^3 producer gas per kg of fuel in updraft gasifier. Schapfer and Tobler (1937) concluded that one kg of biomass produces about 2.5 m^3 of producer gas at standard temperature and pressure. The method requires 1.5 m^3 of air. This data also revealed that the gas production in updraft gasifier was 38.49, 38.83 and 40.05 m^3 per hour of gasifier operation.

3. Carbon Monoxide (CO)

Carbon monoxide is an important constituent of the producer gas because it is a flammable gas. The quantity of CO in producer gas depends upon the ignition environment of the fuel i.e. open burning or controlled burning of the fuel. If the burning of biomass in the gasifier takes place then the quantity of CO will be produced at greater extent. Figure 10 showed that the production of CO with different treatments was not significantly different from each other. The data showed that saw dust, mixture of sawdust + rice husk and rice husk produced 1047.5 ppm, 1031.5 ppm and 965.5 ppm of CO through this gasification process respectively. The mean value and standard error for all treatments was found to be 1014.8 ppm and 29.91 respectively. The standard deviation in the statistically analyzed data was calculated as 33.6, 66.6 and 71.9 for treatments T_1, T_2 and T_3 respectively.

4. Hydrocarbons (C_xH_x)

The data shown in Figure 11 indicated that the production of C_xH_x in the producer gas using different fuels in the updraft gasifier were significantly different from each other for all treatments. The analysis revealed that the burning of rice husk, rice husk + sawdust and sawdust in updraft gasifier produced 229.5, 290 and 306.5 ppm of C_xH_x in the produced gas. The mean of hydrocarbons produced in all treatments was 275.50 ppm with standard error of treatment comparison was 3.051.

Conclusions

Pakistan is facing severe energy crises from the last decade and the increasing prices of primary energy sources have led the scientific community to search for alternate sources of energy generation. As the major sources of farm power have been diesel engines and tractors since long that and increases the cost of production, therefore, gasification might be the most reliable, alternate and cheapest farm resource to get the energy from the biomass. This research paper address the design and development and performance evaluation of an updraft gasifier to run 15 to 18.6 kW (20-25 hp) diesel engine for tube well operation to reduce the cost of operation. Completely Randomized Design (CRD) was used to statistically analyze the collected data. The average gas produced by burning of rice husk, rice husk + saw dust and saw dust was found to be 2.13 m^3/kg, 2.30 m^3/kg and 2.54 m^3/kg, respectively in updraft gasifier. The results showed that the engine running time (hours) was recorded to be 1.66, 1.78 and 1.90 with rice husk, rice husk + sawdust and with sawdust respectively. The gas produced was used to run a 15 kW single cylinder diesel engine with dual fuel (25% diesel and 75% producer gas) at rated rpm successfully. It is also concluded that the unique feature of this gasifier includes its simple design that can be used to test feed stocks with a variety of particle sizes, moisture contents, and ash contents for gasification without its pre-treatment.

Recommendations

This technology is decentralized energy conversion system which operates economically for small scale farming community especially for Village sawmills, tube well operation, rice shelling units, sugar mills where biomass is in excess quantity. Tars are major impurities in the producer gas which should be removed before using the gas in engine. Further research is needed to design and develop gas conditioning unit(s) to improve the producer gas quality.

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