Design and Development of Packed Bed Oil Scrubber for Producer Gas Cleaning

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Abstract— The huge potential of biomass as an alternative energy source can be utilized by gasification process, the only hurdle in this process is tar produced by gasification. Tar is a condensable sticky high molecular weight hydrocarbon which blocks downstream application process of producer gas (gasified biomass).Wet packed bed scrubber can be best tar removal method if used with good scrubbing solvent. In this research palm oil is used as scrubbing solvent which serve the purpose of both cleaning and cooling of gas. Wood chips, crushed stones and jute bags were used as packing material of 300 mm height. Pressure drop generated across the system was 47 mm of water. The tar removal efficiency of the system was in range of 70-80%.

Key words: Producer gas, packed bed, Palm oil, Gas cleaning**.**

I. INTRODUCTION

The demand of energy is increasing along with growing concerns like climate change and national energy security. So, there is an imperative need for developing sustainable alternative energy sources. Biomass can be used an alternative source of energy as it can store sun energy. The major biomass sources include cropping (like rice husk), woody crops, agricultural and forest residues, dry grasses, urban solid and food wastage and algae. Gasification is the best way of utilizing biomass compared to other processes (biochemical and thermochemical).Gasification is a thermochemical process which converts biomass into combustible gases which are called producer gases. In practice 60 to 90 % of biomass can be gasified depending on gasifier type, feedstock and gasifying agent. The main components of producer gas (concentration of component varies with gasifiers) are hydrogen, carbon monoxide, methane, carbon dioxide, and nitrogen along with impurities. Main impurities of this gas are particulate matters, ash, water, organic impurities (mainly tars), and inorganic impurities like ammonia, hydrogen sulfide, sulfur dioxide, and nitrogen dioxide out of which tar is the most dangerous one. The gas can be burned for process heating or for running gas engines/turbines for mechanical or electrical power, or to make synthetic fuels. Estimated Potential of biomass power in India as on 31.03.2014 is 17538 MW [national statistical organization] so biomass can be used in abundant quantity in India. The main hurdle in utilization of producer gas in removal of tar from it as it can get condensed onto the downstream application of producer gas.

Fig1.1:- Effect of tar on downstream app.

Producer gas tars (Impurities): Organics matter (hydrocarbon chain) produced through thermal or partial oxidation of biomass are called tars. There are mainly two categories on tars light and heavy tars (on board view), heavy tars easily condensable while light tars have a low dew point. Quantity, composition and dew point (150^0 to 350^0 C) of tar depends on gasifier type, operating conditions mainly pressure and temperature, feedstock, and residence time. A typical concentration range of tar is 1-100 g/Nm^3 [1]. There are mainly two categories of tar removal, hot and cold cleaning in hot cleaning tar is cracked in smaller no condensable gases at high temp while in cold cleaning tars are made to be condensed and taken away. Hot gas cleaning is more effective but are only beneficial for large MW plants considering the cost factor. There are two types of cold cleaning method, i.e. wet and dry process of which wet is more popular as it serves both cooling and cleaning purposes. Commonly used

scrubbing solvent is water, which now a days replaced by oily solvents as they have more tar absorptivity and can be recycled. A packed bed wet scrubbing column with oily scrubbing solvent is a recent trend in producer cleaning.

II. LITERATURE REVIEW

Many researchers have carried out the experimentation for scrubbing of producer gas with different oil based scrubbing solvent in place of water, but experiments were carried either on laboratory scale or for fluidized bed gasifier. These wet packed bed oil scrubbers never been tested for updraft or downdraft gasifiers.

Tar is a complicated mixture of mostly aromatic hydrocarbons which are condensable at atmospheric temperature. This tar develops during the secondary reaction of organic compounds with gasifying agents and generally exists in the producer gas stream. The tar can be tars are defined as all organic compounds with molecular weight larger than that of benzene with the exclusion of soot and char. This definition has been widely accepted and applied [2]. Bergman et al. (2002) stated that the tar dew-point temperature is the important property in designing producer gas cleaning devices. Dew point temperature of tar is the saturation temperature of tar. A typical tar dew-point temperature varies from 150 to 350°C depending on the tar's specific compounds and associated concentrations [3].

In hot gas cleaning, there are two techniques normally used and many reports mentioned that hot gas cleaning is thermally more efficient compared to cold gas cleaning. This is due to the fact that in cold gas cleaning, the gas first needs to be cooled and cleaned and then further heated up to the desired temperature of the downstream application. However, in hot gas cleaning, the cleaned and hot gas can be directly used in the downstream application at the desired temperature. The hot gas cleaning consists of thermal and catalytic cleaning. In thermal cleaning, the main impurity (tar) is decomposed at relatively higher temperature compared to the usual gasification temperature [4].

Hasler P., Nussbaumer Th. In 1999 explained the cleaning of producer gas from fixed bed gasification before its use in I.C. engine along with that he has given an explanation about particulate filtration with different scrubbers. He said that particulate cleaning can be achieved easily but tar removal techniques need to be bettered [5].

Cold gas cleaning of producer gas consist of mainly two ways dry and wet cleaning. In dry cleaning gas is passed through layers of different material for tar absorption and that in wet cleaning tar gets dissolved in solvents. Most of the application uses both combination of dry and wet cleaning [6].

Wet scrubbing of tars involves absorption of gaseous tar compounds in the scrubbing solvents. Selection of the scrubbing solvent depends on the viscosity, vapor pressure and tar absorptivity of solvent. In addition, environmental, safety and health issues must be considered during the solvent selection [7].

Bhave A. et al., 2007 developed the wet bed packed scrubber using sand as filter and water as solvent to remove the particulate and the tar from the producer gas. The scrubber also server as a heat exchanger for cooling down the producer gas. The particulate removal efficiency was found to be good but the tar removal was fine to use gas in dual fuel mode in the engine [8].

Phuphuakrat T. has compared different scrubbing solvents with water for tar absorption of producer gas. He found that only 31.8% of tar were removed by the water scrubbing whereas the highest removal of gravimetric tar was obtained by a vegetable oil scrubber with a removal efficiency of 60.4% [9].

P Bhoi et al., in his research used vegetable oil as solvent in the wet scrubbers instead of water. In his research he used soya bean and canola oil as scrubbing solvent. Results for tar removal for both oils were same ranging from 99-25 % as time passes concentrations of tar in oil increased resulting less tar solubility [10].

The objective of this work are:-

1. Study different type of scrubbing solvent from literature and select best suited solvents.
2. Design and developing packed bed oil scrubbers.
3. To check the performance of new scrubbing system.

III. DESIGN AND DEVELOPMENT OF EXPERIMENTAL SETUP

Experimental Setup consists of different component like 1) Gasifier 2) Cyclone 3) Scrubber tower 4) Oil tank 5) Pump 6) Palm oil 7) Packing material 8) Blower 9) Instruments

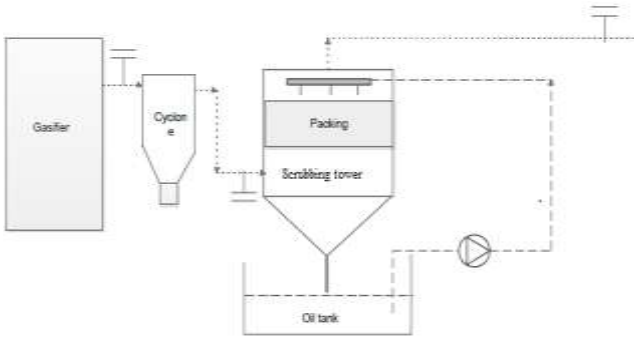


Fig.3.1:- Schematic of Experimental Setup

Above fig.3.1 shows the schematic diagram gas generated through the gasifier is first passed through the cyclone and then it is passed through the scrubber tower. Oil is pumped from the oil tank and sprayed over gas and scrubbing is done in packing section.

3.1 Gasifier

In this experiment 20 kg/hr biomass feed downdraft gasifier is being used. Biomass used were 50mm cubic wooden blocks as feedstock. This gasifier produces 50 Nm^3/hr of producer gas. Gasifier takes 10-15 mins for starting and it has flaring point to check quality of gas produced. Tar content of gas was 1g/Nm^3.

3.2 Cyclone

For removal of Solid particulate and ash cyclone is being used before scrubbing tower. Maintaining gas flow 12-13 m/s by using design process in Handbook of biomass downdraft gasifier cyclone is being designed and fabricated with mild steel material.

3.3 Scrubber tower

The main objective designing the scrubber tower is make it wider instead of conventional heighted tower. The total flow of gas and oil in scrubber tower is 0.036 m^3/s. This flow rate is considered for designing so as the tower shouldn't go in flooding condition. In this experiment considering fact of new packing material height and width were kept at higher side so as to avoid flooding condition. The overall dimension of tower were 750mm in diameter and 800 mm of height kept on 4 supporting legs.4 sprays were attached at top of tower which were used for showering oil on packing resulting scrubbing and cooling of producer gas.

3.4 Oil tank

For recirculation of oil in scrubber tower oil tank is kept below scrubber tower on support. The overall dimension of tank were 420mm*600mm*350mm with capacity of 110 kg of oil sump.

3.5 Pump

A 0.5 hp mini block impeller pump was used in the experimentation. Maximum flow of oil was 6 lpm which can be reduced by an overflow ball valve.

Fig.3.2:- Photographic view of Experimental Setup

3.6 Palm oil

As literature says oily solvents can be more beneficial compared to water, so palm oil is selected as scrubbing solvent in this experiment considering its properties and cost factors.

Property	Value
Density kg/m^3	918
Viscosity Cst	60
Flash point ^oC	280
Cetane number	38-40
LCV Mj/kg	36.9

Table 3.1 properties of palm oil.

3.7 Packing

Three types of cheap and recycling packing material were used in this experiment. The purpose of packing is to have good contact of oil and gas and second purpose is filter insoluble tar on it. First layer of packing were crushed stones second was jute bags and third was woods chips.

3.8 Blower

Forced draft 1Hp centrifugal blower with 150 cfm it serves the both purpose of giving gasifying i.e. air and developing pressure head for producer gas.

3.9 Instrumentation

K- Type thermocouple and u tube manometer were used for measuring pressure and temperature at required location from test points. The thermocouple used was k-type seamless ss 310 series with temp range of 0 to 1050^oC and U- tube manometer was made of transparent material with water filled in it with least count of 1mm. A micro fiber filter is used for tar testing which will accurate impurities on it with pore size of 1 micro meter.

IV. METHODOLOGY

Test methodology has been planned and executed in order to find performance of system and tar solubility in oil:-

1. First of all 50 mm cubic wood block were feed into gasifier and gas gets generated within 10- 15 minutes.
2. Flaring was done to check the quality of gas generated.
3. The gas first passes through cyclone subsequently pump was started at 6 lpm for and gas at outlet of scrubber tower was flared to check whether it was getting cleaned.
4. Packing height was increased till we get the better quality of clean gas. As the packing height was changed gas quality gets better and pressure changes were recorded with change packing height with help of U tube manometer.
5. Temperature drop across scrubber were recorded with thermocouple for different oil flow rates.
6. Finally for check percentage of tar removal fine fiber filter were placed at outlet of scrubber tower and weight of impurities deposition were calculated.

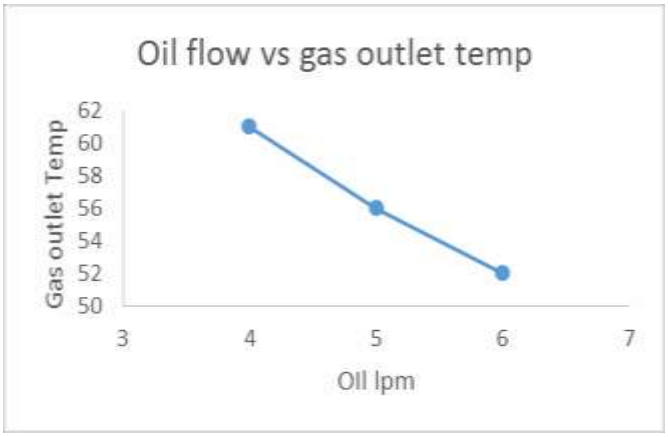
V. RESULTS AND DISCUSSION

The results obtained from the experiment carried out on the scrubber system according to methodology explained. First 2 results are approximate results depending on flaring color and oil density change as discussed earlier. Graphs are plotted for the study of variation packing height and mainly oil flow rate effect on system performance.

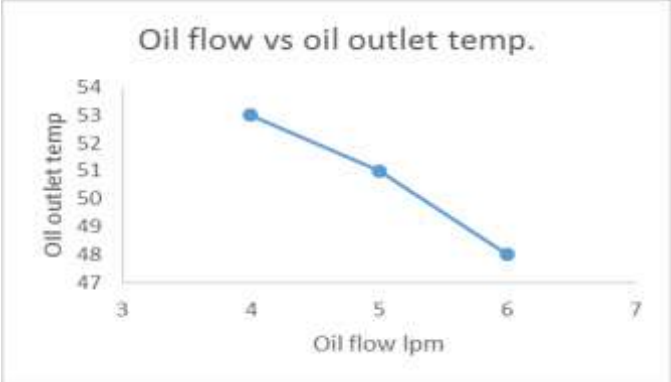
5.1 Pressure temperature graphs for different oil flows and packing

300mm of packing was best suited in experiment and graphs for 3 flow rates, i.e. 4, 5 and 6 lpm (liters per minutes) were performed and following variation was recorded. Graph 5.1 shows pressure drop across the scrubber for different heights of packing in tower, pressure drop increases as the packing height increases. Graph 5.2 show variation of gas outlet temperature for different flow rates of oil. Graph 5.3 shows the rise in the temperature of oil at different flow of oil for same gas flow.

Graph 5.1 Packing vs pressure drop



Graph 5.2 Oil flow vs gas outlet temp.



Graph 5.3 Oil flow vs oil outlet temp.

5.2 Flaring test

Flaring of producer gas before and after scrubbing system and not total but a good amount of tar is removed from gas it can be said, as in latter part there is no yellow flames. In fig 5.1 left side flame is before cleaning of producer gas and right side is

after cleaning producer gas.

Fig 5.1:- Flames before and after scrubbing

5.3 Oil density changes

After 10 hours of gas scrubbing we can see the changes in oil color so as the densities have changed the first left in below figure is fresh oil and remaining 3 samples are of 3 different layer formed in oil tank. After weighting these samples it can be found out 4 gm. of tar has mixed in 200 gm. of oil after 10 hours of operations.

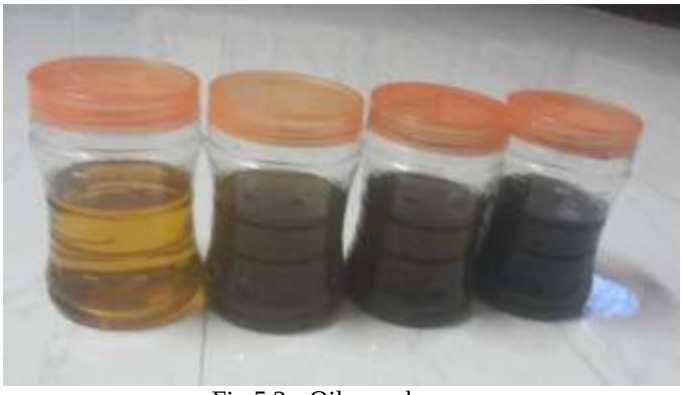
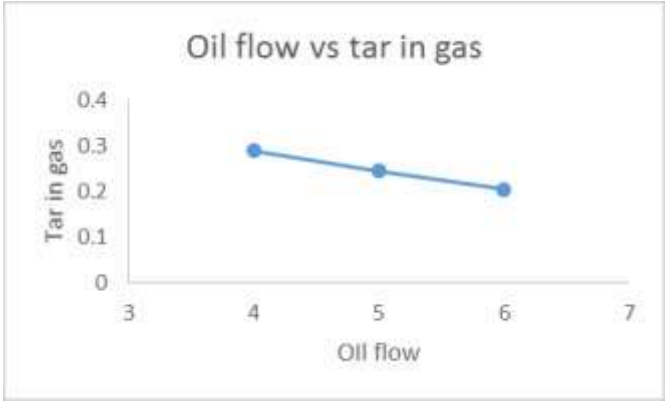


Fig 5.2:- Oil samples

5.3 Fiber filter test

Initially weighed filter paper were kept at outlet of scrubber tower for 15 min for 3 oil flow rates and same gas flow. After that they were kept for drying finally weight of accumulated impurities were measured. The tar removal can be calculated from difference of initial and final weight of filter paper.



Graph 5.4 Oil flow vs tar outlet.

VII. CONCLUSION

Pressure drop across the system was 47 mm of water. Cleaning system of gas was in range of 70-80%. System can be easily coupled to dual fuel gas engine for producer gas power generation. Advanced packing and liquid spray system is required for improving gas cleaning. In future some oil regeneration or recycle method need to attach for long term use of this system.

VIII. ACKNOWLEDGMENTS

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