Experimental Research on the Application of Natural Filters for Eco- Friendly Cleaning and Enrichment of Producer Gas

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Abstract: The practice of burning fossil fuels like petroleum, coal and natural gas will release large amount of carbon dioxide into the atmosphere. The outcome of this carbon dioxide release into our atmosphere will cause global warming. It is vital to develop alternate renewable fuel sources that are sustainable, economical and eco-friendly friendly. Biomass based fuels is gaining attractiveness as a substitute to fossil fuels. The gasification of biomass will generate producer gas. This gas blend can be used as fuel in IC engines, turbines and fuel cells for power generation. Raw producer gas that comes from a gasifier contains impurities like tar and dust particles. Eventually these impurities will reduce the quality of the producer gas and it cannot be used in engines directly. With the help of the natural fibres as filter material, enriched producer gas can be obtained. Therefore a filter box is developed and wood shaves were used as a bio- fibre material to enrich the producer gas. Finally, the producer gas enrichment was done using the wood shaves as filter material.

Keywords : Enriched Producer Gas, Gasification, Global Warming, Natural fibers

I. INTRODUCTION

Gasification is the method of transforming solid fuel into gaseous fuel. This can be done, by reacting unwanted biomass materials at high temperature without combustion with a limited amount of oxygen. During gasification process, the material is heated to high temperature that makes a series of physical and chemical variations that result in the evolution of hazardous products and carbonaceous solid deposits.

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The quantity of hazardous products produced and their compositions depend on the reactor temperature, type, and characteristics of the biomass material. In the deficiency of a catalyst, gasification of char with reactive gases such as H_2O, O_2 and CO_2, occurs at higher temperatures. The producer gas generated from biomass gasification comprises of combustible and non-combustible constituents. The combustible gases contain H_2, CO, CH_4. The major non-combustible constituents are H_2O, CO_2, and N_2, along with impurities. It includes alkalis, HCl, H_2S, NH_3 and particulate matters (Dayton 2002). The formation of H_2S is of lesser importance in biomass gasification as long as the biomass comprises lesser sulfur content. Ammonia depends on the nitrogen content of the biomass and biomass with lesser nitrogen content is safer for gasification (Turare 1997).

Devi et al., (2003) presented that before passing the producer gas into the engine it must be cooled and cleaned of tars, alkalis, and particulate matters. For controlling the tar content in gasifier product gas there are usually two methods depending on where tar is removed, either in the gasifier itself or outside the gasifier.

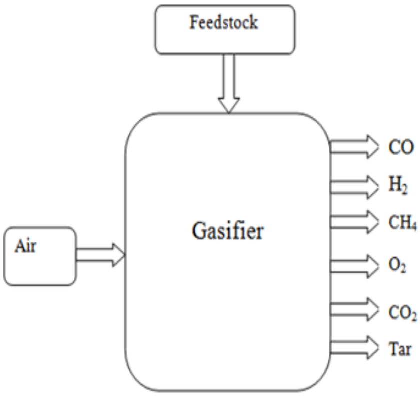

Fig. 1.Gasification Process

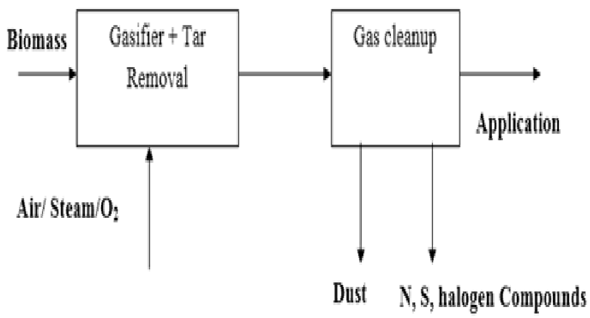

Fig. 2.Concept of Tar Reduction by Primary Methods

Rameshkumar and Mayilsamy, (2012) expressed that the Bio-filter for gas cleaning system is excellent for reducing the tar content and particulate in producer gas and also the operation of the bio- filter system at low temperature range will be convincing relative with other systems, but catalytic crackers that operates at higher temperatures have 90 to 95% efficiency. The major constituents of compact gas cleaning and cooling system comprises of wet charcoal, scrubber and coconut coir pith have claimed an efficiency of 97% by reducing the tar and particulate content from 1680 mg/Nm^3 to 52 mg/Nm^3.

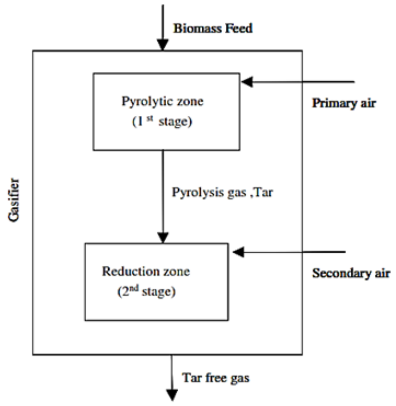

Fig. 3.Concept of Two Stage Gasification

Mukunda et al., (1994) fabricated a sand bed filter to remove the particulates collected by the cooling water in spray tower. The filter is made of coarse filter bed filled with sand of 0.5 – 2 mm size particles and the fine sand bed filled with 0.2– 0.6 mm size.

II. MATERIALS AND EXPERIMENTAL PREPARATION

The experimental preparations and tests are done with the producer gas in the fixed bed downdraft gasifier. The tar and particulate matters generated during the process is one of the most challenging problems concerning biomass gasification. Tar, which is generally an aromatic hydrocarbon is considered to be a complex mixture of the condensable segment of the organic gasification products. Tar and particulates may condense on valves and fittings, hampering the ability of valves to function properly and so it is challenging in integrated biomass gasification systems. This chapter describes about the experimental setup and methodology used to design and fabricate the filter box with bio fibre.

A filter box was fabricated to clean the producer gas by providing proper bio- fibre inside the box. The filter box was fabricated with 900mm in height and 800mm in diameter. Sun dried wood shaves were used as a bio- fibre to remove tar, moisture content and particulate matters. Air is used as the gasification agent at atmospheric pressure while the gasification process was carried out.

A. Filter Box Specifications

To conduct the desired experiments in this work an experimental setup was build. The filter is fabricated from mild steel sheet with 2 mm thick, and wire meshes which is used to separate filter bed is fabricated from stainless steel 304. Inlet and outlet pipes are provided to bypass the producer gas through the filter, each pipe has 32 mm in diameter.

B. Selection of Fibre Material

To reduce the particulate matters and tar content from the raw producer gas to the nominated levels, gas cleaning methods are used. For different materials absorption and adsorption capacity may varies due to the variations in particle size, pores, density, etc. Wood shaving is the material selected in the producer gas filtration process.

C. Wood Shaves

For removing the moisture from the producer gas, wood shaves dried under sunlight as shown in fig. 5 are used. Real densities of the wood shaves were taken as the actual density of the solid wood block. The apparent density of the wood shaves are found to be 160 kg/m^3. The light weight aggregates or wood shaves is both sizable and flexible for tar absorption. Dry shavings are separated from all fine and coarse particles to achieve proper particle size for filtration of producer gas.

Fig. 4.Sun Dried Wood Shaves

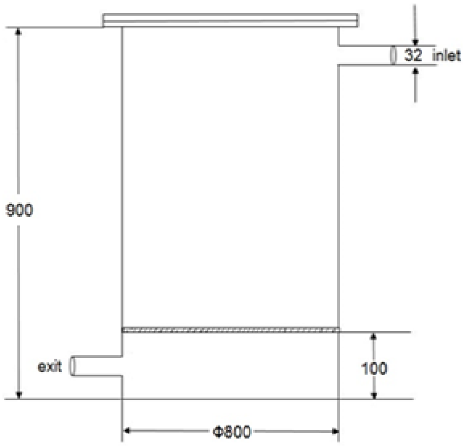

Fig. 5.Schematic Diagram of Filter Box

D. Sieve Analysis of Bio- Fibre

Sieve analysis or gradation test is a procedure to find the particle size of a coarse material. The percentage of various grain sizes present within the material is determined by sieve test. During the sieve test for wood shaves, maximum passing was obtained through 2.36 mm sieve, thus it is being taken as the size for the material. Fig.6. shows the result of sieve analysis. From this result it understands that maximum passing for wood shaves is 2.36 mm sieve.

Fig. 6.Sieve Shaker

E. Experimental Setup and Procedure

To conduct the desired experiments in this work an experimental setup was build.

The filter is fabricated from mild steel sheet with 2 mm thick, and wire meshes which is used to separate filter bed is fabricated from stainless steel 304. Inlet and outlet pipes are provided to bypass the producer gas through the filter, each pipe has 32 mm in diameter.

The improvement of producer gas composition using the filter by removing tar and particulates is evaluated by developing an experimental set up. The set up comprises of 50kW fixed bed down draft gasifier, bio-filter system and cooling tower. Total length of the gasifier accounts to about 2040 mm. The gasifier has three nozzles separated with a phase angle of about 120˚. The nozzles are inclined radial along the circumference of the gasifier at an angle of 45˚.

In the reactor, both biomass feedstock and gas travels downward as the reaction continues. When biomass is flowing due to gravity, a blower is used to induce airflow. The air is partially drawn from three air nozzles which are placed at 45˚ inclination around the combustion region. The biomass gradually travels downwards along with the air moving through a series of thermochemical reactions in the reactor for converting into producer gas, which departs the reactor at the lower end through the grate. The outlet of the biomass gasifier was connected with the bio-filter system to clean the producer gas. To keep the char particles at higher temperature, gasifier grate is used. Thus, special welding techniques are used to fabricate the steel grate to withstand high temperatures. The following parameters are determined to calculate the performance of the bio-filter.

(i)Tar & particulate substances removal, (ii) Gas composition (iii) Pressure drop across filter

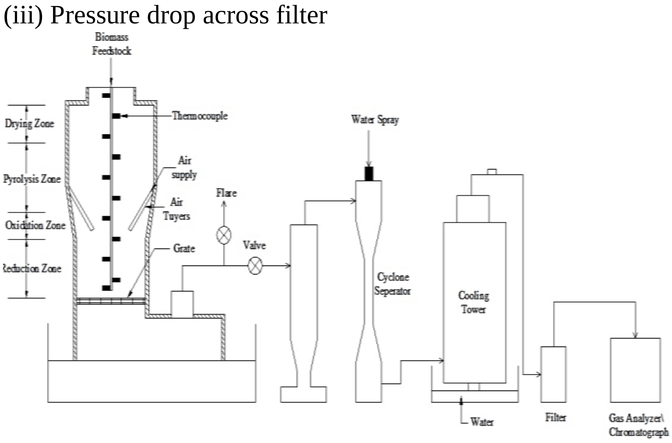

Fig. 7.Layout of Fixed Bed Downdraft Gasifier

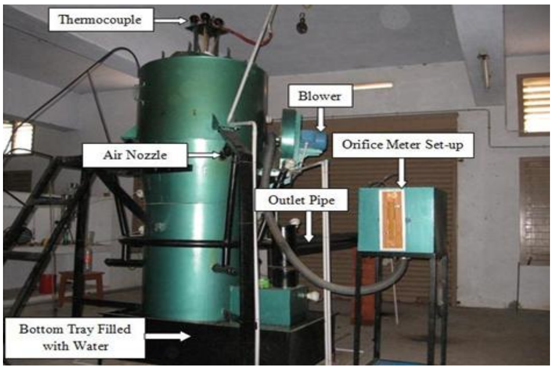

Fig. 8.Experimental Setup of Downdraft Gasifier

F. Analysis of Tar Removal.

The producer gas generated is guided to the compact gas cleaning system for removing tar and dust particles. The tar and dust particles are packed inside the filter material (wood shaves), so the weight of the filter material will be increased.

In order to find out the concentration of tar present in the producer gas, initially the mass of the filter material should be noted before filtration. Bypass the producer gas through the filter material and check the weight of filter material after filtration, so that the tar content absorbed in the filter material can be analyzed by differentiating the weight before and after filter.

In this process, initial weight of wood shaves is about 4.5 kg before filtering as shown in fig.9 and final weight of wood shaves after filtration is about 4.935 kg as shown in fig.10. So the tar and particulate matters adsorbed from the producer gas is 0.435 kg.

Fig. 9.Before Filter

Fig. 10. After Filter

G. Measurement of Pressure Difference.

U-tube manometer is used to find the quantity of air flow rate in the system with the orifice diameter of 15mm. The rate of flow of producer gas was determined using a orifice meter which is already provided by the manufacturer. The difference in pressure across the U-tube reading gives the actual air flow rate in the gasifier.

Fig. 11.U- Tube Manometer

H. Composition of Producer Gas and Measurement of Calorific Value.

The composition of gas and calorific values are measured using the multi gas analyser as shown in fig.12. By using this, the changes in calorific value can be measured. Gas analyser shows different gas compositions such as calorific value, H_2, CO, CH_4, CO_2 and O_2.

Fig. 12.Gas Analyser

III. RESULT AND DISCUSSION

The results obtained from the experiments done to examine the improvement of producer gas compositions, based on percentage by volume, for using the newly selected bio- filter, and also the removal of particulate matters and tar from the gas have been presented in this section. The parameters such as pressure drop across the tar, filter and particulate matters of the producer gas before and after the filter were measured. The particle size of the wood shaves also measured using sieve analysis.

A. Analysis of Particle Size

Sieve test is conducted to determine the concentration of different grain sizes contained within the material and a sample observation is given in the table I. During the sieve test for wood shaves, maximum passing was obtained through 2.36 mm sieve, thus it is being taken as the size for the material. From this result it understands that maximum passing for wood shaves is 2.36 mm sieve.

Table – I: Sieve Analysis of Wood Shaves

Sieve Size ***(mm)***	**Weight of Wood Shaves Passing** ***(gm)***
2.36	66
1.18	18
0.6	11
0.3	3
0.15	2
0.09	0

Total weight of wood shaves = 100 gm
Particle size of wood shaves = 2.36 mm

B. Pressure Difference

A liquid column is used by manometer to measure the pressure. The liquid columns in vertical or inclined tubes were provided in the pressure measuring devices and it is called as manometers. The water filled u-tube manometer will helps to measure pressure difference in orifice, which is placed in the airflow in air handling system.

Pressure drop across the filter was measured during the test as shown in the table II, the variations in the u- tube manometer shows that the tar and dust particles were filtered from the producer gas.

Table – II: Pressure Drop across Filter

Time (min)	**Pressure Drop (mm of H_2O)**
5	8
10	6
15	8
20	10
25	9.3
30	7
35	7.8
0	11
5	9
50	8
55	7.5

C. Effect of Gas Composition

The gas compositions for the producer gas was analyzed with the help of multi gas analyser. The producer gas compositions were noted for 5 minutes of time interval and given in table III and table IV. The variations for different gases are plotted in the graph with respect to time. The effect of gas composition varied according to the removal of tar and particulate matter. The readings were noted before filtration and after filtration, so that the variations could be found.

The average concentrations of the combustible gases such as hydrogen (H), methane (CH_4) and carbon monoxide (CO) achieved were within the bounds. By the way, the rather higher percentage of Nitrogen (N) in the producer gas mixture could be expounded by the fact that air was used as a gasification medium.

Table – III: Gas Compositions without filter

Time	**CO**	**CO_2**	**CH_4**	**H_2**	**O_2**	**N_2**	**CV**
min	**%vol**	**%vol**	**%vol**	**%vol**	**%vol**	**%vol**	**kcal/m^3**
5	9.19	18.3	2.09	4.97	0	65.45	405
10	8.96	18.43	2.17	5.13	0	65.31	422
15	9.38	18.51	2.39	5.66	0	64.06	462
20	9.87	18.22	2.48	6.1	0	63.33	498
25	10.06	18.24	2.49	6.24	0	62.97	510
30	10.29	18.29	2.53	6.39	0	62.5	523
35	10.34	17.89	2.61	6.47	0	62.69	539
40	10.35	17.92	2.52	6.93	0	62.28	548
45	10.38	18.01	2.91	6.32	0	62.38	557
50	10.34	18.34	2.76	6.51	0	62.05	568
55	10.42	18.26	2.75	6.73	0	61.84	577

Table- IV: Gas Compositions with Filter

Time	CO	CO_2	CH_4	H_2	O_2	N_2	CV
min	*%vol*	*%vol*	*%vol*	*%vol*	*%vol*	*%vol*	*kcal/m*^{3}
5	13.86	21.56	6.56	8.05	0.541	49.43	651
10	13.16	21.44	6.45	7.63	0	51.32	621
15	13.15	21.89	6.35	7.55	0	51.06	617
20	13.16	22.00	6.56	7.49	0	50.79	610
25	13.01	22.15	6.6	7.22	0	51.02	602
30	13.02	22.21	6.67	7.38	0	50.72	602
35	12.96	22.39	6.61	7.24	0	50.80	591
40	12.87	22.42	6.59	7.2	0	50.92	584
45	12.99	22.14	6.49	7.14	0	51.2	604
50	12.95	22.00	6.58	7.28	0	51.19	611
55	12.84	21.8	6.44	7.03	0	51.89	615

When comparing with the table III and table IV, the calorific value of the producer gas is enhanced by using the bio-filter material. The readings were noted at a time interval of 5 minutes. The experimental results of tar and particulate matters were measured before and after testing with the help of weigh scale.

D. Carbon Monoxide (CO) Composition

The carbon monoxide (CO) composition reached the maximum 10.42% by volume at a time period of 60 minutes without filter. During the time span of one hour the average value in the composition of CO without filtering was 9.96% which was increased to 13.08% by using bio- filter. This rise in the composition of CO has positive impact on the calorific value.

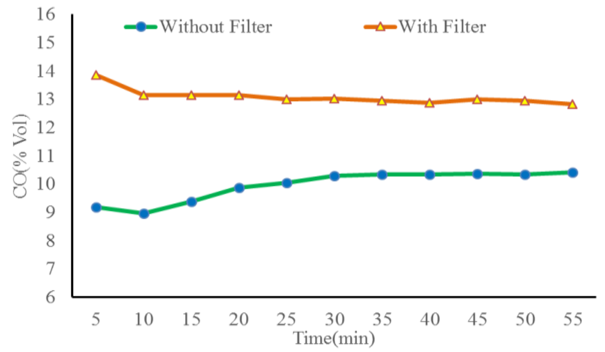

Fig. 13. CO Composition

E. Methane (CH_4) Composition

The methane composition reached the maximum 2.91% by volume at a time point of 45 minutes without filter. In a time span of one hour the average value in the composition without filter is 2.52%. The methane composition reached the maximum 6.67% by volume at a time point of 30 minutes with filter and for the time span of 1 hour, the methane composition was increased to 6.53% using bio- filter system.

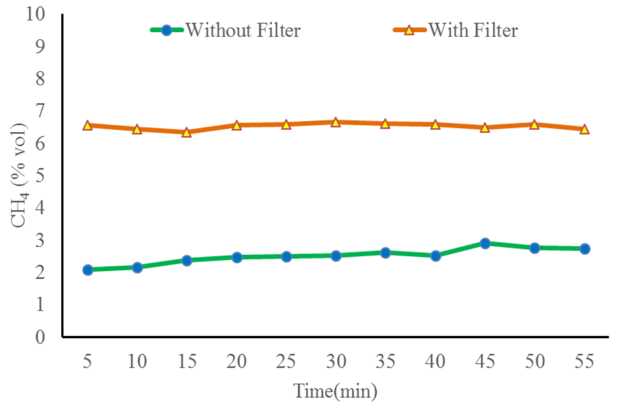

Fig. 14.Methane (CH4) Composition

F. Hydrogen (H_2) Composition

The hydrogen (H_2) composition of the gasifier remains almost stable with filter and without filter. In a time span of one hour the average value in the composition of hydrogen without filter is 6.13% and it is increased to 7.38% by volume using bio- filter system. This improvement in the composition of the hydrogen has significant impact in the change of calorific value.

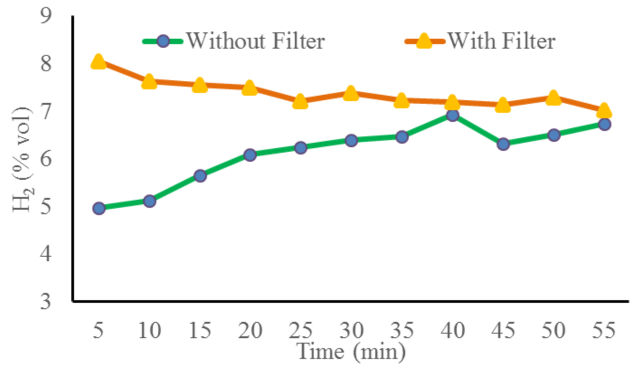

Fig. 15. Hydrogen Composition

G. Calorific Value

During the transferring of producer gas through bio-filter, its calorific value got increased. The average calorific value achieved without filter for the period of 1 hour was 509.9 kcal/m^3 and the CV was increased to 609.8 kcal/m^3 by using bio- filter.

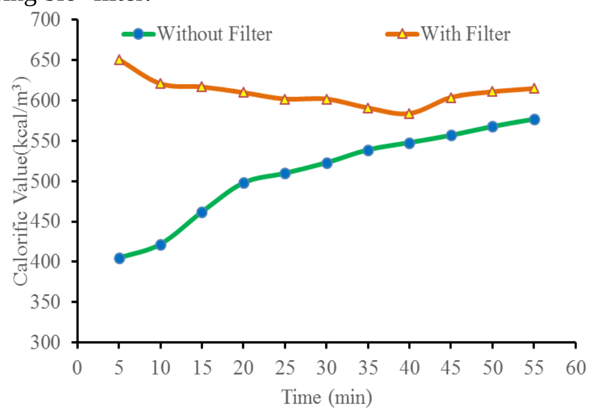

Fig. 16. Calorific Value

H. Summary of Tar and Particulates Removal

During the formation of producer gas using downdraft gasifier, the gas compositions were increased using the bio-filter system when compared with the conventional gasifier i.e., without filter system. The unwanted tar and dust particles were removed using the filter system, so the quality of gas also improved. Wood shaves were used as the filter material for removing tar and it has very good tar removing capacity.

The initial weight of filter material was about 4.5 kg before the cleaning of producer gas. The final weight of filter material was about 4.935 kg after cleaning the producer gas for a period of 1 hour. Approximately 435 g of tar and dust particles were absorbed by the filter material in 1 hr as shown in table V. Thus the producer gas can be enriched using this bio- filter set up.

Table- V: Gas Compositions with Filter

Weight of Wood Shaves (kg)	
Before Filter	***After Filter***
4.5	4.935

Amount of tar and particulate matters removed in 1 hr= 435 g

IV. CONCLUSION

The focus of this work is to enrich the producer gas quality by using natural fibres in a downdraft gasifier. For enriching the gas, proper filter materials were selected and it will eliminate the tar and dust particles from the producer gas. Sun dried wood shaves are used in this work for the gas cleaning process. The proposed bio- filter system worked satisfactorily by removing tar and particulate matters, also it has a very good capacity for the enrichment of producer gas. During the duration of test, the pressure drop across the filter was increased, which specifies that the tar and particulate matters being wiped out from the producer gas.

From this work various conclusions obtained are listed below:

- The Calorific value is increased from 509 kcal/m^3 to 609 kcal/m^3 before filter and after filter respectively.
- The CO concentration increased from 9.96% to 13.08% by volume before and after filter respectively.
- The CH_4, concentration increased from 2.51% to 6.53% by volume before and after filter respectively.
- The H_2 concentration increased from 6.13% to 7.38% by volume before and after filter respectively.

Thus the proposed filter material could be a good substitute for conventional filter materials.

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