Journal of Scientific & Industrial Research
Vol. 72, November 2013, pp. 663-668

A novel hybrid compact filter system for a down-draft gasifier : an experimental study

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Received 2 August 2012; revised 10 December 2012; accepted 27 June 2013

A major problem in biomass gasification is tar formation which in subsequent stages decomposes under the conditions such as temperature, pressure drop, gas flow rate and retention time. The potential of proposed hybrid filter for gas cleaning system analyzed here is excellent for reducing the tar and particulate in producer gas. Critical review of literature reveals that all existing system have maximum tar removal capacity of 90%. However, an exemption, catalytic crackers have efficiency in the range of 90 to 95% ,but it operates at very high temperatures (900°C). An attempt has been made to develop an efficient hybrid filter system and analyze its performance characteristics that operates in a low temperature range of 50-70°C. The performance of developed compact hybrid filter was successfully tested with a 20 kW open core downdraft TNAU-SPRERIôs gasifier. The concept of hybrid compact filter presented in this study, is first of its kind and it claims maximum tar reduction rate, than any other system reported and its magnitude varies from 93% - 97%. Moreover, the experimental results reveals that tar and particulate content is converged to 52 mg/Nm^3 from an initial range of 1680 mg/Nm^3 and greatly useful for reducing the engines wear and tear. Furthermore the filter design was developed with cost benefit on commercial basis.

Keywords : Biomass gasification, Downdraft gasifier, Hybrid filter, Gas cleaning, Tar and particulate, Internal Combustion Engines.

Introduction

Biomass is one of the important primary energy source as well as renewable energy source. Biomass resources include agricultural residues, animal manure, wood wastes from forestry and industry, and residues from food and paper industries. Biomass combustion is a carbon-neutral process as the CO_2 emitted has previously been absorbed by the plants from the atmosphere. With the global warming issues and depletion of fossil fuel sources, the biomass utilization has been more and more concerned. Biomass energy constitute a major role in global energy supply from renewable source as it contributes 67.86% of the current energy levels[1]. (Rogner *et al.*, 2000).

Biomass can be utilized through three different process for energy conversion: gasification, pyrolysis and direct combustion. Gasification process is one of the most extensive method of biomass utilization resulting in the production of combustible producer gases consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4) by incomplete combustion. Producer gas can be used to run internal combustion engines (both compression and spark ignition), as well as a substitute for furnace oil in direct heat applications. Successive heating of biomass fuel commences at about 230°C, where the composite polymers are wrecked down resulting in a producer gas consisting mainly of CH_4, NO_2, SO_2, H_2, tar and char. The tar comprises of various heavy organics that can condense at low temperatures and lead to clogged fuel lines, filters and engines. Moreover, the utilisation efficiency of biomass is also reduced by too much of tar in producer gas. Henceforth, the decomposition of tar in producer gas is one of the biggest barrier in utilisation for power generation[2].

Tar content in producer gas is undesirable which makes pavement for serious problems in the equipments as well as the engines used in the IC engine applications[3,4].Numerous works have been reported in the view to reduce the wear of the engine[5,6,7,8]. The magnitude of tar and particulate content in the producer gas was postulated as less than 100 mg/Nm^3 and less than 50 mg/Nm^3 respectively for IC engine applications.[9,10]

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Small-scale gasifiers use physical tar filters (Wet scrubbers, ESP, Packed bed filter, Sand filter) and large-scale commercial gasifiers make use of other methods (catalytic cracking, thermal tar cracking, partial oxidation) for tar removal[11,12,13,14,15]. Various gas cleaning system developed by different researchers include filter materials such as wet scrubbers[16,17], fabric[18], electrostatic precipitators[19], ceramics[20] and sand bed separately for their filter design. Very few research work have been attempted for producing tar-free gas at around 30-40°C temperature, for better IC engine efficiency[21,22]. Although few filters were implemented for conditioning , appropriate design procedures and operation data lacks clarification[23].

However, to the authorôs knowledge design and development of a hybrid compact filter system without pre-heating has not been addressed do far. Moreover, increasing the efficiency beyond 90 % is also a difficult task. In this work, an attempt has been made to develop a new hybrid compact filter system, which has a better efficiency.

Materials and methods

The proposed cylindrical hybrid filter is fabricated with mild steel having 4mm thickness along with wire meshes to separate filter bed. The materials used in the compact filter system for three different layers are wet scrubber, wet charcoal and dry coconut coir with different dimensions. In the first section, the raw producer gas is collected, and cooled by the counter water flow which removes most of the dust particles and limited quantity of tar. Then the gas is expanded and its velocity is reduced to remove the tar which is settled in filter bed of the second section. The last section is used for condensing the moisture content of gas and removing the tar left behind.

The novel hybrid gas cleaning and cooling system was designed, developed and tested with an existing 20 kW open core downdraft gasifier at Tamil Nadu Agriculture University, coupled with an IC engine for testing various performance characteristics. The wood chip comparatively identical in size and shape are fed from top of gasifier. The length and width of the wood chips fall between 3.0 - 3.5 cm respectively and the thickness in the range 2 - 3 cm. The wood chip consumption rate for supplying producer gas lie between 1 and 1.2 kg/kWh. Approximately 1.8 - 2.0 Nm^3/h of producer gas is generated per kg of biomass input. In this experimental study, the specification of parameters such as the wood consumption, gas generation rate and gas flow rate are 20 kg/h (20kW X 1 kg/kWh), 38 m^3/h (20kW X 1.9 Nm^3/h) and 38 m^3/h respectively.

The generated producer gas is sent to the hybrid gas cleaning and cooling system for removal of tar and dust particulates. U-tube Manometers were utilized to measure variation in the gas flow rate and hot wire Anemometer was employed to measure the pressure drop across the filter. A Micro DAQ K type Chromel - Alumel Thermocouple and RTDs were installed to measure the flame and gas temperature respectively. An unique system in zigzag nature, made up of copper material is being immersed in water at an temperature range of 3-6°C, is used as an tar condenser. Gas sampling measurement was accomplished with an iso kinetic sampling train activated by a single phase vaccum pump and a blower. A gas chromatograph was used for analyzing the composition of gas at outlet. A single cylinder four stroke Internal Combustion Engine was provided for power generation.

Design and Development of hybrid compact filter

The dimensions of the three different filter sections were calculated based on producer gas generation rate, flow rate, velocity in the filter, and retention time. The retention time in the filter section I, II and III are 3.5s, 7.0s and 11.0s respectively. Based on the retention time, filter bed height is calculated. The filter bed height in the filter section I, II and III are 0.8m, 0.6m and 0.5m respectively. The gas flow rate is maintained constant. The filter diameter for three different filter layers were calculated from the following equations (1-4) in view to achieve maximum tar and particulate reduction rate of magnitude less than 50 mg/Nm^3 in producer gas. The parameters are then rounded-off to standard values for developing the experimental design.

$$\text{Retention time} = \frac{\text{Bed height}}{\text{Velocity}} \quad \text{é} \quad (1)$$

$$\text{Discharge (Q)} = \text{Area (A)} \times \text{Velocity (V)} \quad \text{é} \quad (2)$$

$$Q = \frac{\pi}{4} \times D^2 \times \text{Velocity} \quad \text{é} \quad (3)$$

$$\text{Diameter} = \sqrt{(Q/(\pi/4 \times V \times 3600))} \quad \text{é} \quad (4)$$

Results and discussion

The novel compact hybrid filter system was extensively tested to evaluate major performance

Table 1ð Experimental results

S.No	Time (pm)	Gas Temperature (°c) Inlet	Water Scrubber Exit	Wet charcoal Exit	Outlet	Pressure drop (mm H_2O)	Tar and Particulate (mg/N m^3) Initial	Final	Tar reduction (%)
1	2:40	260.42	166.21	78.86	51.22	18	1678	59	96.66
2	3:00	282.34	191.34	83.17	54.81	19	1439	58	95.96
3	3:20	301.83	204.68	89.02	58.74	21	1148	56	95.12
4	3:40	329.56	229.46	94.50	62.38	22	966	53	94.51
5	4:00	352.10	247.90	99.20	65.93	24	801	52	93.51
6	4:20	376.62	271.44	105.42	68.84	25	699	52	92.56

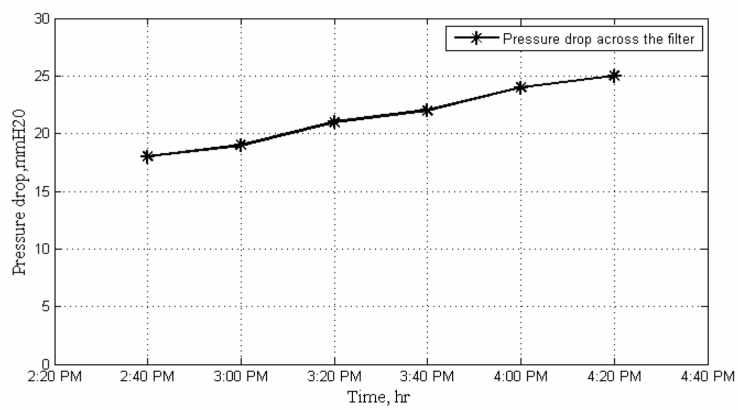

Fig. 1ð Pressure drop across the filter

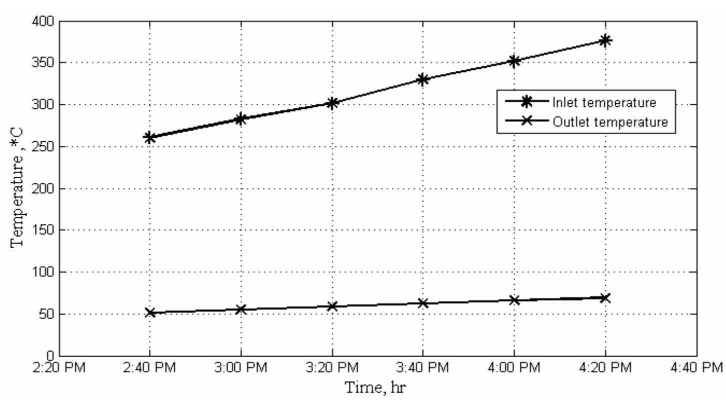

Fig. 2ð Temperature of the producer gas

parameters like gas inlet and outlet temperature at each filter layer, pressure drop across the filter, tar content and particulates in the producer gas at inlet and outlet and tar reduction. The measurements were taken in a time interval of 20 minutes. The experimental results of measured performance parameters are tabularized as shown in Table 3. From the results it is obvious that the tar and particulate content significantly reduces with the time due to deposition of tar in the filter.

The variation of pressure drop across the filter with respect to time is presented (Fig 1). It can be observed that the pressure drop increases with time. Moreover, the pressure drop is low in the first two filter layers when compared with the third one, as the diameter of the filter increases in the newly proposed design.

The variation of gas inlet and outlet temperature of the filter with respect to time is shown. (Fig 2). From the graph ,it can be observed that for an increase in the inlet

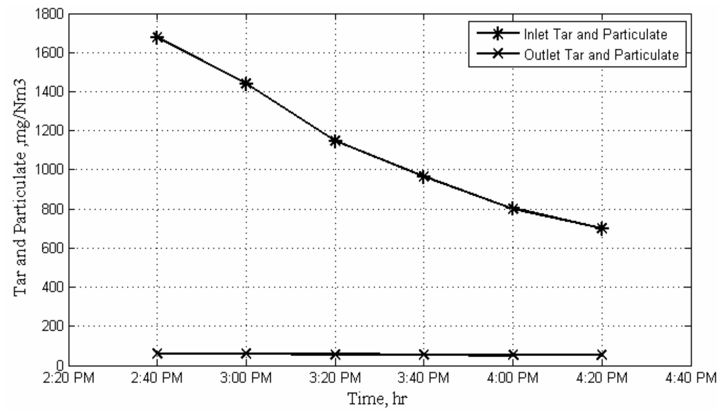

Fig. 3— Tar and Particulate w.r.t time

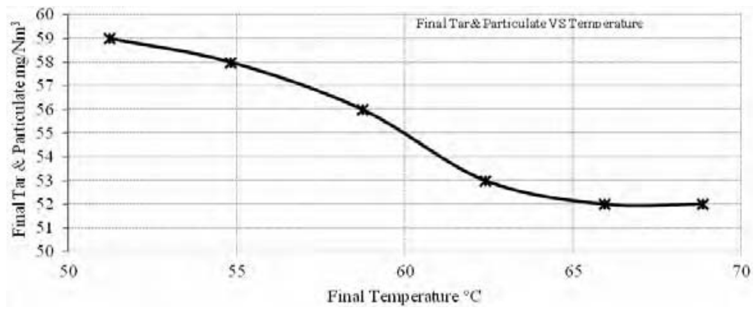

Fig. 4— Final Tar content Vs Temperature

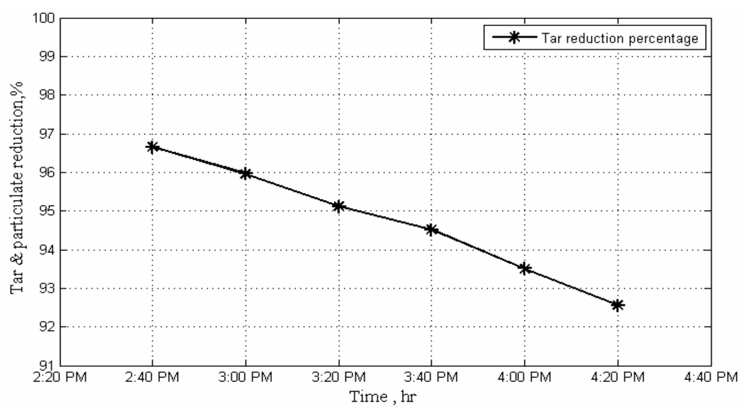

Fig. 5— Tar reduction Percentage

temperature there is slight proportional increase in the outlet temperature. However, there is high temperature drop in the first two sections due to the spray of water to condensate the tar and particulates.(Fig 3)shows the variation of Tar and particulate with respect to time. From the results, it can be observed that there is a large decrease in inlet tar and particulate content with respect to time.

Moreover, the tar and particulate content at the outlet is almost constant . Also, it depicts a the significant difference between the outlet and outlet tar-particulate content, due to the effective gas cleaning and cooling process by the hybrid compact filter system.The variation of final tar content with respect to temperature is shown in the (Fig 4). The final tar and particulate content can be observed to vary slightly for a small variation in the outlet temperature.

(Fig 5). shows the tar and particulate reduction with respect to time. The tar reduction efficiency of the hybrid compact filter system can be observed to vary between 93 and 97%. Further, the temperature and particle reduction was observed to vary between 50-70ºC and 93-97% respectively. The tar and particulate reduction have been compared with the published literature[23] on similar studies and were observed to be satisfactory. The tar and particulate reduction values in this experimental

Table 2ð Estimated Cost of the compact hybrid filter device

S.No	Component	Rupees	Operating cost/hr in Rs
1	Wet scrubber	12,500.00	4.17
2	Wet charcoal	15,000.00	5.00
3	Dry coconut coir	17,000.00	5.67
	Total	44,500.00	14.84

study are better than those of others, which in turn complies with the gas quality requirement[24,25] for an IC engine application.

The total investment cost of compact hybrid filter for gas cleaning systems have been determined for a state-of-the-art downdraft biomass gasifier with 20 kW capacity. Unlike the complex, high cost ceramic filters, simple and readily available filters were used in view of developing cost effective gas cleaning system. As a part of further extension to this work, an activated carbon based adsorber is preferred as an additional tar removal unit in the filer section II of the design.

Cost of the proposed system is almost 0.45 lakh shown in Table 2. less than the conventional system because the catalytic/thermal cracking filter system costs significantly more but less than a wet electrostatic precipitator based system. Moreover, the proposed filter components in gas cleaning system is an eco friendly equipment. Henceforth, this design would be a better option for industries (5kW-50kW).

Conclusion

From the present investigations, the following conclusions could be drawn:

1. The proposed novel compact hybrid filter system demonstrated a high rate of success in removing tar and particulate content.
2. This system claims a tar reduction rate of 93-97%, which is far ahead than any other existing methodology in an operating temperature range of 50-70ºC.
3. Also, the particulate content in the producer gas is only 3%.
4. This gas cleaning system is a compact hybrid filter, delivering improved efficiency and reduced cost, a viable option for industries. Hence the gas delivered could be treated as almost pure which in turn is highly effective in operating an IC engine with highest efficiency as the wear and tear is greatly minimized due to the purity of the producer gas.

Acknowledgements

The authors are grateful for the support of the Department of Bio Energy, Tamil Nadu Agricultural University(TNAU),India.

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