International Journal of Agriculture, Environment and Biotechnology
Citation: IJAEB: 11(1): 39-44, February 2018
DOI: 10.30954/0974-1712.2018.00178.5

ENVIRONMENTAL SCIENCE

Tar and Particulate Matters Removal from Producer Gas by using Oily Organic Filter Media

Prakash Chandra Jena[1*], Murari Shyam[2] and Asim Kumar Joshi[3]

[1]ICAR-Central Institute of Agricultural Engineering, Nabibagh, Bhopal, Madhya Pradesh, India
[2]Sardar Patel Renewable Energy Research Institute, VV Nagar, Gujarat, India
[3]Sardar Patel Renewable Energy Research Institute, VV Nagar, Gujarat, India

*Corresponding author: prakiitkgp@gmail.com (ORCID ID: 0000-0003-0826-8661)

Paper No. 648 Received: 09-10-2017 Accepted: 23-01-2018

ABSTRACT

The present study showed that the quality of producer gas obtained by thermo-chemical conversion of crop residues varied due to organic nature of biomass and the variation in operating parameters such as equivalence air fuel ratio and superficial velocity. The range of tar and particulate matters (TP) in producer gas obtained from downdraught gasifier generally varied from 110-14000 mg/Nm^3, which makes it unsuitable for internal combustion (IC) engine operation. Hence, a reduction in TP below 150 mg/Nm^3 is necessary for long run engine operation. Controlling operating parameters is a very sophisticated process and can be applicable only in laboratory experiments. Therefore, improvement in physical cleaning process to reduce TP and improve producer gas quality is very important for sustainable IC engine operation. The experiments were conducted by mixing jatropha oil with saw dust and wood shavings as filter media with the existing cooling and cleaning train (version 6). Result showed a reduction of TP (< 150 mg/Nm^3) value in the range of 12-17 mg/Nm^3, which was much below the recommended limit of TP as prescribed by Ministry of New and Renewable Energy, Government of India for engine operation.

Highlights

- Tar and particulate matters (TP) in cleaned producer gas was reduced to 12-17 mg/Nm^3 and was suitable for long term engine application
- Cost effective, suitable and organic method for removing TP in crop residue briquette based power generation system through gasification route

Keywords: IC Engine, organic filter, jatropha oil, saw dust, wood shavings

India is blessed with various sources of renewable energies and has a greater potential to harness these energies (solar, wind, biomass, etc.) for heat and electricity generation. Besides all other sources and routes to harvest the renewable energy, the gasification route to produce producer gas from crop residue and its efficient utilization in engine operation is a challenge. The performance of IC engine depends on the quality of producer gas obtained by thermo-chemical conversion of crop residues. The thermo-chemical conversion takes place approximately at a temperature of 600–1000 °C (Balat 2009) and produces a gas mixture comprising of CO (20-22%), H_2 (10-12%), CH_4 (1-2%), N_2 (50-55%), CO_2 (10%). etc. along with impurities such as tar and particulate matters, water vapour, etc. (Sooch and Gautam 2013). The variation in producer gas quality and proportion of impurities are primarily due to organic nature of biomass and its chemical compositions (cellulose, hemicellulose and lignin) and physical properties (moisture, ash, volatile matter, fixed carbon, calorific value, carbon, hydrogen, nitrogen, sulphur, oxygen and other trace elements). However, more frequent variation in tar and particulate matters (TP) content in producer gas varies due to variation in gasifier zone temperature, equivalence air fuel ratio (ER) and superficial velocity (SV). The producer gas composition mainly depends on the temperature inside the reactor, which in-turn is influenced by ER. The amount of CO and H_2 in producer gas increases with increase in ER but further increase in concentration of these components decrease at higher ER, due to increase in CO_2 and N_2 concentrations in the producer gas (Sheth and Babu 2009). The TP content in the producer gas generally varied more in the range of 110-14000 mg/Nm^3, which not only deteriorates the performance of IC engine but also makes it unsuitable for long term engine operation due to the deposition of tar in the engine manifold, engine turbo-charger as well as inside the engine cylinder and it also causes filter clogging.

Hence, a reduction in TP below 150 mg/Nm^3 is necessary for long run engine operation (Anonymous 2000). It have been reported that besides operational parameters (ER and SV), design parameters such as location of air inlets, volume of gasification zone and grate design also affect the performance of gasifier (Martinez *et al.* 2012). The typical ER value should be maintained within 0.2 to 0.4 for getting quality producer gas with reduced TP. Sheth and Babu (2009) and Yamazaki *et al.* (2005) observed that quality of producer gas also varied with the variation in SV which ultimately affects the gasification rate, producer gas calorific value, gasifier fuel consumption, rated power output and TP production rates. However, controlling ER and SV for improving producer gas quality with reduced TP amount is a very sophisticated process and can be applicable only in laboratory experiments. TP can be reduced by primary (reduction of tar in the gasifier itself) as stated above and secondary (down steam hot gas cleaning) methods. The limiting factor to use primary method is the proper selection of gasifier operating condition, use of suitable additive or catalyst for tar cracking and proper design of gasifier. Secondary method includes cleaning of hot producer gas leaving the gasifier.

However, combinations of both the methods are reported to be effective in the removal of TP (Devi *et al.* 2003). In this study, use of secondary methods of TP removal by mechanical/physical means was investigated. In physical absorption/adsorption method gas is brought into an intimate contact with the liquid, however, the effectiveness largely depends on the direction of the liquid flow as well as the degree of contact between gas and liquid phase (Rajivgandhi and Singaravelu 2014). The mechanical separation of TP could be done by using dry (cyclone separator, rotating particle separators, electrostatic precipitators, bag filters, baffle filters, ceramic filters, sand bed filters, different adsorbers, etc.) and wet (spray towers, packed bed scrubber, venturi scrubbers, wet electrostatic precipitators, wet cyclones, etc.) methods of gas cleaning. However, long run IC engine operation depends on the reduction in TP and gas temperature prior to engine inlet. This can be possible if the cooling and cleaning train have the combinations of both wet and dry approaches. Further, the methods such as wet electrostatic precipitator, catalytic tar cracker, rotational particle size separator and electrostatic precipitator are not cost effective and require frequent attention. Therefore, filter media, which can be less costly and can be made with locally available materials will be a feasible solution for the sustainability of briquette based power generation.

Some authors also stated that condensation temperature (dew point temperature) should be considered for tar separation as it varies with tar components. It has been observed that tar class of II (heterocyclic), IV (light PAH) and V (Heavy PAH) are the most important tar compounds, which are to be either removed or converted for the successful application of producer gas (Anis and Zainal 2011). It can be assumed that most of the class-I, II, III and V tar is being removed in wet wash, and the remaining can be filtered through organic and fabric filters. However, some compounds of class III and IV might be creating problem in tar separation and may be in vapour form even after passing through fabric filter.

Phuphuakrat *et al.* (2011) reported the effect of hydrophobic absorbents (diesel fuel, biodiesel fuel, vegetable oil, and engine oil) over water for absorbing TP. They found the highest gravimetric tar removal (60.4%) by oily materials when compared to only 31.8% by water. Therefore, it is envisaged from the above observation that upgradation of producer gas to obtain required TP value may be possible by combining both dry and wet mechanical methods. Previously, TP of producer gas was reduced to a range of 21- 45 mg/Nm^3 by using version-6 cooling and cleaning system (hot cyclone, twin spray towers with improved spray nozzles, cold cyclone, charcoal filter, wood shavings filter and organic filters) of Sardar Patel Renewable Energy Research Institute (SPRERI). In this mode the IC engine was run satisfactorily for 16-28 h without changing the filter media. But the engine could not perform as desired due to the accumulation of TP on wall and fan of engine turbo-charger as well as inside the engine cylinder. Hence, this study was conducted to remove tar and particulate matters from producer gas by using version-6 cleaning and cooling system along with oily organic filter media.

MATERIAL AND METHODS

Experimental setup and procedure

The study was conducted at Thermo-chemical division, SPRERI, V.V. Nagar, Gujarat, India. The gasification system, materials and different equipments used for the study are described in the following sub sections:

Gasifier system and procedure

A throat-less down draft open core gasifier of 100 kWe capacity with energy input of 2198 MJ/h was used for the study having briquette consumption rate of 150 kg/h. The producer gas cooling and cleaning system shown in Fig. 1 comprised of cyclone-I (hot cyclone), twin spray towers (improved spray nozzles), cyclone-II (cold cyclone), charcoal filter (higher surface area), wood shavings filter and an organic filter. Experiment was conducted to prove the efficiency of oily materials in removal of TP from producer gas.

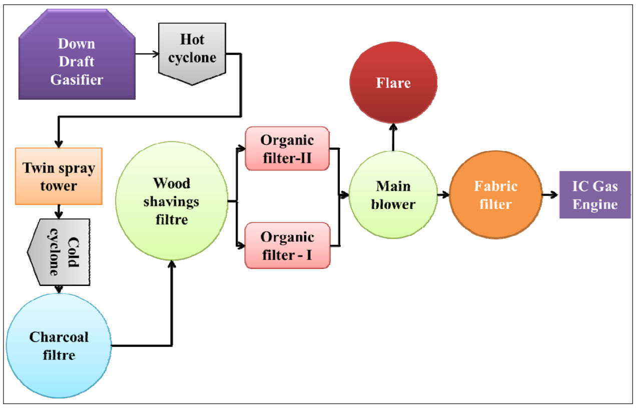

Fig. 1: Schematic of biomass gasifier with cleaning and cooling unit

The first compartment of organic filter- I was filled with wood shavings (10 mesh size), whereas the second compartment was filled with mixture of saw dust (30-40 mesh size) and jatropha oil at a ratio of 2.46:1 w/v. Similarly, the mixture of wood shavings and jatropha oil at the rate 5.97:1 w/v was used in wood shavings filter. However the other components of the system were kept unchanged.

Feeding materials for gasifier operation

Briquettes of cotton stalk powder (CSP) and pigeon pea powder (PPP) mixture at a ratio of 1:1 w/w having diameter of 52 to 54 mm were used for operation of the gasifier (Fig. 2).

Fig 2: Briquettes of cotton and pigeon pea powder

The physical properties such as moisture content, volatile matter and ash content were determined by ASTM D-3173, ASTM 3175 and ASTM 3174, respectively. The fixed carbon was calculated by subtracting the sum of moisture content, volatile matter and ash content from hundred. The calorific value (CV) of the briquettes was determined as per IS: 1350 (Part II). Bulk density of ground biomass and briquette was determined by taking the bulk weight of the material in a rectangular wooden container having volume of 0.125 m^3 (Srivastava *et al.* 2014). The density was determined by dividing bulk weight of the briquettes or ground biomass with the total volume of container. The measurements were repeated 5 times and the average value was taken. The true density of the briquettes was determined by stereometric method (Rabier *et al.* 2006). Dimension of briquettes (length and diameter) was measured using caliper having the least count 0.01 mm and weight was measured by using electronic balance of 0.0001g as the least count. The true density was determined by dividing the weight of the sample with its actual volume.

Instrumentation and measurement

TP in the producer gas was measured by using IIT Bombay sampler. The IIT Bombay sampler comprised of a piston and cylinder assembly; a non-return valve; filter paper holder assembly; stroke counter; and pedal and base assembly. Whatman glass micro-fibre filter papers (diameter – 47 mm, grade GF/C, Cat no. 1822047) were used in the filter paper holder for getting TP impression. The sampling was done by moving the pedal of sampler at uniform rate either for 5-8 min or upto 50 strokes. Producer gas composition such as CO, CO_2, CH_4, H_2 and O_2 was measured using portable gas analyzer (Model – ACE 9000X CGA) along with the calculation of calorific value.

Pressure drop in different components of gas purification system was measured by U-tube manometers. Temperature at different zones of gasifier, gas cooling and cleaning unit were measured using Cr-Al (K-type) thermocouples and data were recorded with the help of 16 channel data logger (Make: Data-taker, Model: DT-85).

RESULTS AND DISCUSSION

Proximate properties of briquettes

The properties determination is required to assess the compatibility and performance of gasifier for different biomass. Proximate value of individual biomass powder and briquette are given in Table 1.

Table 1. Proximate value of materials used for the study

Bio-mass	Moisture content, %	Ash content, %	Volatile matter, %	Fixed carbon, %	Calorific value, kcal/kg
CSP	6.18	3.34	82.94	13.72	4157
PPP	8.28	4.89	72.67	22.44	4214
Briquette	7.43	4.22	79.75	16.03	4203

The values of moisture content, ash content, volatile matters, fixed carbon and calorific value of briquette were found to be 7.43%, 4.22%, 79.75%, 16.03% and 4203 kcal/m^3, respectively. The average true density of the briquette was measured to be 1022 to 1114 kg/m^3. Similarly, the bulk density was found to be 703 kg/m^3 after densification of mixture of CSP and PPP having a bulk density 187 kg/m^3.

PERFORMANCE OF GASIFIER

The gasifier was operated at a gas flow rate of 260 -315 Nm^3/h. Variation of gas composition and calorific value is shown in Fig. 3.

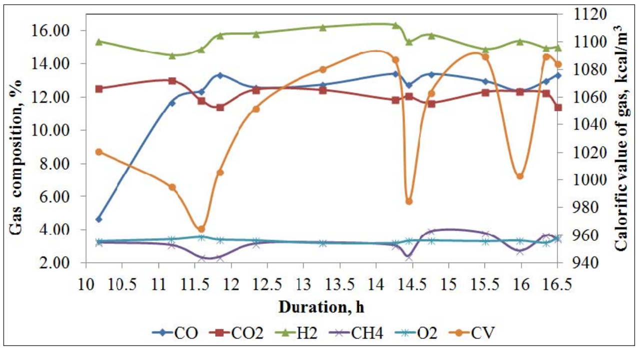

Fig 3: Variation in producer gas compositions and calorific value with duration

The maximum calorific value was obtained to be 1089 kcal/m^3. But during the initial phase of gasifier run calorific value of producer gas was found to be 965 kcal/m^3. This could be due to the less exposed surface area for uniform partial combustion and improper oxidation zone temperature. It can also be seen from Fig. 3 that CV of producer gas was lower at 11.5, 14.5 and 16 h of gasifier operation. This could be due to the formation of air pockets inside the gasifier. But after rotating the grate it was found to be increasing.

Further, air pockets or void space inside the gasifier is depends on the size of feedstock, type of material, flow of feedstock inside the gasifier and uniformity of combustion zone. The void space can be minimized by providing suitable vibrator in the gasifier to regularize biomass flow to the combustion zone, maintaining uniform air flow rate through the bed in the gasifier and the removal of ash from ash pit by rotating the grate.

Similarly the gas composition such as CO, CO_2, H_2, CH_4 and O_2 was found to be varying with the air flow rate and the range of variation was observed to be 4.68-13.39%, 11.42-13%, 14.51-16.35%, 2.33-3.93% and 3.2-3.55%, respectively. Similar results of producer gas composition have been reported for the gasification of biomass (Gil *et al*. 2008; Jaojaruek 2011).

Temperature variations

Variation in the temperature of different zones was observed due to variation in operational condition (gas flow rate and material flow) and with increase in the operation hours. The temperature variation inside the reactor is shown in Fig. 4.

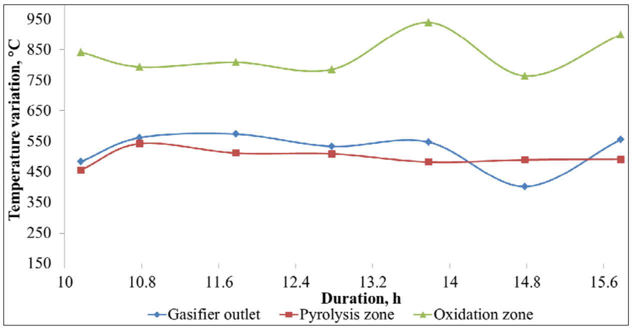

Fig. 4: Temperature variation in the reactor

The pyrolysis and oxidation zone temperature was observed to be varying between 483-543 ˚C and 765-940 ˚C, respectively, whereas the variation in gas outlet temperature was in the range of 402-574 ˚C. Besides that flame temperature at flare was found to be 850 ˚C. The gas temperature in the cooling and cleaning train was found to be 30-43, 32-40, 32-41, 26-40 and 36-43 ˚C, respectively after spray tower-I (ST-I), spray tower-II (ST-II), charcoal filter, wood shavings filter and organic filter-I (Fig. 5).

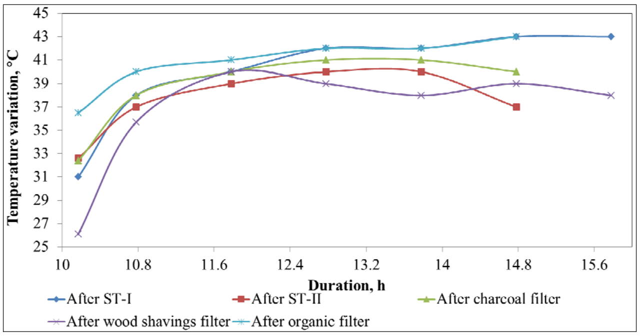

Fig 5: Temperature variation in the cooling and cleaning train

Performance of cooling and cleaning system

TP reduction was found to be more in organic filter-I (filter media with oil) than organic filter-II (filter media without oil). The Fig. 6 depicts that TP is more at the gas outlet and is gradually decreasing in the cleaning train except in the charcoal filtre. This could be due to the removal of previously accumulated TP in the charcoals. It can also be clear that water plays an important role in removing 72.66% of TP from the producer gas prior to entering into other components of the cooling and cleaning system.

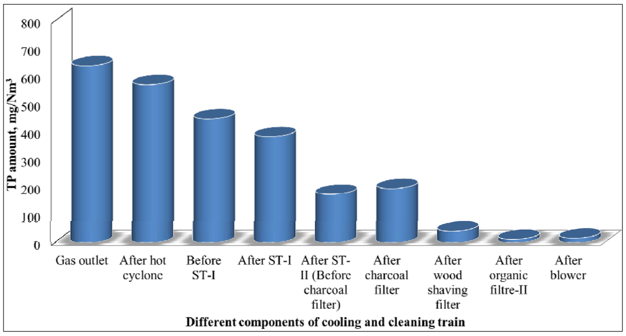

Fig. 6: Trend of TP observed in the cooling and cleaning train

More reduction in TP after organic filter-I could be due to the absorption of tar components by oil mixed in the saw dust. It would be clear that tar components are organic in nature therefore they were absorbed by oil due to their higher solubility in oil. The value of TP at gas outlet, after hot cyclone, before ST-I, after ST-I, after ST-II (before charcoal filter), after charcoal filter, after wood shavings filter, after organic filter-I and after blower was found to be 638.29, 570.21, 446.80, 382.97, 174.46, 195.74, 42.55, 12.76 and 17.02 mg/Nm^3, respectively. The wood shavings filter was found to remove 78.26% of TP from producer gas when compared to 70% in the organic filter I. In TP the colour of sampled papers shown in Fig. 7 indicates the amount of TP in the producer gas at different points and the letters A, B, C, D, E, F, G, H, I, and J represents samples obtained at gas outlet, after hot cyclone, before ST-I, after ST-I, after ST-II (before charcoal filter), after charcoal filter, after wood shavings filter, after OF-I, after OF-II and after blower, respectively.

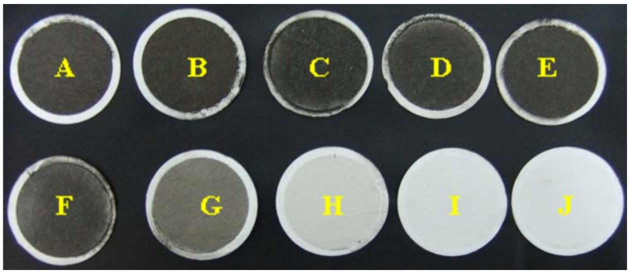

Fig. 7: Impression of TP on sampled papers collected at different points

No slagging and clinker formation were observed during the experiment, this could be due to the proper combustion zone temperature and air flow rate through the gasifier. The maximum pressure drop across hot cyclone, spray tower-I, spray tower-II, charcoal filter, wood shaving filter, organic filter-I, organic filter-II and across orifice meter was found to be 40, 35, 30, 10, 50, 15, 10 and 40 mm of H_2O, respectively.

CONCLUSION

The average TP reduction in the producer gas was observed as 12-17 mg/Nm^3, which was much below the recommended value for continuous IC engine operation. The wood shavings filter was found to remove 78.26% of TP from producer gas when compared to 70% in the organic filter I. The pressure drop and temperature reduction in the cleaning and cooling train was observed nominal for satisfactory engine operation. This method of TP removal promises the quality of producer gas and it did not affect the composition of producer gas obtained. This method seems to be economical due to the use of non-edible oil sources but the investigation on deposal of the waste material of organic filters should be investigated.

REFERENCES

Anis, S. and Z.A. Zainal. 2011. Tar reduction in biomass producer gas via mechanical, catalytic and thermal methods: A review. *Renewable and Sustainable Energy Reviews*, **15**: 2355–2377.

Anonymous. 2000. Qualifying, testing and performance evaluation of biomass gasifiers and gasifier-thermal systems: Test procedures, methodology and protocols. Ministry of New and Renewable Energy, Government of India (Prepared by Indian Institute of Technology, Bombay).

ASTM D3173, Standard test method for moisture in the analysis sample of coal and coke, *ASTM International*, West Conshohocken, PA, www.astm.org.

ASTM D3174, Standard test method for ash in the analysis sample of coal and coke from coal, *ASTM International*, West Conshohocken, PA, www.astm.org.

ASTM D3175, Standard test method for volatile matter in the analysis sample of coal and coke, *ASTM International*, West Conshohocken, PA, www.astm.org.

Balat, M. 2009. Gasification of biomass to produce gaseous products. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **31**: 516-526.

Devi, L., Ptasinski, K.J. and Janssen, F.J.J.G. 2003. A review of the primary measures for tar elimination in biomass gasification processes. *Biomass and Bioenergy*, **24**: 125–140.

Gil, J., Corella, J., Aznar, M.P. and Caballero, M.A. 2008. Biomass gasification in atmospheric and bubbling fluidized bed: effect of the type of gasifying agent on the product distribution. *Biomass Bioenergy*, **17**: 389–403.

IS 1350-2, Methods of test for coal and coke, Part II: Determination of calorific value, Bureau of Indian Standards, New Delhi, www.bis.org.in.

Jaojaruek, K., Jarungthammachote, S., Gratuito, M.K.B., Wongsuwan, H. and Homhual, S. 2011. Experimental study of wood downdraft gasification for an improved producer gas quality through an innovative two-stage air and premixed air/gas supply approach. *Bioresource Technology*, **102**: 4834–4840.

Martinez, J.D., Mahkamov, K., Andrade, R.V. and Lora, E.E.S. 2012. Syngas production in downdraft biomass gasifiers and its application using internal combustion engines. *Renewable Energy*, **38**: 1-9.

Phuphuakrat, T., Namioka, T. and Yoshikawa, K. 2011. Absorptive removal of biomass tar using water and oily materials. *Bioresource Technology*, **102**: 543–549.

Rabier, F., Temmerman, M., Bohm, T., Hartmann, H. and Jensen, P.D. *et al.* 2006. Particle density determination of pellets and briquettes. *Biomass & Bioenergy*, **30**: 954–963.

Rajivgandhi, M.M.C. and Singaravelu, M. 2014. Upgrading biogas to biomethane by physical absorption process. *International Journal of Agriculture, Environment & Biotechnology*, **7:** 639-644.

Sheth, P.N. and Babu, B.V. 2009. Experimental studies on producer gas generation from wood waste in a downdraft biomass gasifier. *Bioresource Technology*, **100**: 3127-3133.

Sooch, S.S. and Gautam, A. 2013. Present status of renewable energy sources in Punjab. *International Journal of Agriculture, Environment & Biotechnology*, **6:** 317-333.

Srivastava, N.S.L., Narnaware, S.L., Makwana, J.P., Singh, S.N. and Vahora, S. 2014. Investigating the energy use of vegetable market waste by briquetting. *Renewable Energy*, **68**: 270-275.

Yamazaki, T., Kozu, H., Yamagata, S., Murao, N., Ohta, S. and Shiya, S. *et al.* 2005. Effect of superficial velocity on tar from downdraft gasification of biomass. *Energy and Fuels*, **19**: 1186-1191.