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Experimental Study on Dual Air Supply Downdraft Gasifier for an Improved Producer Gas Quality

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Tar reduction is a major technical challenge which needs to be addressed in biomass gasifier systems. This study presents an experimental evaluation of dual air supply downdraft gasifier with respect to better producer gas quality in terms of reduced tar and particulate content. Experiments were conducted by varying the secondary air flow from 15 to 30 % at constant equivalence ratio of 0.4. The secondary air flow was optimized at 25 % with tar content of 241 mg Nm^{-3} and lower calorific value of 4.51 MJ Nm^{-3}. The dual air supply in the gasifier allowed a reduction of 79 % tar content as a result of partial oxidation of volatile compounds in the pyrolysis zone.

Key words: Downdraft gasifier, Dual air supply, Producer gas, Tar, Particulate

In 2017, about 19.3 % of global energy consumption was met by renewable energy sources, of which 13 % comprise biomass (REN, 2018). To bring down greenhouse gas emissions by reducing the reliance on fossil fuels, the use of biomass as a source of energy is important for sustainable development in developing countries. One of the appropriate ways of biomass conversion into fuels is gasification i.e., conversion of biomass at higher temperature into producer gas by partial oxidation. The composition of producer gas depends mainly on biomass composition, gasification agent and gasifier type (Mckendry, 2002). Producer gas contains impurities such as tars, particulates, nitrogen (NH_3, HCN) and sulfur (H_2S) compounds. Tar is one of the considerable technical barriers because of its characteristics (high molecular weight) which makes the gas not suitable to be used in engines. Tar compounds begin to condense at lower temperatures which may cause choking of filters, hindering the smooth movement of piston and cylinder and corroding the cylinder liner.

Hence, tar reduction is an inevitable task with respect to producer gas based power generation. There are two methods in tar reduction: primary methods, where tar reduction occurs inside the gasifier and secondary methods, where tar reduction is done at the exit by a secondary gas conditioning system (Devi *et al.,* 2003). Primary method may be more appropriate as it has the advantage of enhancing the energy content of producer gas in addition to tar reduction.

This study has been carried out with a specific objective to determine the optimum primary and secondary air flow combination and characteristics of a cylindrical single throat downdraft gasifier, on the tar and particulate content of the producer gas with coconut shell as feedstock.

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Material and Methods

This section contains detailed description on biomass characterization techniques, dual air supply downdraft gasifier and experimental procedures adopted for the study.

Biomass characterization

Coconut shells manually broken into pieces of size ranging from 4 to 6 cm were used as feedstock for the experiment. The proximate analysis using standard ASTM procedures (moisture content - ASTM D-871-82, volatile matter - ASTM D-3175-07 and ash content - ASTM D-3174-04) and ultimate analysis were performed for the coconut shell. The calorific value of the feedstock was determined using bomb calorimeter (ASTM D-2015-77).

Dual air supply gasification system and instrumentation description

The dual air supply gasification system was based on providing additional air supply at the pyrolysis zone, called secondary air supply. The secondary air supply was varied from 15 to 30 % of total air supply (20 Nm^3 h^{-1}) at constant equivalence ratio of 0.4. A single throat downdraft gasifier with a total capacity of 30 kg was used in the experiments. The reactor is cylindrical in shape with an internal diameter of 0.48 m and a height (from top of the reactor to grate) of 1.04 m. The downdraft gasifier is made of mild steel and has double layer with air gap. Four K-type thermocouples were fixed along the reactor height to record temperature profile and another thermocouple to measure the exit gas temperature. The air was supplied by a 0.5 hp blower. The primary air supply is given 0.39 m above the grate and the secondary air 0.37 m over the primary. The location of secondary air supply port was found by determining the length of pyrolysis zone from temperature profile of the gasifier.

The schematic diagram of dual air supply downdraft gasifier is shown in Fig 1. The air and gas flow rate were monitored by using gas flow meter (Testo 435-1). The producer gas was analyzed for its composition and heating value using portable gas analyzer (Gas Board 3100 P). The producer gas was sampled by a tar sampling train at the gasifier exit in accordance with European Fifth Framework Programme Report (Neeft *et al.,* 2002) and tar yield was determined by gravimetric method.

Results and Discussion

This section presents in detail about the characteristics of biomass and the results obtained for varied secondary air flow from 15 to 30 % at an equivalence ratio of 0.4.

Table 1. Properties of Coconut shell

Parameter	Value
Proximate analysis (wet basis)	
Moisture content (%)	5.25
Volatile matter (%)	72.55 0.62
Ash content (%)	21.58
Fixed carbon (%)	
Ultimate analysis	
Carbon (%)	49.52 6.85
Hydrogen (%)	43.36
Oxygen (%)	0.23
Nitrogen (%)	0.04
Sulphur (%)	
Lower heating value (MJ kg^{-1})	18.5

Biomass characteristics

The proximate analysis, ultimate analysis and lower heating value of coconut shell were determined and presented in Table 1. The moisture content (5.25 %) in coconut shell was low which is preferable for gasification process. As high moisture in feedstock leads to loss of thermal energy from the process for the evaporation of feedstock water. Higher volatile matter content (72.55 %) was observed which is a major cause for tar formation in gasification. This gives a comparatively greater amount of tar that could be cracked and reformed for conversion into combustible gases. Coconut shell had a fixed carbon content of 21.58 % and low ash content (0.62 %) which was reflected in its heating value (18.5 MJ kg^{-1}). The carbon and hydrogen content of coconut shell were found to be 49.52 and 6.85 %, respectively. A higher carbon and hydrogen content would be instrumental in higher production of carbon monoxide and hydrogen gas in the gasification process. The oxygen and sulphur content of coconut shell were 43.36 and 0.04 %, respectively.

Gasifier temperature

For an equivalence ratio of 0.4, the total air supply was maintained at 20 $Nm^3 h^{-1}$. At varying secondary air supply of 0 % (single-stage), 15, 20, 25 and 30 % (double stage) of total air flow, the temperature profile of the gasifier was recorded (Table 2). It was found that average gasifier zone temperatures increased with increase in secondary air supply. The pyrolysis zone temperature increased from 323 to 565 ˚C which may be due to the development of flaming pyrolysis zone by oxidation of volatile compounds. The oxidation zone temperature increased from 856 to 921 ˚C which may be due to heat generated from pyrolysis zone by oxidation of volatile compounds gave additional heat to the oxidation zone. Reduction zone temperature increased from 493 to 591 ˚C which may be the result of additional heat supplied by oxidation zone. Exit gas temperature increased from 391 to 470 ˚C due to rise in gasifier zone temperatures. By diverting a part of primary air into the pyrolysis zone, volatile matter liberated at the pyrolysis zone gets partially oxidized which results in increased temperature of the pyrolysis zone (Martınez *et al*., 2011).

Table 2. Average values of gasifier temperature in different zones

Secondary air flow (%)	Drying (°C)	Pyrolysis (°C)	Oxidation (°C)	Reduction (°C)
0	112	323	856	493
15	123	412	879	527
20	131	437	893	543
25	138	546	918	584
30	140	565	921	591

Producer gas composition and lower calorific value

The producer gas composition (CO, H_2, CH_4 and CO_2) and lower calorific value was observed (Table 3).

Table 3. Composition and LCV of the producer gas

Secondary air flow (%)	CO (%)	H_2 (%)	CH4 (%)	CO_2 (%)	LCV (MJ Nm^{-3})
0	14.98	12.02	2.43	12.47	4.15
15	15.21	13.6	2.02	11.98	4.22
20	15.73	14.2	1.74	11.12	4.36
25	18.12	15.9	1.08	10.76	4.51
30	16.92	15.97	0.89	11.93	4.24

The highest concentration of carbon monoxide (18.12 %) and lowest concentration of carbon dioxide (10.76 %) was attained at 25 % secondary air flow which may be the result of tar cracking reactions at the pyrolysis zone. The hydrogen concentration of producer gas increased from 12.02 to 15.97 % with increase in secondary air supply which might be the result of tar cracking and methane reforming reactions at higher temperature. A similar result was observed during the gasifcation of wood in a modified flow downdraft gasifier (Machin *et al.,* 2015). Maximum calorific value of producer gas (4.51 MJ Nm^{-3}) was obtained at 25 % secondary air supply. Marginal increase in hydrogen and carbon dioxide concentration and greater reduction in carbon monoxide concentration and lower calorific value of the producer gas was obtained by increasing the secondary air flow from 25 to 30 %. It is predicted that further increase in secondary air flow may combine pyrolysis and oxidation zone to act as single combustion zone and encourage complete oxidation reactions which will result in reduced carbom monoxide concentration leading to decrease in calorific value of the gas as found in 30 % secondary air flow. This is similar to the results obtained by other studies (Bhattacharya *et al.,* 1999; Jaojaruek *et al.,* 2011 and Martinez *et al.,* 2011).

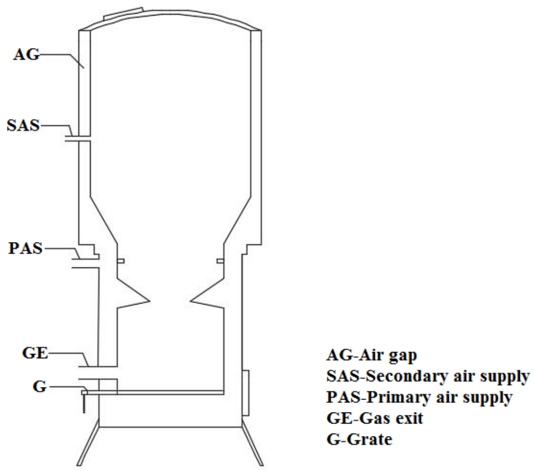

Fig. 1. Schematic diagram of dual air supply downdraft gasifier

Tar and particulate content of producer gas

The effect of secondary air flow on tar and particulate content of producer gas is shown in Fig 2. Tar reduction efficiency ranged between 72.33 and 79.88 % and particulate reduction efficiency ranged between 16.15 and 23.44 % for varied secondary air flows.

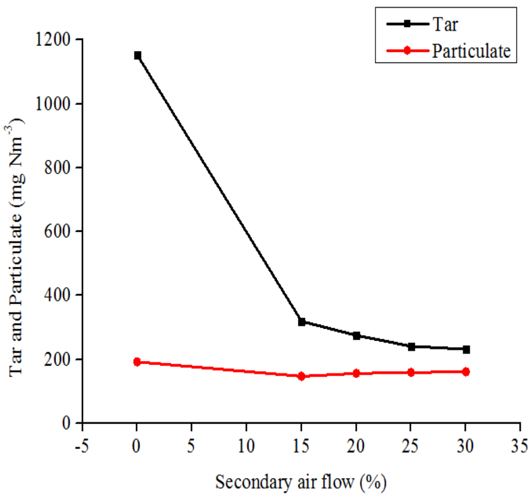

Fig. 2. Tar and particulate content of producer gas

Tar concentration of producer gas decreased from 1153 to 232 mg Nm^{-3} with increase in secondary air flow which implies that increasing the secondary air supply favors temperature rise in the gasifier and promotes tar reduction by thermal cracking which resulted in increased production of hydrogen. Tar concentration was highest (1153 mg Nm^{-3}) in the absence of secondary air flow, which was due to the low temperature at the pyrolysis zone. Tar concentration was lowest (232 mg Nm^{-3}) at 30 % secondary air flow as higher temperature facilitates tar cracking reactions. Tar concentration of 241 mg Nm^{-3} was obtained at 25 % secondary air flow which is marginally higher than 30 % secondary air flow. Particulate matter decreased from 192 to 147 mg Nm^{-3} with increase in secondary air flow from 0 to 15 %. But the particulate matter slightly increased with further increase in secondary air flow. This is because higher air flows escalates the ash carryover by the producer gas and formation of soot particles by the destruction of tar in the oxidation zone. This agrees well with the results obtained by similar studies (Galindo *et al.,* 2014 and Ma *et al.,* 2012).

Conclusion

In the study on dual air supply gasification by varying secondary air flow from 15 to 30 % at constant equivalence ratio of 0.4, it is concluded that dual air supply in gasification is a feasible way to enhance the product gas quality in a downdraft gasifier. The effect of secondary air supply on tar and particulate content of producer gas is a result of temperature increase in pyrolysis and oxidation zones. The particulate content of producer gas decreased by 17.19 % at 25 % secondary air flow.

Tar content of producer gas (232 mg Nm^{-3}) was least at 30 % secondary air supply. But 25 % secondary air flow achieved higher energy content producer gas with an average heating value of 4.51 MJ Nm^{-3} and tar content (241 mg Nm^{-3}) slightly greater than 30 % secondary air supply. As tar reduction cannot be compromised with energy content of producer gas, 25 % secondary air supply was concluded as best treatment for tar reduction in dual air supply gasification. The results given in this study will assist in fixing the parameters for optimal operation of a dual air supply downdraft gasifier, ensuring a good quality product gas.

References

Bhattacharya, S, Siddique, A. M. and H. L. Pham. 1999. A study on wood gasification for low tar gas production. *Energy*., **24:** 285-296.

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

Galindo, A. L, Lora, E. S, Andrade, R. V, Giraldo, S. Y, Jaen, R. L. and V. M. Cobas. 2014. Biomass gasification in a downdraft gasifier with a two-stage air supply: Effect of operating conditions on gas quality. *Biomass and Bioenergy.,* **61:** 236-244.

Jaojaruek, K, Jarungthammachote, S, Gratuito, M. K, Wongsuwan, H. and S. Homhual. 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.

Machin, B. E, Pedroso, D. T, Proenza, N, Silveira, J. L, Conti, L, Braga, B. L. and A. Machin. 2015. Tar reduction in downdraft biomass gasifier using a primary method. *Renewable Energy.,* **78:** 478-483.

Martınez, J. D, Silva, L. E, Viera, A. R. and J. R. Lesme. 2011. Experimental study on biomass gasification in a double air stage downdraft reactor. *Biomass and Bioenergy.,* **35:** 65-80.

Ma, Z, Zhang, Y, Zhang, Q, Qu, Y, Zhouc, J. and H. Qinc. 2012. Design and experimental investigation of a 190 kWe biomass fixed bed gasification and polygeneration pilot plant using a double air stage downdraft approach. *Energy.,* **46:** 140-147.

McKendry, P. 2002. Energy production from biomass (part 3): gasification technologies. *Bioresource Technology.,* **83:** 55-63.

Neeft, J, Knoef, H, Zielke, U, Sjo, S. K, Hasler, P. and P. Simell. 2002. Guideline for sampling and analysis of tar and particles in biomass producer gases. Final report documenting the Guideline, R& D work and dissemination, **95**.

Renewable Energy policy Network. 2018. http://www.ren21.net/status-of renewables/global status-report. Global status report.

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