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Gasification of biomass waste in a downdraft gasifier

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ABSTRACT

Silver oak wood chips and coconut shell chips in different ratio was used in the downdraft gasifier. The air flow rate was varied from 50 lpm-125 lpm. The effect of air flow rate on producer gas composition, producer gas production rate and calorific value of producer gas were studied. The temperature distribution along the reactor in the vertical direction was studied. The producer gas composition was analyzed by a gas chromatography. The producer gas consists of carbon monoxide, carbon dioxide, methane, oxygen, nitrogen and hydrogen. The ultimate and proximate analysis of feed material was carried out by an elemental analyzer. The maximum value of hydrogen in the producer gas is 13.6 %. The calorific value of coconut shell chips and wood chips is 3.95 MJ/m^3 for the feedstock ratio of 2:1. The producer gas can be used as fuel gas.

KEYWORDS

Coconut shell chips;
Wood chips;
Downdraft gasifier;
Gasification;
Producer gas.

INTRODUCTION

Gasification, a thermo chemical process, is a century old technology, which flourished quite well before and during the Second World War. The technology disappeared soon after the Second World War, when liquid fuel became easily available. The interest in the gasification technology has undergone many ups and downs in last century. Today, because of depletion of fossil fuels, increased energy demand, fuel prices and environmental concern, there is renewed interest in this century old technology. The advantage of this technology is a decentralized energy conversion system which operates economically even for small scale. The fundamental advantage of a gasifier coupled to a burning system is its ability to produce higher temperatures that can be achieved with conventional grate. Coconut shell is one of the sources of biomass that can be gasified and it has the greatest potential of any renewable energy option for power production and heating. Biomass gasification is the incomplete combustion of biomass resulting in production of combustible gases consisting of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. This mixture is called producer gas. There may be nitrogen and sulphur in addition, which are present only in small quantities; the woody biomass is heated by combustion of a part of the fuel. The combustion gases are then reduced by being passed through a bed of charcoal at high temperature to get converted into a mixture of the gases CO, H_2, CH_4, N_2, C_xH_x, CO_2 called producers gas and the combustible components are CO, H_2, CH_4 and C_xH_x. The composition of the gases is analyzed using a gas chromatography and, the calorific value of the gas is determined by a theoretical calculation under different operating conditions to optimize the process parameters for heat application. Biomass is useful to meet different kinds of energy needs, including fueling vehicles, providing process heat for industrial facilities, generating electricity and heating homes. It is a renewable source of energy and has many advantages from an ecological point of view. Figure 1 shows a downdraft gasifier.

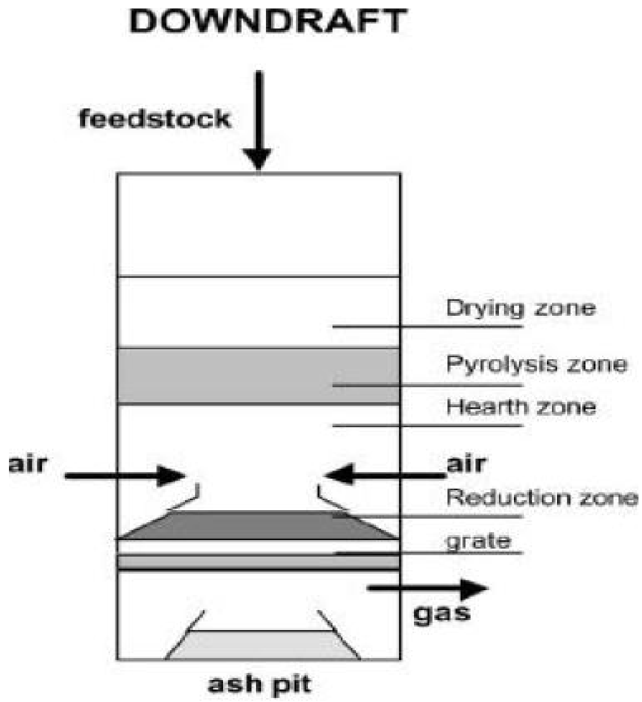

Figure 1 : Downdraft gasifier

The downdraft gasifier has the same mechanical configuration as the updraft gasifier except that the oxidant and product gases flow down the reactor, in the same direction as the biomass. A major difference is that these processes can combust up to 99.9% of the tars formed. Low moisture biomass (<20%) and air or oxygen are ignited in the reaction zone at the top of the reactor. The flame generates pyrolysis gas/vapor, which burns intensely leaving char and hot combustion gas. These gases flow downward and react with the char, generating more CO and H_2. Finally, unconverted char and ash pass through the bottom of the grate and are sent for disposal. In the down-draught gasifier, the fuel is introduced at the top, the air is normally introduced at some intermediate level and the gas is taken out at the bottom. It is possible to distinguish four separate zones in the gasifier, each of which is characterized by one important step in the process of converting the fuel to a combustible gas.

The reactor

Gasifier is a unit which generates producer gas by thermo chemical conversion processes. The developed gasifier is made up of mild steel and it consists of an inner shell and outer shell. The air is admitted into the gasifier in two ways,

1. Through the air injection nozzles around the pe riphery. (primary air)
2. From the top of the reactor. (secondary air)

The reactor is the heart of the gasification system; it has a total height of 1000 mm. It consists of a centre mild steel cylindrical vessel of height 700 mm, internal diameter 190 mm. A stainless steel throat of height 300 mm and of equal thickness is provided below the vessel. Both the vessels are lined with a refractory material of 3 mm thickness. Fire clay is used as refractory material which is a resistant to high temperature, and it has a fusion point higher than 930°C. Thus the heat loss from the furnace was prevented in order to create a high internal temperature and to reduce the tar formation. It has an ash pit at the bottom of the throat and a wood and coconut shell feeding section at the top. The throat experiences high temperatures and reducing atmosphere, its life is less than that of the other parts. The volatiles are released at some stage in the down ward path of wood and coconut shell chips. The transfer of heat to the upper zone causes an earlier initiation of the release of volatiles. The reactor vessel is to hold wood and coconut shell chips of dimensions 12.5 x 12.5 x 12.5(approx). The actual volume is 39 liters.

Figure 2 shows the components of a reactor. The reactor is a throated down draft gasifier and the air is admitted through circumferential nozzles (primary air). Major part of the air supplied for sustaining the combustion was made through the primary air nozzles provided around the circumference of the gasifier. The primary air is controlled using needle valves. Through the top part of a reactor, feedstock is fed. The top part is made of mild steel and joined to the cylindrical part with flange joint. The cylindrical part is made of mild steel. The various zones such as drying, pyrolysis and oxidation are identified by knowing the temperature history inside the reactor. The inner surface is lined with refractory material. Primary air is fed into the oxidation zone at four different points around the circumference. It is also made of mildsteel. Reduction takes place at conical part. It is covered with refractory lining internally. It is joined to the cylindrical part and ash pit with flange joint and high temperature gasket. Grate is provided at the end of conical part, which is made of mild steel. Syn gas produced in the reactor leaves through the ash pit to cyclone separators. Ash is collected in the ash pit.

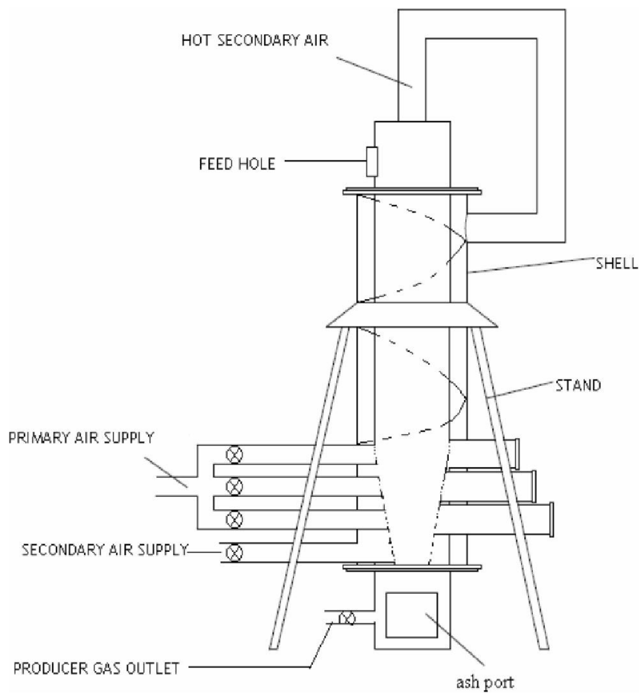

Figure 2 : Reactor

Gases generated from the gasifier normally carry moisture upwards, carbon dust and some tar. This moisture in the gas has a tendency to condense in the pipeline, and collect sub micron particles from the gas. Thus it leads to clogging of the pipes. Therefore a cyclone separator is introduced into the circuit to remove any moisture and dust in the gas.

A galvanized iron shell of 125 mm diameter and 1400 mm effective length with a shower is used as cooling tower for cooling producer gas. Apart from cooling, it washes the gas by removing the dust particle present in the gas. With the use of water in the cooling train, the dust level in the gas is reduced. Scrubber systems are a diverse group of air pollution control devices that can be used to remove tars in syn gas. A wet scrubber is used to clean air, flue gas or other gases of various pollutants and dust particles. A compressor is used to supply air for gasification process.

Eductors are venturi jet devices that use pressurized liquid to entrain, mix and pump other liquids, slurries, gases or dry solids. The eductor has four basic parts they are, driving nozzle, suction chamber, throat and diffuser. In the biomass gasifier system the gas is produced by the gasification process inside the reactor. The gas produced will be having carbon content which is not desirable and which is to be removed. For the removal of the carbon particles present, gas filters are used.

MATERIALS AND METHODS

Figure 3 shows the layout of a biomass gasifier. Biomass materials such as coconut shell chips and silver oak wood chips were used as feed materials. The gasifier consists of an air compressor to supply the sub-stoichiometric quantity of air. The air flow rate was measured using a rotameter at the entrance to the gasifier. The primary air enters to the gasifier through the injection nozzles around the periphery of the throat and the secondary air is preheated and enters through the top of the reactor. It is made up of a mild steel body with two concentric shells of outer diameter 200 mm and 320 mm respectively. The annular space between shells provides passage for secondary air to flow, where it is preheated. The inner shell has two parts. The upper part is cylindrical and has a height of 700 mm. The lower part which is conical in shape has a height of 300 mm. The total volume of the shell is 0.0243 m^3. The primary air enters inner shell. A fire clay lining of 3 mm thickness is provided to the conical part and a grate is fixed to the bottom of the conical part. A cooling tower is used to cool the hot gas from the reactor and two cyclone separators are used to reduce the dust level in the gas. A bed of charcoal and rice husk is used to remove the moisture and dust present in the gas. Three bag filters are also used to remove tar and other fine dust particles. An eductor is provided for torching the feed material and to stabilize combustion inside the reactor in the beginning.

The bio mass used was silver oak and coconut shell. Before each test the moisture of the feed stock was measured and its value was found to be always between 10 to 15%. The feed stock level inside the gasifier was maintained approximately constant before starting the experiment and after the gasification process the little quantity of carbon which is not converted into fuel gas is turned off from the reactor. The sample gas was collected next to the bag filters and the samples were

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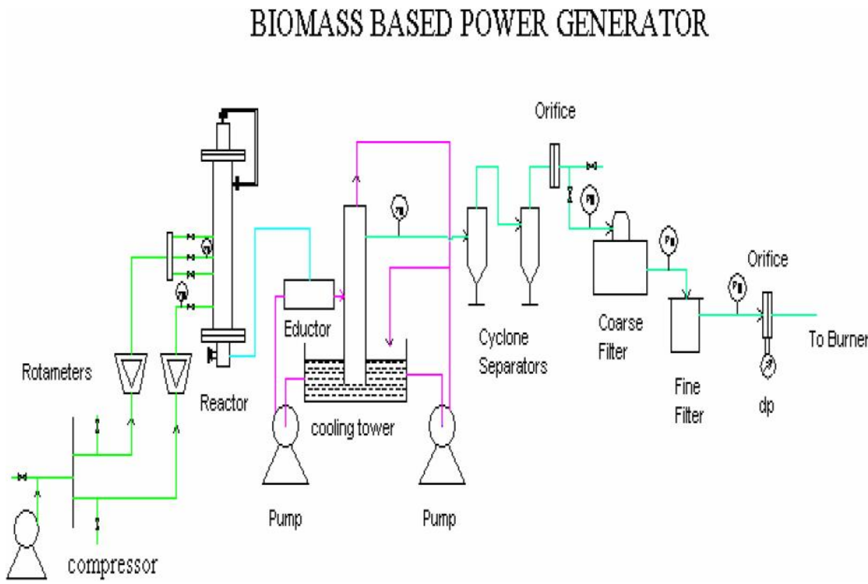


Figure 3 : Biomass gasifier

analyzed. K type thermocouples were used to measure the temperature distribution inside the reactor. The temperatures are measured at intervals of 5mins to record the thermo chemical conversion phases drying pyrolysis, combustion and reduction. Two more thermo couples were used to measure the exit temperature of the producer gas before and after the cooling tower. The batch experiments were carried out as described.

The reactor was filled with 6 kg of wood and coconut shell pieces of size approximately 2.5 cm x 2.5 cm x 2.5 cm and density 589.33 kg/m^3 through the top and was sealed. The fuel bed was torched, at the preset port. After stabilizing combustion, the compressor was started and the air flow was set at a particular flow rate and the eductor was detached from the reactor. The temperature was recorded at different locations at an interval of 5 mins during the experiment. Gas samples are collected at regular intervals, when nearly steady state was reached in the combustion zone. The gaseous products were analysed using TCD gas chromatograph. Knowing the air flow rate and the time taken for experiment and the amount of air used in each experiment was calculated. The amount of producer gas obtained is evaluated by using an orifice meter. The experiments were repeated for different flow rates and different ratios of feed stock such as 1:1, 2:1. Keeping the secondary air flow rate constant (25 lpm), experiments was conducted by varying the primary air flow rate from 25 lpm with an increase of 10-15 lpm used.

Ultimate analysis and proximate analysis of feedstock

The characteristics of biomass feed stock have a significant effect on the performance of the gasifier. Silver oak wood and coconut shell was taken as feedstock material.

TABLE 1 : Proximate analysis of silver oak wood chips

Moisture	Ash	Volatile Matter	Fixed carbon
7.15%	2.04%	82.56%	8.25%

TABLE 2 : Proximate analysis of coconut shell

Ash	Volatile Matter	Fixed carbon
0.80%	78.90%	20.30%

TABLE 3 : Ultimate analysis of silver oak wood chips

Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Gross Calorific value
42.55%	4.22%	43.65%	0.33%	0.06%	16.05 MJ /kg

TABLE 4 : Ultimate analysis of coconut shell

Carbon	Hydrogen	Oxygen	Gross Calorific value
52.20 %	6.40%	42.60%	20.10 MJ /kg

The ultimate and proximate analysis of the silver oak wood and coconut shell chips used for the experiments were carried out and the results are shown in TABLE 1-4

RESULT AND DISCUSSIONS

Effect of air flow rate on producer gas composition

TABLE 5 shows the variation of H_2, O_2 and N_2

content in producer gas with different airflow rate for different feedstock ratio. TABLE 6 shows the variation of CH_4, CO and CO_2 content in producer gas with different air flow rate for different feedstock ratio. The composition of the producer gas was determined by AUTO-CHRO WIN gas chromatography. After the gasification process was established gas samples were collected every 15 minutes. During the sampling period the gas was burnt with the help of pilot burner. Minimum five samples were collected in each run for analysis. Thermal conductivity detector and carrier gases N_2 and H_2 were used to detect the volumetric compositions of gases like O_2, H_2, N_2, CO, CH_4 in a molecular sieve column, and CO_2 was determined using chromosorb102 column.

TABLE 5 : Variation of H_2, O_2 and N_2 content in producer gas with airflow rate for different feedstock ratio

Air flow rate (lpm)	Percentage of H_2 in producer gas		Percentage of O_2 in producer gas		Percentage of N_2 in producer gas	
	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 2:1	Feedstock ratio 1:1
50	12.8968	12.8968	2.7468	2.6874	53.490	51.2868
75	13.6738	14.2212	2.8722	3.4404	49.590	55.2060
100	13.1920	13.2100	5.7465	1.8240	55.664	52.3350
115	12.8394	12.6898	4.3020	4.0182	53.940	56.0400
125	13.4816	13.1400	3.7806	3.4700	53.440	52.1620

(Feedstock Used: coconut shell and silver oak wood)

TABLE 6 : Variation of CH_4, CO and CO_2 content in producer gas with airflow rate for different feedstock ratio

Air flow rate (lpm)	Percentage of CH_4 in producer gas		Percentage of CO in producer gas		Percentage of CO_2 in producer gas	
	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 2:1	Feedstock ratio 1:1
50	1.716	1.176	11.470	12.470	17.170	17.07
75	2.201	1.317	13.670	10.760	17.778	14.54
100	2.126	1.165	13.414	14.730	14.230	13.06
115	1.816	1.208	12.430	10.959	14.540	15.20
125	2.002	1.964	11.800	11.150	13.668	12.49

(Feedstock Used: coconut shell and Silver oak wood)

TABLE 7 : Variation of calorific value of producer gas, producer gas production and conversion efficiency with air flow rate for different feedstock ratio

Air flow rate (lpm)	Calorific value of the producer gas (KJ/m^3)		Producer gas production, (m^3/h)		Conversion efficiency, %	
	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 1:1	Feedstock ratio 2:1	Feedstock ratio 1:1	Feedstock ratio 2:1
50	3630.03	3471.09	11.11	12.11	83.44	87.55
75	3954.36	3316.42	13.88	15.28	85.93	91.30
100	3734.90	3672.13	16.44	19.44	87.45	89.66
115	3724.76	3538.47	10.04	16.72	82.04	85.34
125	3587.59	3429.41	09.43	14.72	80.47	82.64

(Feedstock Used: coconut shell and silver oak wood)

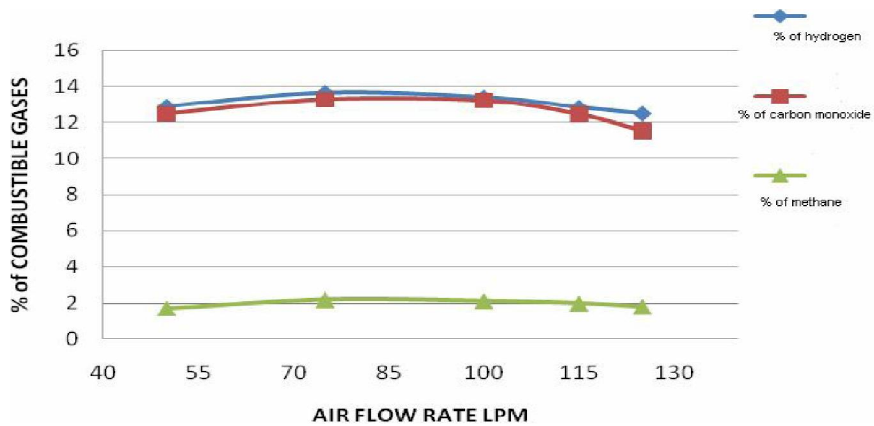
The producer gas contains both the combustible gases and non-combustible gases. The combustible gases contain the gases such as H_2, CO, CH_4 and traces of C_2H_2 and C_2H_6 and the non combustible gases contain N_2 and CO_2.

The producer gas consists of tars and condensable liquids. Some of the tars and condensable liquids were removed in a cooling tower. The temperature of the gas was reduced to room temperature and passed through a filter containing charcoal and rice husk, and then passed through a series of bag tilters to obtain a tar-free gas suitable for engine operation. The producer gas flow is measured at regular intervals of five minutes using a calibrated orifice meter.

Conversion efficiency is the ratio of thermal power of the producer gas produced to the thermal power of input feedstock. It gives a general idea of how much of the energy from the wood is effectively utilized. TABLE 7 shows the variation of calorific value of producer gas, producer gas production and conversion efficiency with air flow rate for different feedstock ratio

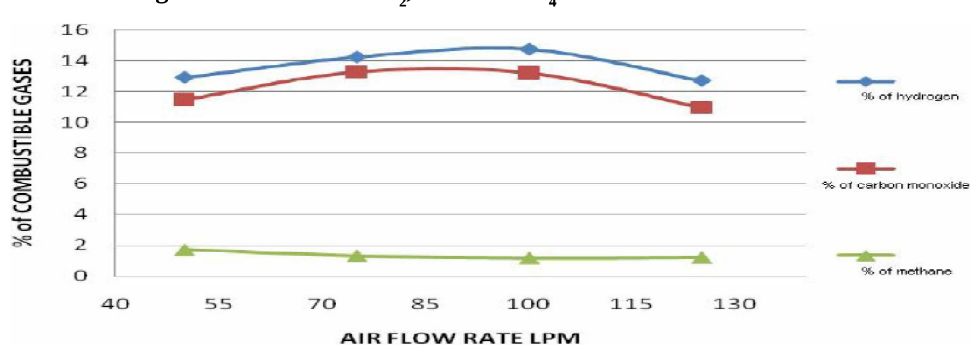
Conversion efficiency, ς_t = (m_{gas} x HHV of fuel gas)/(m_{wood} x HHV of wood)

The hydrogen content in the producer gas slightly increases with the air flow rate. It reaches a peak at 75 lpm to 100 lpm and then steadily decreases with increasing air flow. The gain in H_2 reduces CO content of the gas. Hydrogen content of the producer gas has been found better at the flow rate between 75-100 lpm for all feedstock ratios. Figure 4 and Figure 5 shows the variation of H_2, CO and CH,, content in the producer gas with different air flow rate and different feedstock ratios.



(Feedstock ratio 2:1; Feedstock Used: coconut shell and Silver oak wood)

Figure 4 : Variation of H_2, CO and CH_4 content with airflow rates



(Feedstock ratio 1:1; Feedstock Used: coconut shell and Silver oak wood)

Figure 5 : Variation of H_2, CO and CH_4 content with airflow rates

Effect of air flow rate on calorific value of producer gas

The Figure shows the variation of calorific value with different ratio of mixture feedstock. The calorific value as seen from the Figure is found to slightly increase with increase in reactor air flow rate. The highest calorific values of gases were produced at flow rates between 75-100 lpm. The results show that there is no significant variation in the high heating value of the product gas with air flow rate between 50-125 lpm for 1:1 ratio. The reason is that the calorific value increases with increase in equivalence ratio within the optimum value which is reported as 0.56 for 2:1. From the above discussion it may be concluded that as the heating value for 2: 1 ratio is always lower than the 1:1 ratios at all flow rates.

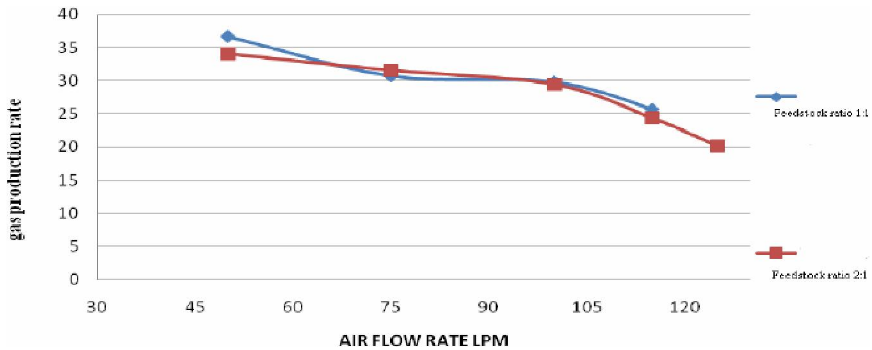
Effect of air flow rate on producer gas production

The producer gas flow was measured at regular intervals and integrated over the entire period of the wood and coconut shell consumption. The air flow rate across the gas flow was determined using a manometer and the time of duration during which the gas sustains flame is noted.

Figure 6 shows variation of gas production rate with air flow rate. The volume of gas produced generally decreased with increase in equivalence ratio but the variation between them depended upon the equivalence ratio and air fuel ratio varied little. It was revealed that the residence time, reactivity of char produced during pyrolysis step, temperature influenced of gas production and gas quality.

Effect of air flow rate on conversion efficiency

Thermal efficiency is the ratio of thermal power of the fuel gas produced to the thermal power of the input feedstock. It gives a general idea of how much energy from the mixture is effectively utilized.



(Feedstock Used: coconut shell and silver oak wood)

Figure 6 : Variation of gas production rate with air flow rate

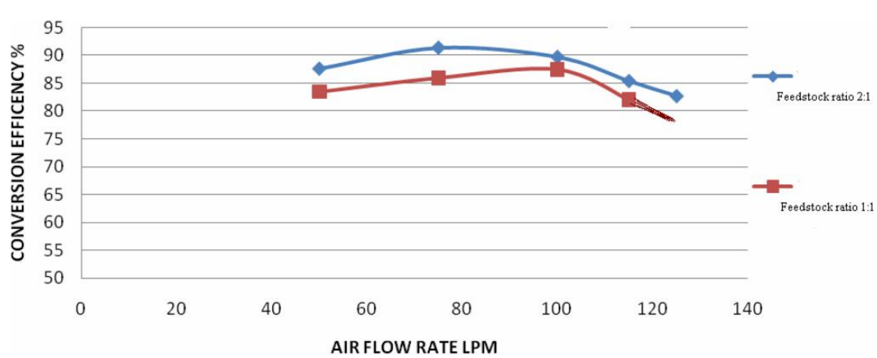
Thermal efficiency, $ç_c = (m_{gas}$ x HHV of fuel gas) / (m_{wood} x HHV of wood)

Figure 7 shows the variation in conversion efficiency with increase in air flow rate. There is a decrease in the conversion efficiency with increase in air flowrate. This is mainly due to decrease in the residence time of the gas. It depends mainly on volume of combustible and calorific value of gases.

Temperature distribution in the reactor

Figure shows the temperature distribution along the length of the reactor for feedstock ratio 2:1. The feedstock used was coconut shell and Silver oak wood. The average temperature was found to vary between 311K at the top (drying zone) of the gasifier and 773 K at the bottom (reduction zone). The temperature attains 712 K at 15 cm height in the combustion zone. It is observed that the heat is transferred by conduction and radiation of the flame due to which the temperature gradient is found to decrease from 773K to 311K. The temperature produced in the oxidation zone depends on the fuel used.

Figure 8 shows temperature distribution along the vertical length of reactor. The temperature produced in the oxidation zone depends on the fuel used. In the reduction zone endothermic reaction occurs and the



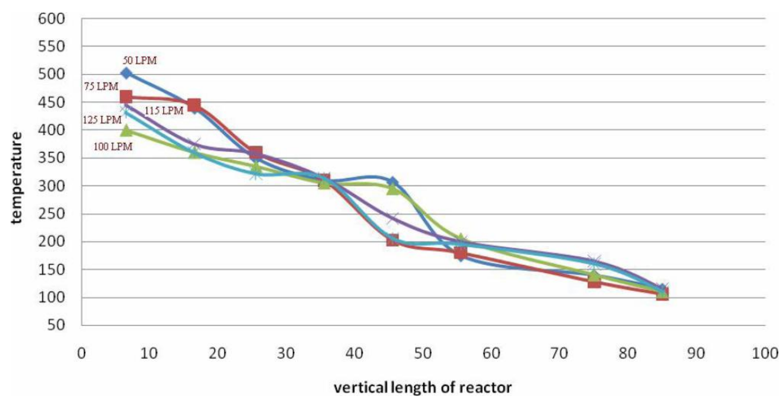
(Feedstock Used: coconut shell and Silver oak wood)

Figure 7 : Variation of conversion efficiency with air flow rate

TABLE 8 : Temperature distribution along the vertical length of reactor

Length (cm)	50 LPM	75 LPM	100 LPM	115 LPM	125 LPM
	Temperature, °C	Temperature, °C	Temperature, °C	Temperature, °C	Temperature, °C
06.5	503	460	400	445	432
16.5	440	445	360	375	360
25.5	350	360	335	358	322
35.5	310	310	305	314	314
45.5	307	203	295	242	206
55.5	175	180	205	200	195
75.0	140	128	140	165	160
85.0	115	106	110	115	110

(Feedstock ratio 2:1; Feedstock Used: coconut shell and silver oak wood)



(Feedstock ratio 2:1; Feedstock Used: coconut shell and Silver oak wood)

Figure 8 : Temperature distribution along the vertical length of reactor

temperature drops. The degree of temperature drop depends upon the extent of the reactions. The extent of the reaction depends upon the reactivity of the char and the thermal history. For higher char reactivity the reduction zone temperature drops faster and the reaction completion occurs rapidly. Higher the temperature inside the reactor helps in better tar cracking. It is not possible to reduce or remove tar effectively from the gas once it comes out of the reactor. The only way to achieve it is to maintain high temperature inside the reactor. TABLE 8 shows temperature distribution along the vertical length of reactor.

CONCLUSION

For the feedstock ratio of 2:1, the producer gas production rate increased from 11.11 m^3/h to 19.44 m^3/h for an air flow rate of 50- 125 lpm. The conversion efficiency was in the range of 82.64 % to 91.3 % for an air flow rate of 50 – 125 lpm for the feedstock ratio of 2:1. The highest calorific value of wood chips and coconut shell chips is 3.95 MJ/m^3 for the feedstock ratio of 2:1. The producer gas can be used as fuel gas. The producer gas consists of carbon monoxide, carbon dioxide, methane, oxygen, nitrogen and hydrogen. The maximum value of hydrogen in the producer gas is 13.6 %. The producer gas can be used as a source of heat for pyrolysis reactor. It can be used as fuel in internal combustion engine in dual fuel mode.

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