

Experimental Studies on Gasification of Pine Wood Shavings in a Downdraft Biomass Gasifier

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Abstract

Biomass is the oldest form of energy used by human beings, mainly in the form of wood. It is a renewable source of energy and has many advantages from an ecological point of view. The direct combustion of biomass generates concern among environmentalists, as it is incomplete and inconsistent and may produce organic particulate matter, carbon monoxide and other organic gases. Biomass gasification has attracted the greatest interest as it offers a higher efficiency as compared to combustion and pyrolysis. Gasification is the process of conversion of solid carbonaceous fuel into combustible gas by partial combustion. Various groups of researchers have carried out experimental studies on downdraft biomass gasifier with different biomass materials such as wood, wood chips, hazelnut shell, agricultural wastes, saw dust, etc. It is reported that bridging is a normal occurrence in the gasifier. It occurs mainly in the pyrolysis zone of the downdraft biomass gasifier. In the present study, wood shavings of pine wood are used as biomass in a downdraft biomass gasifier. To overcome bridging, the design of the biomass gasifier is modified by incorporating a shaking mechanism. With this modified design of the biomass gasifier, experiments are carried out with pine wood (*Pinus roxburghii*) shavings as biomass covering wide range of operating conditions. The performance of the biomass gasifier system is evaluated in terms of equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate, zone temperatures and cold gas efficiency.

Keywords: *Biomass Gasification, Producer Gas, Pinus roxburghii, Equivalence ratio.*

1. Introduction

There are many ways by which the energy, available in abundance around us, can be stored, converted and amplified for our use. Energy sources will play an important role in the world's future. The cost of producing energy from biomass fuels is less than that from fossil fuels. The term biomass is used to describe all the biologically produced matter. Biomass is the oldest form of energy used by human beings, mainly in the form of wood. It has either been burned directly in furnaces, or processed to increase its energy content (Haykiri-Açma, 2003). 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

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and has many advantages from an ecological point of view (Babu and Sheth, 2006). Biomass gasification is the incomplete combustion of biomass resulting in production of combustible gases consisting of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen (Sheth and Babu, 2009a). This mixture is called producer gas. It is burnt to produce process heat and steam or used in gas turbines to produce electricity (Sheth and Babu, 2006; Sheth and Babu, 2009b). The concentration of hydrogen in producer gas depends upon many factors such as moisture content of biomass, type and composition of biomass, operating conditions, configuration of the biomass gasifier, etc. (Sheth and Babu, 2010).

Dogru et al. (2002) carried out gasification studies using hazelnut shell as a biomass. Jayah et al. (2003) used a downdraft biomass gasifier using rubber wood as biomass in a tea drying unit. In order to assess the potential of the saw dust as a biomass material, a fixed bed, downdraft, stratified and open top gasifier was used by Wander et al. (2004). Zainal et al. (2002) performed experimental studies on a downdraft biomass gasifier using wood chips and charcoal. Sheth and Babu (2009b) carried out experiments with waste wood blocks of *Dalbergia sisso* as biomass in a downdraft biomass gasifier to generate the producer gas. In the present study, the composition of the producer gas is measured using a gas chromatograph and the effects of equivalence ratio on producer gas composition, calorific value of the producer gas, gas production rate, zone temperatures and cold gas efficiency are studied. It is reported that bridging of biomass loaded in the gasifier is a common problem in the operation of the gasifier. This problem is mainly found with low density biomass materials such as rice husk, wood shavings, etc. It occurs mainly in the pyrolysis zone of the downdraft biomass gasifier.

In the present study, gasification experiments with wood shavings of *Pinus roxburghii*, commonly called Chir wood, as biomass are carried out in downdraft biomass gasifier. The wood shavings of the pine wood, a waste material, are collected from the carpentry section of the institute's workshop. The problem of bridging was faced in the initial trial runs. The biomass gasifier is modified by incorporating a shaking mechanism to reduce bridging of biomass in the pyrolysis zone of the biomass gasifier. The experiments are carried out on the modified gasifier with *Pinus roxburghii* wood shavings as biomass, covering a wide range of operating conditions. The effects of varying parameters such as air flow rate and moisture content on the quality of the producer gas generated are studied. The performance of the biomass gasifier system is evaluated in terms of equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate, zone temperatures and cold gas efficiency.

2. Biomass Gasification

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are drying of fuel, pyrolysis, combustion and reduction (Babu and Sheth, 2006b). An Imbert downdraft biomass gasifier is used in the present study. It has throated combustion zone and different area of cross section for pyrolysis and reduction zone unlike a stratified downdraft biomass gasifier in which gasifier cross sectional area is uniform throughout the gasifier (Sheth and Babu, 2009b). The products of wood pyrolysis depend upon temperature, pressure, residence time and heat losses. Pyrolysis produces large quantities of tar and gases containing carbon dioxide. In downdraft gasifiers, pyrolysed gas generated in pyrolysis zone gets mixed with the moisture coming from drying zone and flows downward. The tars have to go through combustion and reduction zone and are partially broken down. The combustible substance of a

solid fuel is usually composed of elements carbon, hydrogen and oxygen. In combustion, carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction is exothermic. The heat generated in the combustion zone is transferred to the pyrolysis and drying zone (Sheth and Babu, 2009b). The products of partial combustion (water, carbon dioxide and uncombusted partially cracked pyrolysis products) pass through a red-hot charcoal bed where endothermic reduction reactions take place (Rajvanshi, 1986). Biomass is fed to the gasifier and oxidized in the zone where air is continuously supplied from two air nozzles. The dimensional details of the biomass gasifier used in the present study and experimental procedure are reported in Sheth and Babu (2009b).

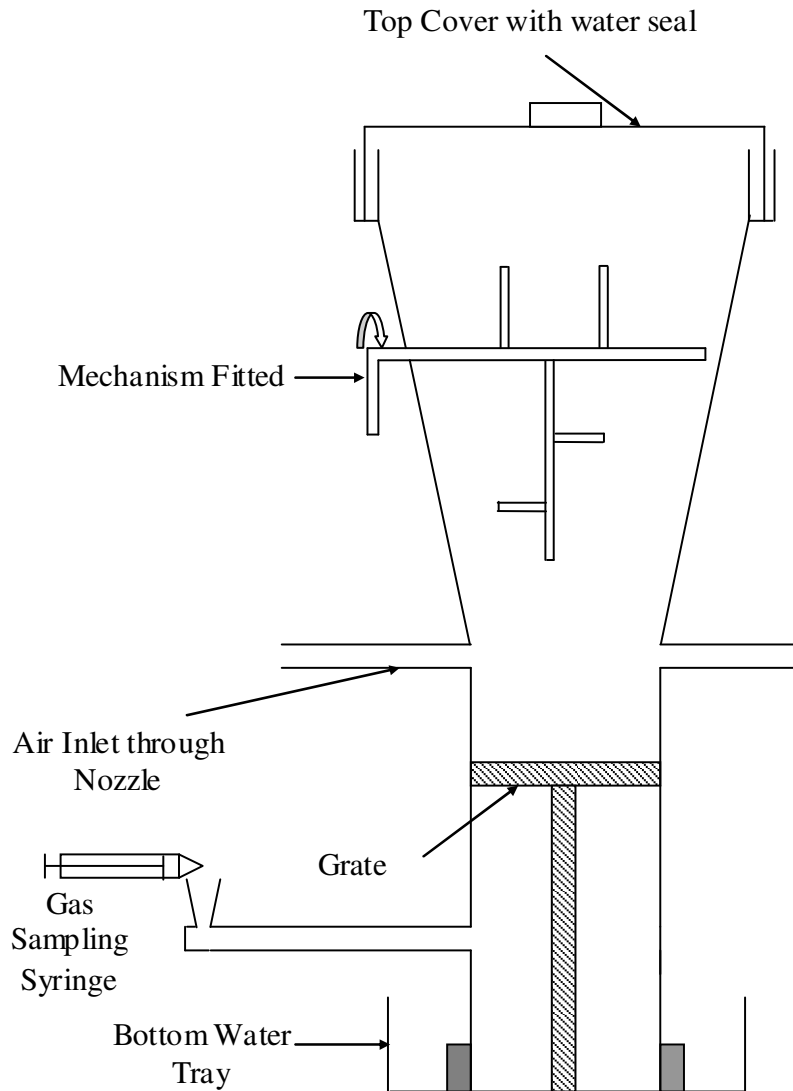


Figure 1: Schematic of modified downdraft gasifier

As soon as the biomass in combustion zone gets consumed, biomass in the pyrolysis zone flows downward due to gravity. If the biomass doesn't flow downward easily, it leads to bridging. There are two main reasons for bridging *viz.* (1) the bulk density of the biomass is too low, and

(2) cone angle is less than angle of repose of the biomass. The second criterion is generally taken care of while designing the downdraft biomass gasifier. However, while using light weight biomasses such as wood shavings, moist saw dust, rice husk, etc. in a downdraft biomass gasifier, the practical operating problem of bridging is faced. During the initial experimental runs, bridging occurs and gasifier cannot be operated continuously for more than 10 minutes. It is due to the low bulk density of the wood shavings of the pine wood. To overcome the bridging, the design of the biomass gasifier is modified by incorporating the shaking mechanism. The 'L' shape steel rod is placed in the gasifier, one end of which is extended along the axis of the gasifier up to the oxidation zone. Some small rods (in the radial directions up to the wall of the gasifier) are welded on its axial part of 'L' shaped rod at different heights. The other part of the rod is positioned to protrude through the side wall to the outside of the gasifier. Mechanical fitting is carried out to ensure that there is negligible leakage and free movement while the biomass of pyrolysis zone is shaken from outside the gasifier.

3. Results and Discussion

3.1. Producer gas composition and Temperature profiles

The physical properties of the *Pinus roxburghii* are listed in Table-1 (Jain, 1992).

Table -1 Characteristics of Pinus roxburghii

Physical Properties	
Density (kg/m ³)	480
Proximate Analysis (% by wt. dry basis)	
Fixed Carbon (FC)	54.82
Volatile Matter (VM)	43.26
Ash	1.91
HHV (MJ/kg)	23.17

The producer gas composition and the temperature profile in the gasifier for Experimental Run 1 are presented in sections 3.1.1 and 3.1.2. The analysis for the other experimental runs conducted is carried out in a similar manner.

3.1.1. Producer gas composition

The composition of the producer gas, sampled at five minute intervals during gasification experiments, is found using a gas chromatograph (NUCON 5765) with a thermal conductivity detector. The molar compositions of the producer gas obtained in Experimental Run 1 are shown in Fig.2. It is found that the quantities of CO and H₂ gases obtained are good during steady operation between 10 and 20 minutes. A large molar fraction of N₂ gas is observed at 5 minutes corresponding to startup and at 25 minutes from the start of the gasifier. The operation of gasifier is stopped at 25 minutes for all the experimental runs carried out in the present study.

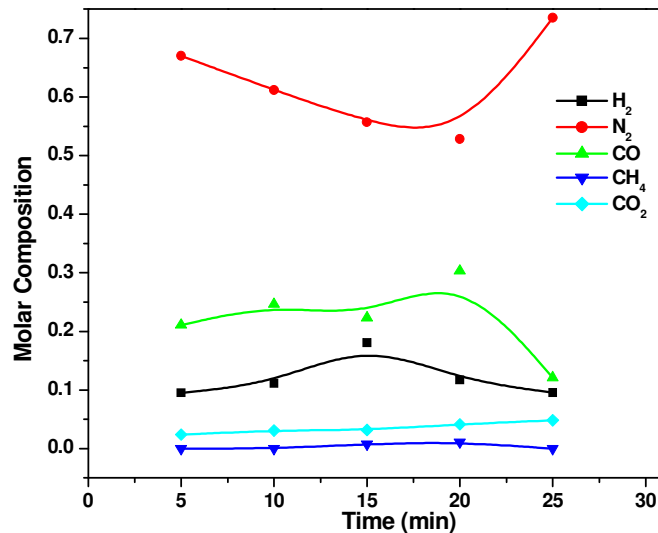


Figure 2: Variation of molar composition with time for Experimental Run 1

3.1.2. Temperature Profile

The temperatures displayed by various thermocouples embedded in the gasifier are noted during the experimental runs at time intervals of 5 minutes. Fig.3 shows the plot of these temperatures as a function of time. In the gasifier, the reduction zone is present between 0 – 90 mm from the grate, while the oxidation zone lies between 90 -150 mm from the grate. Between 200 – 450 mm from the grate, the pyrolysis and drying zones are encountered. Fig.4 shows the temperature at various heights from the grate at the centre ($r = 0$) of the gasifier and at half the radius ($r = R/2$) of the gasifier. The temperature of the oxidation zone (distance from grate (dfg) = 130 at $r = 0$) varies from 750 – 1150°C, while that of the pyrolysis zone (dfg = 245 at $r = 0$) varies from 230 – 550°C. For the drying zone (dfg = 430 at $r = 0$), temperature varies in the range of 100 – 300°C. It can be seen that the temperatures at $r = 0$ are generally greater than those at $r = R/2$ during steady operation of the gasifier.

The mechanism for reduction of bridging, described in section 2 of this paper, is utilized every five minutes during the operation. This moves part of the unconsumed biomass into the lower regions of the gasifier hence allowing continuation of operation of the gasifier. It can be seen in Fig.3 that the temperature of the oxidation zone falls from around 1060°C to around 700-800°C in about 20 minutes. The temperatures of the upper regions of the gasifier, such as the pyrolysis zone and the drying zone increase. This occurs when the biomass in the oxidation zone is consumed and some bridging in the uppermost regions of the gasifier, beyond the reach of the mechanism, prevents the unconsumed biomass from entering the oxidation zone. Fig.4 shows the temperature variation as a function of distance from grate at time intervals of 5 minutes for Experimental Run 1. It provides an idea of the temperatures at different points covering the height of the gasifier at intervals of 5 minutes.

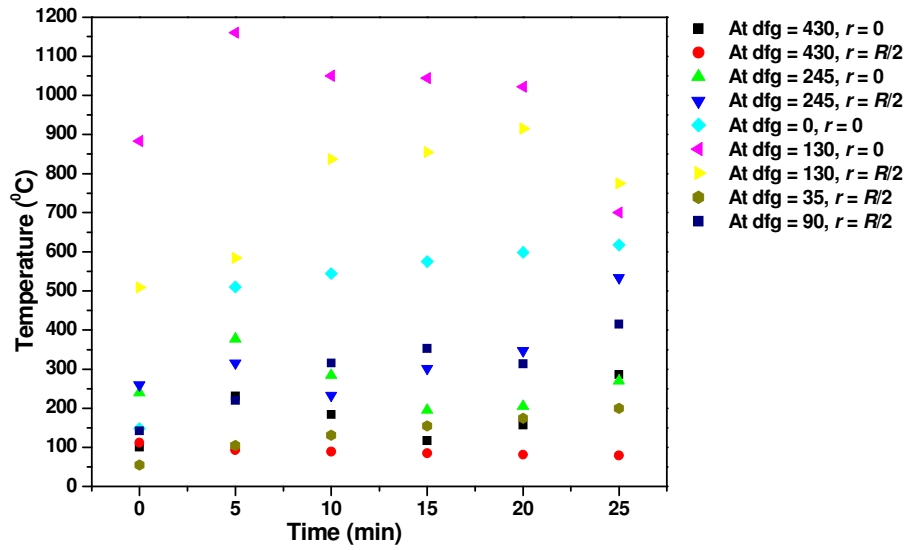


Figure 3: Temperature variation as a function of time for Experimental Run 1

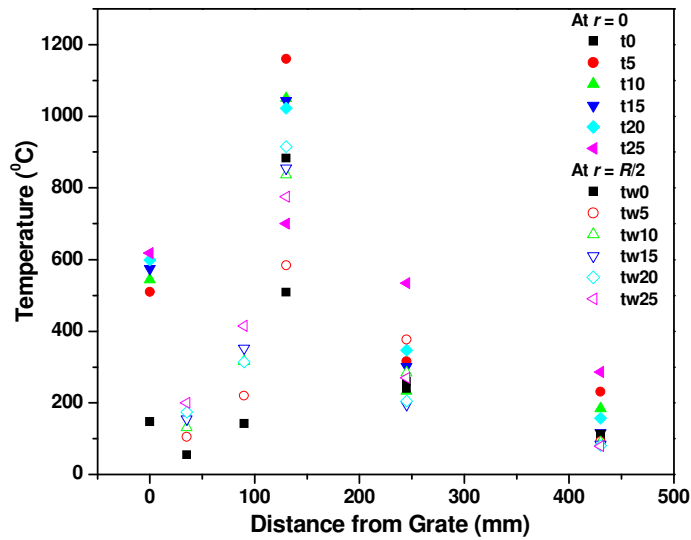


Figure 4: Temperature variation as a function of distance from grate at time intervals of 5 minutes for Experimental Run 1

3.2. Analysis with respect to equivalence ratio

The details of parameters varied during present experimental study are given in Table-2. Biomass consumption rate is found to vary from 0.72 to 1.92 kg/h for an air flow rate varying from 1.54 to 2.16 m³/h. Moisture content is varied from 0.0366 to 0.363 wt. fraction on wet basis. In order to reduce the number of parameters on which the performance of the biomass gasifier depends, an equivalence ratio is defined to reflect the combined effect of air flow rate,

rate of wood supply and duration of the run. The equivalence ratio (ϕ) for each run is calculated by Eq. (1) (Reed and Das, 1988).

$$\text{Equivalence ratio } (\phi) = \frac{(\text{Air flow rate/ Biomass consumption rate})}{(\text{Air flow rate/ Biomass consumption rate})_{\text{Stoichiometric}}} \quad (1)$$

The stoichiometric ratio of air flow rate to biomass consumption rate is 5.22 m³ air/kg of wood (Zainal et al., 2002). The values of equivalence ratio are calculated for each run and reported in Table 2.

Table 2: Details of the experimental runs for biomass gasification

Experimental Run No.	Air flow rate (m³/h)	Initial moisture content (wt fraction, wet basis)	Biomass consumption Rate (kg/h)	Equivalence ratio(Φ)
1	2.16	0.0366	1.92	0.2155
2	1.851	0.0366	1.7	0.1738
3	1.5425	0.0366	0.72	0.4104
4	1.5425	0.3490	1.44	0.2052
5	1.5425	0.3630	1.2	0.2462
6	1.5425	0.1608	0.9	0.3283

The performance of the biomass gasifier system is evaluated in terms of the producer gas composition, the calorific value of producer gas, zone temperatures, gas generation rate, and cold gas efficiency.

3.2.1. Variation of producer gas composition with equivalence ratio

The average gas composition for each experimental run is plotted against the equivalence ratio of the corresponding experimental run and shown in Fig.5. The average should take care of the variation with respect to time. It is noted that the molar fractions of nitrogen and carbon dioxide decrease with an increase in ϕ up to a value of $\phi = 0.21$. Molar fractions of nitrogen and carbon dioxide increase for higher values of ϕ . The fractions of carbon monoxide and hydrogen increase up to $\phi = 0.21$ and then decrease while the opposite trend is observed for nitrogen and carbon dioxide. A higher value of ϕ indicates a higher air flow rate for a specific biomass consumption rate. This leads to a larger CO₂ production in combustion zone and a larger quantity of N₂ entering the gasifier through the air supply. The rate of reactions occurring in the reduction zone and length of the reduction zone control the conversion of CO₂ to CO. A greater amount of CO₂ is converted to CO and H₂ in the combustion zone corresponding to an increase in ϕ from 0.174 to 0.21. Thus, the fractions of CO and H₂ increase with ϕ till a value of $\phi = 0.21$ and fractions of CO₂ and N₂ decrease. The increase in CO₂ and decrease in CO & H₂ fractions for the equivalence ratio higher than 0.21 indicate that production of CO₂ in combustion zone exceeds the conversion capacity of reduction bed to convert it to CO. As mentioned earlier, for larger values of ϕ ranging from 0.21 to 0.41, a larger quantity of N₂ enters the gasifier through the air supply and hence an increase in N₂ fraction is observed.

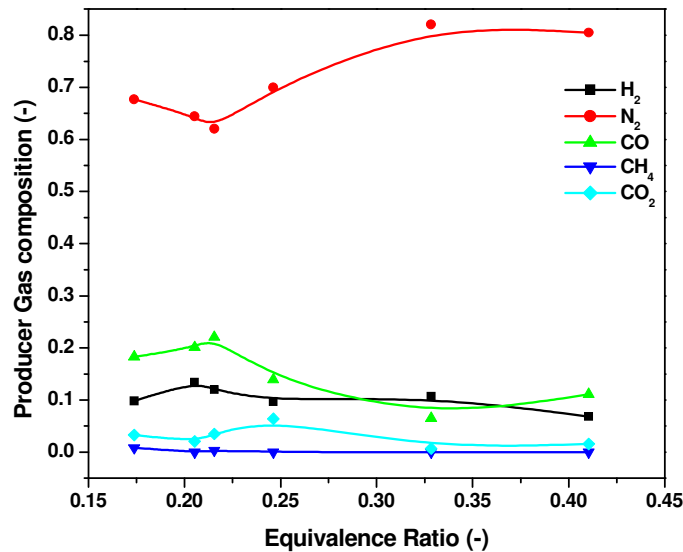


Figure 5: Effect of equivalence ratio on producer gas composition.

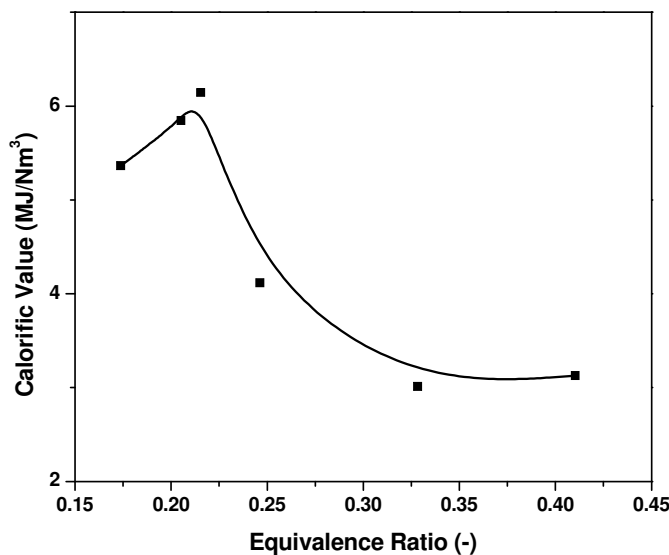


Figure 6: Effect of equivalence ratio on calorific value of producer gas

3.2.2. Variation of calorific value with equivalence ratio

The calorific value can be calculated based on the composition of the producer gas. As mentioned earlier, carbon monoxide and hydrogen are the main components of the producer gas. A greater concentration of carbon monoxide and hydrogen corresponds to a higher calorific value. The presence of methane in the gas increases the calorific value but as seen in Fig.5, the fraction of methane is very small. Variation of calorific value of the producer gas with equivalence ratio is presented in Fig.6. It is found that at an equivalence ratio of 0.174 the

calorific value is the least at 5.36 MJ/Nm^3 . With a small increase in the equivalence ratio at $\phi = 0.21$, the calorific value reaches a maximum of 6.14 MJ/Nm^3 and then follows a decreasing trend. Calorific value steadily decreases with a further increase in the equivalence ratio beyond 0.21. This is in agreement with the decreasing trends of carbon monoxide and hydrogen fractions with increase in ϕ value beyond 0.21 as discussed in section 3.2.1.

3.2.3. Variation of zone temperatures with equivalence ratio

The variation of the average temperature of pyrolysis and oxidation zone of the downdraft biomass gasifier with the equivalence ratio is shown in Fig.7. The temperature of oxidation zone is found to vary from 900°C to 1100°C and that of the pyrolysis zone between 150°C and 400°C . The oxidation zone temperature depends upon the heat released due to the biomass combustion and air flow rate. An increase in air flow rate increases the oxygen available for oxidation but also increases the amount of N_2 entering the gasifier. N_2 being inert, acts as a heat carrier and reduces the temperatures in the oxidation and pyrolysis zones. The maximum value of temperatures in the oxidation zone represents the optimum amount of equivalence ratio ($\phi = 0.21$). This is in agreement with the optimum equivalence ratio obtained in the previous sections based on producer gas composition and calorific value analysis.

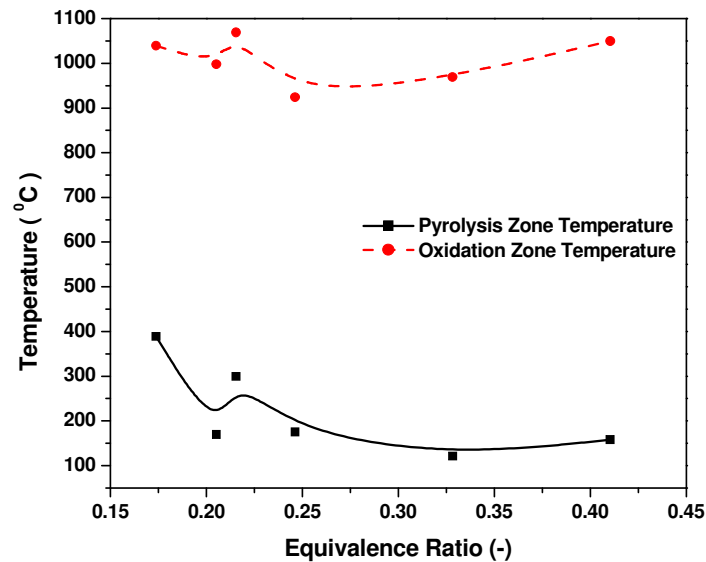


Figure 7: Effect of equivalence ratio on zone temperatures.

3.2.4. Variation of gas production rate with equivalence ratio

In section 3.2.1, we have seen that a higher equivalence ratio corresponds to a higher air flow rate for a specific biomass consumption rate. Fig.8 shows that with an increase in the equivalence ratio, producer gas production rate increases with maxima at an equivalence ratio of 0.21. After a certain value of the equivalence ratio, calorific value of the producer gas deteriorates due to higher amounts of carbon dioxide but the production rate of producer gas continues to increase. This increase in production rate of producer gas is due to the larger quantity of N_2 entering the gasifier through the air supply for larger equivalence ratios.

3.2.5. Variation of cold gas efficiency with equivalence ratio

Cold gas efficiency is defined as the ratio of energy of the producer gas per kg of biomass to the HHV of the biomass material. The cold gas efficiency depends upon the calorific value and the amount of producer gas released at constant HHV of biomass (Sheth and Babu, 2009b). Fig.8 shows that the amount of producer gas increases continuously and the cold gas efficiency passes through maxima at $\phi = 0.21$ with an increase in the equivalence ratio.

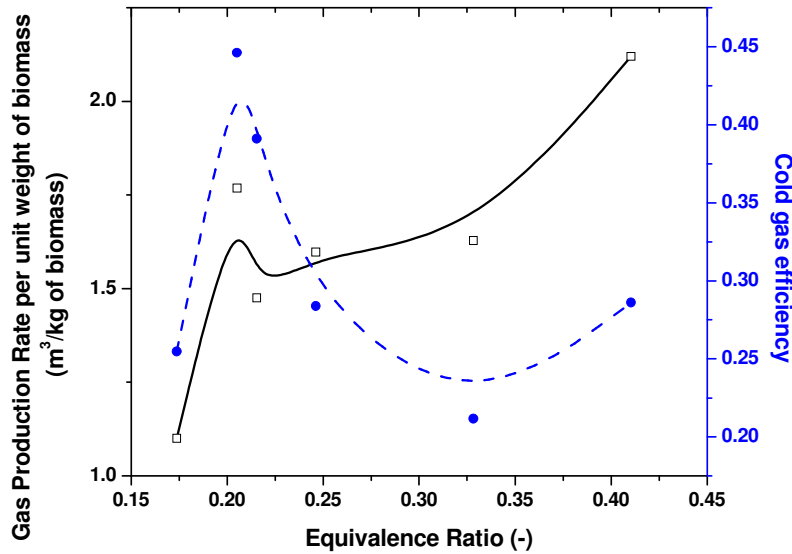


Figure 8: Effect of equivalence ratio on producer gas production rate per unit weight of biomass and on cold gas efficiency.

4. Conclusions

- Good amounts of CO and H₂ gases are obtained during steady operation between 10 and 20 minutes. The percentage of H₂ gas obtained is between 6.8% and 13.4% and that of CO is 6.5 % to 22%.
- Molar fractions of N₂ and CO₂ decrease up to an equivalence ratio of 0.21. For larger values of ϕ ranging from 0.21 to 0.41, there is an increase in N₂ and CO₂ fractions. This is opposite to the trend observed for H₂ and CO molar fractions.
- The temperature of oxidation zone varies from 900°C to 1150°C and that of pyrolysis zone varies between 150°C and 400°C. At an equivalence ratio of 0.21, the oxidation zone temperature passes through maxima.
- The trend of calorific value, producer gas production rate and cold gas efficiency variation is similar to that of variation of CO and H₂ fractions with an increase in equivalence ratio. With an increase in the equivalence ratio, calorific value, producer gas production rate and the calorific value have maxima at an equivalence ratio of 0.21.
- The optimal equivalence ratio for *Pinus roxburghii* wood shavings in the downdraft gasifier studied is 0.21.

5. References

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