INVESTIGATION OF BIOMASS GASIFICATION SIMULATION USING AIR, STEAM AND OXYGEN AS GASIFYING AGENT

Anbazhaghan NATARAJAN[1*], Dillibabu VENUGOPAL[2], Lakshmanan THANGAVELU[3],

[1]Department of Mechanical Engineering, VRS College of Engineering and Technology, Anna University, Villupuram, India

[2]Department of Automobile Engineering, KCG College of Technology, Anna University, Chennai, India

[3]Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, India

[*] Corresponding author, E-mail: anbazhaghan1968@gmail.com

The syngas produced from gasification process is used for many applications; the selection of fuel, gasifying medium and operating condition has major influence on the final gas composition. In the present work, rice husk air gasification,rice husk steam gasification, sawdust air gasification and sawdust oxygen gasification simulation were carried out by non-stoichiometric equilibrium model based on Gibbs free energy minimization using FactSage 6.3 software. The investigation is carried out to study the effect of operating conditions on biomass gasification. In rice husk air gasification, increase in temperature enhances H_2 value at equivalence ratio ϕ = 0.25, at other ϕ values after reaching optimum value H_2 formation decreases. In sawdust oxygen gasification, increase in ϕ value enhances CO_2 formation for all temperatures and increase in temperature reduces CO_2 formation for all ϕ value.Increase in equivalence ratio for all the temperatures decreases the combustible gases formation due to the oxidation reactions. Gas compositions were compared to study the effect of fuel quality and gasifying medium on the gasification process. Rice husk air gasification has 5.85 % higher CO formation than sawdust air gasification at 800 ℃ & ϕ = 0.45. The maximum difference of 13.8 % was observed for H_2 content at 700 ℃ & ϕ = 0.45 between sawdust air and oxygen gasification. Gas heating value and gasification efficiency were determined for the biomass gasification processes.

Keywords: rice husk, sawdust, air gasification, steam gasification, oxygen gasification, gas heating value, gasification efficiency.

1. Introduction

Rice husk is an agricultural waste and sawdust is an industrial by-product, both wastes are available in large quantity and suitable for energy generation. Air gasification, steam gasification and oxygen gasification were commonly used gasifying mediums; steam and oxygen were used to produce gases with enhanced heating value [1]. The operating condition of the gasification process decides the gas composition which in turn determines the end application of the producer gas. The influence of fuel quality and gasifying medium on final gas composition gives the insight for fuel and gasifying medium selection [2,3].

Moghadam et al. [2] used coconut shell in a lab-scale gasifier for the integration of pyrolysis and air-steam catalytic gasification. Maximum H_2 yield and syngas yield of 83.3 g/kg and 485.9 g/kg were obtained respectively. Effect of temperature, equivalence ratio and steam to biomass ratio were analyzed for finding the optimum condition of gasification. The operating temperature has a major influence on syngas production. Optimum equivalence ratio value varies with the operating condition while the optimum S/B ratio depends on the composition of the feedstock. Steam injection on catalytic bed reduces tar formation. Ceroneet al. [3] gasified lignin rich residue of straw and cane in a pilot-scale 20 kg/h updraft gasifier with air-steam and oxy-steam gasifying mediums. The reactivity of residues was investigated by TGA; 75 % - 80 % of organic matter pyrolyzed at 700°C, indicates the domination of biomass conversion by primary and secondary pyrolysis process. A maximum H_2/CO ratio of 2.08 and lower heating value of 10.9 MJ/Nm^3 were obtained from oxy-steam gasification. Steam improved the hydrogen content of syngas and corresponding gas heating value. Ismail & El-Salam [4] carried out experimental work and numerical modelling of wood pellet gasification in an updraft high temperature air gasifier. The influence of equivalence ratio on bed temperature, gas composition and energy efficiency was studied. High equivalence ratio reduced CO and H_2 concentration and increased CO_2 content of syngas by participating in combustion. Gasifier operating temperature selection depends on char conversion and H_2 production.

Susastriawan et al. [5] studied the performance of downdraft gasifier using rice husk, sawdust and co-gasification of rice husk and sawdust for ϕ = 0.15, 0.2 & 0.25. Temperature profile, fuel consumption rate, combustible gas composition, gas heating value and gasification efficiency were analyzed. Optimum equivalence ratio condition is 0.2, 0.2 & 0.15 respectively for rice husk, sawdust and co-gasification. The gas lower heating value of 3.13 MJ/Nm^3, 2.69 MJ/Nm^3&0.35 MJ/Nm^3 and gasification efficiency of 72.73%, 69.27% & 82.08% were attained. Ajay Kumar et al. [6] performed gasification of distiller grains in a bench-scale fluidized bed gasifier using steam and air as the fluidizing and oxidizing agent. Effect of temperature, steam to biomass ratio and equivalence ratio on gas composition was investigated. An increase in temperature improved H_2 content, energy efficiency and carbon conversion efficiency of the gasification process. High temperature provides the energy needed for H_2 formation reactions.

In the present work, the gas composition of rice husk air gasification, rice husk steam gasification, sawdust air gasification and sawdust oxygen gasification is determined by non-stoichiometric equilibrium model by Gibbs free energy minimization method using FactSage 6.3 software. An investigation is carried out to study the effect of operating condition, fuel quality and gasifying medium on gas composition. The maximum value of major combustible gases, gas heating value and gasification efficiency were determined for different gasification processes.

2. Methodology

The simulation of the gasification process is carried out by non-stoichiometric equilibrium model based on Gibbs free energy minimization. Lagrange multiplier iterative method was employed to determine the final gas composition by FactSage software. Many researchers used Lagrange multiplier method to predict the performance of commercial gasifiers [7-9]. The objective function of the model was subjected to mass balance and non-negativity of the number of moles to find the equilibrium composition of final products. Biomass elemental composition, gasifying medium quantity and operating condition were the input details for simulation. The elemental composition of rice husk taken from Karmakar et al. [10] and sawdust from Lahijani& Zainal [11] is shown in Tab 1.

Table 1. Biomass elemental composition.

S.No	Fuel	Proximate Analysis [Wt.%]				Ultimate Analysis [Wt.%]				
		Volatile Matter	Fixed Carbon	Moisture	Ash	C	H	N	O	S
1	Rice husk	55.54	14.99	9.95	19.52	49.07	3.79	0.63	46.42	0.09
2	Sawdust	76.1	8.9	14.6	0.40	44.96	5.83	3.10	45.5	0.61

In rice husk air gasification, the gas composition was determined for ϕ = 0.25, 0.35 and 0.45 and T = 600 – 800 °C. Rice husk steam gasification was carried out for S/B ratio=1 &1.32 and T = 690 - 750°C. Sawdust air and oxygen gasification carried out for the simulation condition of ϕ = 0.3-0.6 and T = 600 – 900 °C. To determine the performance of the gasification process, gas heating value and gasification efficiency were determined. Gas lower heating value is determined from Eq.(1) given by Cheng et al. [12]. Biomass heating value found from Eq.(2) given by Proll and Hofbauer [13]; gas yield represents the volume of gas produced per unit mass of biomass, calculated from Eq.(3) given by Ngo et al. [14] and gasification efficiency is determined from Eq. (4).

$$LHV_{gas} = (CO\% \times 126.36 + H_2\% \times 107.98 + CH_4\% \times 358.18)\ [\text{kJ Nm}^{-3}] \quad (1)$$

$$LHV_{biomass} = (34835\ C + 93870\ H - 10800\ O + 6280\ N + 10465\ S)\ [\text{kJ kg}^{-1}] \quad (2)$$

$$\text{Gas yield} = \text{Volume}_{gas} / \text{Mass}_{biomass}\ [\text{Nm}^3\text{kg}^{-1}] \quad (3)$$

$$\eta = (LHV_{gas} / LHV_{biomass}) \times \text{gas yield} \times 100\ [\%] \quad (4)$$

2.1. Model Validation

Simulation results are validated with literature value; rice husk air gasification simulation validated with the experimental value of Karmakar et al. [10], rice husk steam gasification validated with the result of Loha et al. [15], sawdust air gasification validated with the result of Lahijani& Zainal [11] and sawdust oxygen gasification validated with the result of Wang et al. [16]. Average RMS error value of 4.91, 4.67, 7.71 and 4.68 were obtained for rice husk air gasification, rice husk steam gasification, sawdust air gasification and sawdust oxygen gasification respectively. For more details regarding model validation, refer to author's previous publications [17, 18].

3. Result and Discussion

The gas composition of rice husk air gasification, rice husk steam gasification, sawdust air and oxygen gasification were determined for different simulation conditions. To study the effect of fuel quality on final gas composition, comparison of rice husk air gasification with sawdust air gasification was carried out. To find the influence of gasifying medium on final gas composition, comparison of rice husk air and steam gasification, sawdust air and oxygen gasification was carried out. Maximum combustible gas composition attained and optimum performance parameters were compared.

For rice husk air gasification, simulation was carried out for three equivalence ratios ϕ= 0.25, 0.35 & 0.45;the temperature for ϕ= 0.25 is in the range 650 – 725 °C with 25°C increments. For ϕ =

0.35, temperature range is 600 - 750°C and for ϕ = 0.45, the range is 600 - 800°C. The common temperatures for all the equivalence ratios were 650 °C, 700 °C & 725 °C. Rice husk steam gasification was carried out for steam to biomass ratio of 1, 1.32 and T = 690 – 750°C.Sawdust air and oxygen gasification simulation was carried out for ϕ=0.3-0.6 and T = 600 – 900°C.

3.1. Gas Composition at Different Simulation Conditions

Effect of temperature and gasifying medium quantity on individual gas composition is discussed in this section. Hydrogen and carbon monoxide are the major combustible gas produced during gasification [19-21]. Rice husk air gasification composition is shown in Fig. 1. At ϕ = 0.25, increase in temperature enhances the H_2 content; at ϕ= 0.35 & 0.45, optimum H_2 values were attained at 725 °C & 650 °C respectively. Increase in equivalence ratio for all the temperatures decreases the combustible gases formation due to the oxidation reactions [22]. The maximum H_2 and CO values of 17.97% & 35.53% were attained at 725 °C & ϕ = 0.25.

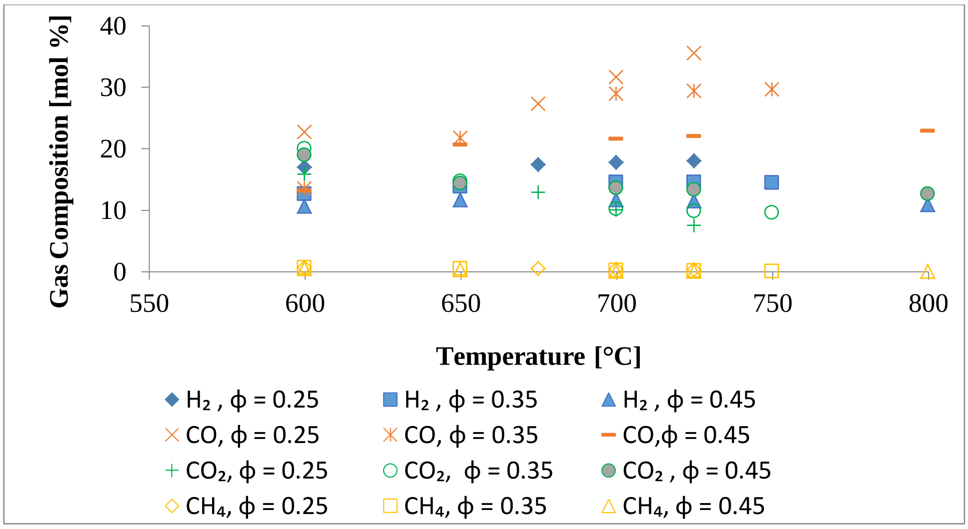


Figure 1. Rice husk air gasification gas composition.

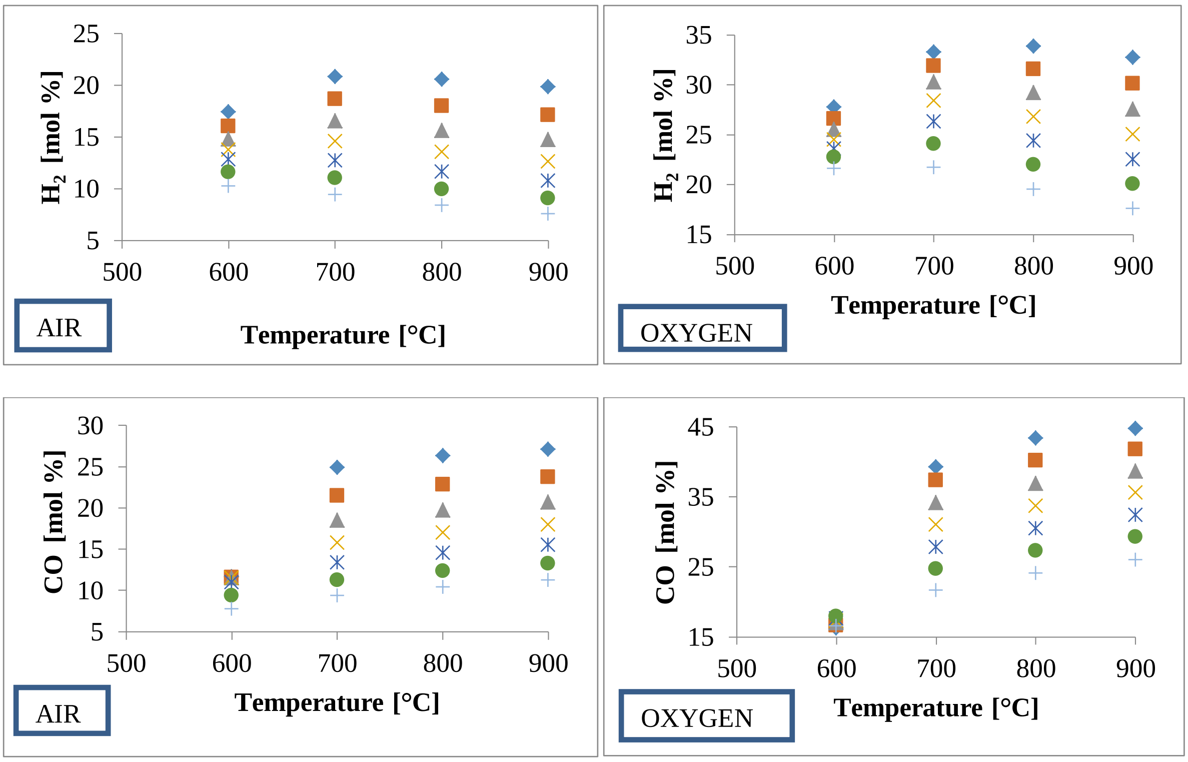
In rice husk steam gasification, slight H_2 reduction and CO augment was observed with increase in temperature at S/B ratio= 1.32. At 750°C, increase in the S/B ratio enhances the H_2 content due to water gas reaction and reduces the CO content due to water gas shift reaction.Gas composition of rice husk steam gasification is shown in Tab. 2.

Table 2. Rice husk steam gasification gas composition

S. No	T [°C]	S/B Ratio	Rice husk steam gasification [mol %]			
			H_2	CO	CO_2	CH_4
1	690	1.32	56.06	19.06	24.44	0.43
2	730	1.32	55.85	20.81	23.20	0.14
3	750	1.32	55.65	21.59	22.67	0.08
4	750	1.00	53.74	26.49	19.59	0.17

Hydrogen enhancement was observed in sawdust air gasification at ϕ = 0.3 - 0.45 for the temperature change from 600 °C to 700 °C; increase in temperature reduces the H_2 content for other simulation conditions. From 700°C onwards the CO_2 formation enhances with the ϕ value. Increase in the ϕ value reduces the CO content for all temperatures; the CO content increases with temperature at all ϕ value for air and oxygen gasification process [23, 24]. Increase in equivalence ratio reduces the H_2 content for all temperatures in both sawdust air and oxygen gasification. In sawdust oxygen gasification, temperature change from 600 °C to 700 °C enhances the H_2 content for all ϕ value; increase in temperature reduces the H_2 content for other simulation conditions, except for ϕ = 0.3 in temperature range 700 – 800°C. At 600 °C, CO formation increases with ϕ value up to ϕ = 0.55; for other conditions, increase of ϕ value reduces the CO content. Increase in ϕ value enhances the CO_2 formation for all temperatures while increase in temperature reduces the CO_2 formation for all ϕ values.

Maximum H_2 value was reached at 700 °C in sawdust air gasification and at 800 °C in sawdust oxygen gasification. A distinct difference in maximum value of $H_2$was observed for oxygen as gasifying medium. Maximum CO value of 27.11 % and 44.74 % are attained at 900 °C & ϕ = 0.3 for sawdust air and oxygen gasification respectively. For both sawdust air and oxygen gasification high CO_2 formation was observed at 600°C for all ϕ value. Gas composition of sawdust air gasification and sawdust oxygen gasification is shown in Fig. 2.



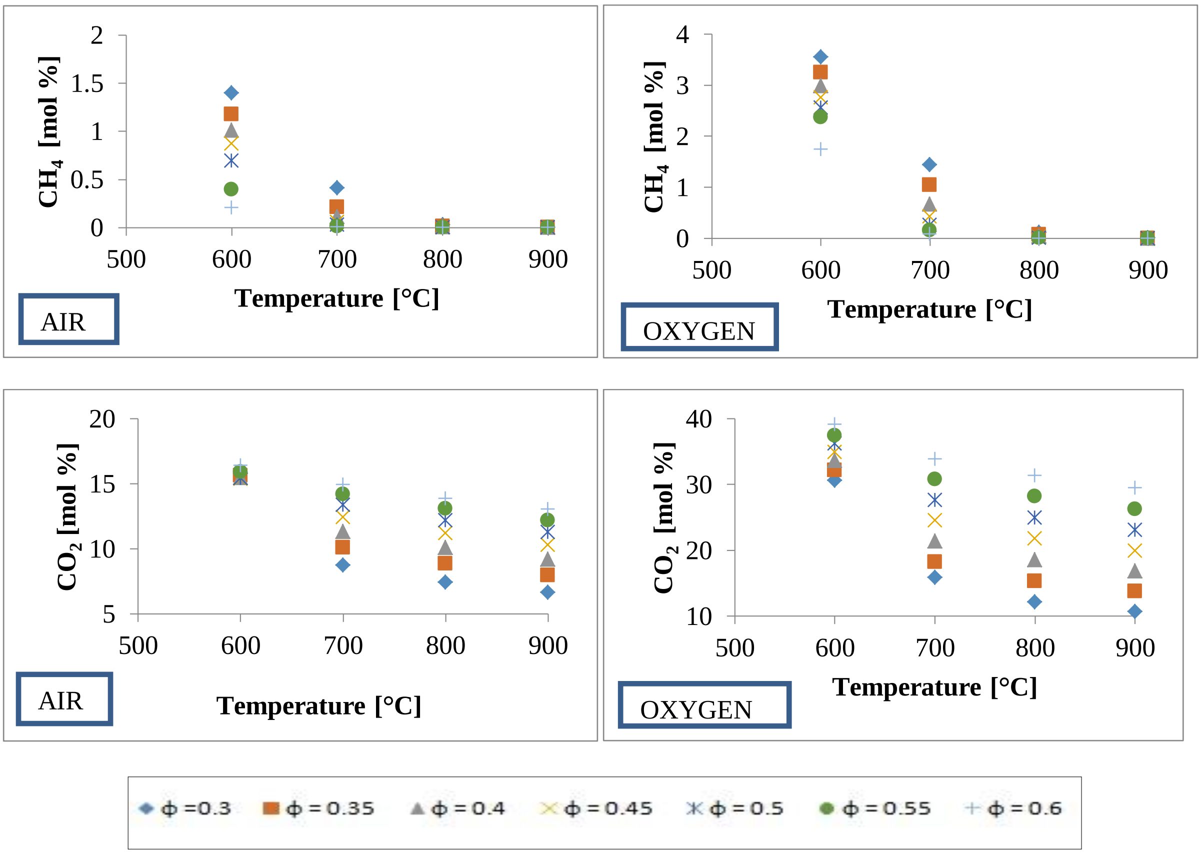


Figure 2. Gas composition of sawdust air gasification and sawdust oxygen gasification.

3.2. Comparison of Gasification Results

The effect of fuel composition on gasification was studied by comparing the rice husk air gasification and sawdust air gasification. Comparison of rice husk air gasification and rice husk steam gasification was carried out to find the effect of the steam medium; sawdust air gasification and sawdust oxygen gasification were compared to find the effect of oxygen medium. The important outcomes of the individual gasification process were discussed in this section.

3.2.1. Effect of Fuel Quality on Gas Composition

Rice husk is found to have higher C and O content than sawdust from the elemental composition. Temperatures taken for analysis were 600 °C & 700 °C for ϕ = 0.35 and 600 °C – 800 °C for ϕ = 0.45. Rice husk gas has superior CO and CO_2 formation; sawdust gas has better H_2 content, similar to the fuel composition [25, 26]. At 600 °C, rice husk gas has 1.95 % and 1.64 % higher CO content than sawdust gas at ϕ = 0.35 and 0.45 respectively; sawdust gas has 3.39 % and 3.13 % higher H_2 content, as shown in Fig. 3. At 700 °C, rice husk gas has 7.42 % and 5.81 % higher CO content than sawdust gas;sawdust gas has 4.1 % and 2.93 % higher H_2 content. At 800 °C & ϕ = 0.45, rice husk gas has 5.85 % higher CO formation and 2.66 % lower H_2formation.

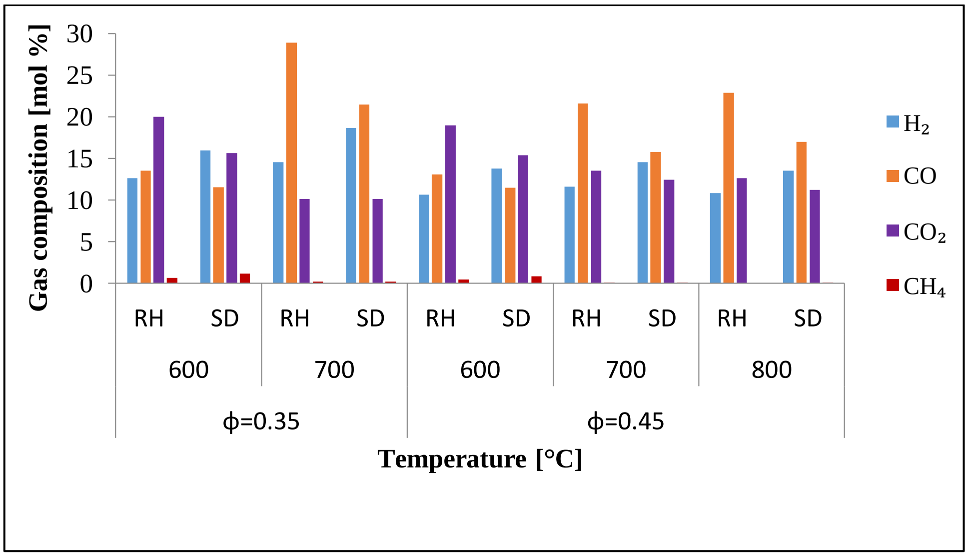


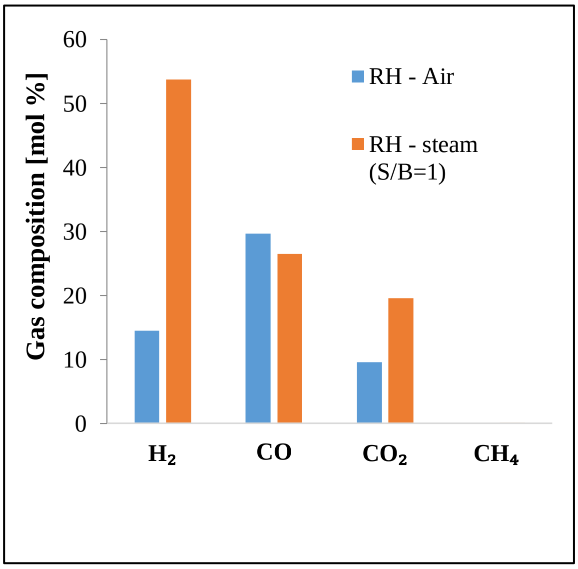
Figure 3. Comparison of rice husk air gasification and sawdust air gasification.

3.2.2. Effect of Gasifying Medium on Gas Composition

The effect of steam on gas composition was studied by comparing rice husk air gasification and rice husk steam gasification. Sawdust air gasification and sawdust oxygen gasification were compared to show the effect of oxygen medium on gas composition.

3.2.2.1. Rice husk air gasification vs rice husk steam gasification

The gas composition of rice husk air gasification and steam gasification were compared at 750 °C. The equivalence ratio was 0.35 for air gasification and S/B ratio = 1 & 1.32 for steam gasification. Steam gasification has superior H_2 and CO_2 formation compared to air gasification. In steam gasification, low CO formation takes place due to the predominant water-gas shift reaction [22-24]. Methane content was low in both cases. The difference in hydrogen content between steam and air gasification was 39.27 % - 41.18 %; the difference in CO content was 3.17 % - 8.07 %, as shown in Fig. 4.



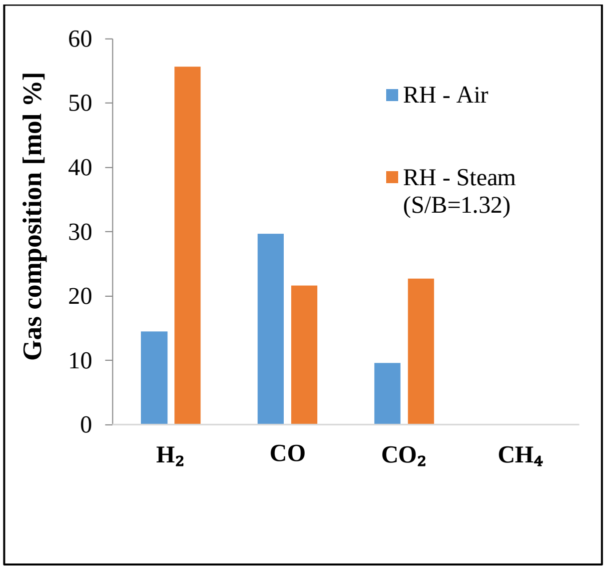


Figure 4. Comparison of rice husk air gasification and rice husk steam gasification.

3.2.2.2. Sawdust air gasification vs sawdust oxygen gasification

Individual gas contents were high in oxygen gasification due to the absence of nitrogen dilution [27, 28]. The maximum value of combustible gases was reached at ϕ=0.3 for air and oxygen gasification process. The gas composition of sawdust air and oxygen gasification were compared for T=600°C – 900°C at ϕ=0.3, shown in Fig. 5. Hydrogen, CO and CO_2 contents were found to be higher in oxygen gasification by 10.34 % - 13.28 %, 4.57 % - 17.64 % and 4.1 % - 14.87 % respectively at ϕ = 0.3. The maximum difference of 13.8 % was observed at 700 °C & ϕ = 0.45 for H_2 content; 18.02 % was observed at 900 °C & ϕ = 0.35 for CO content.

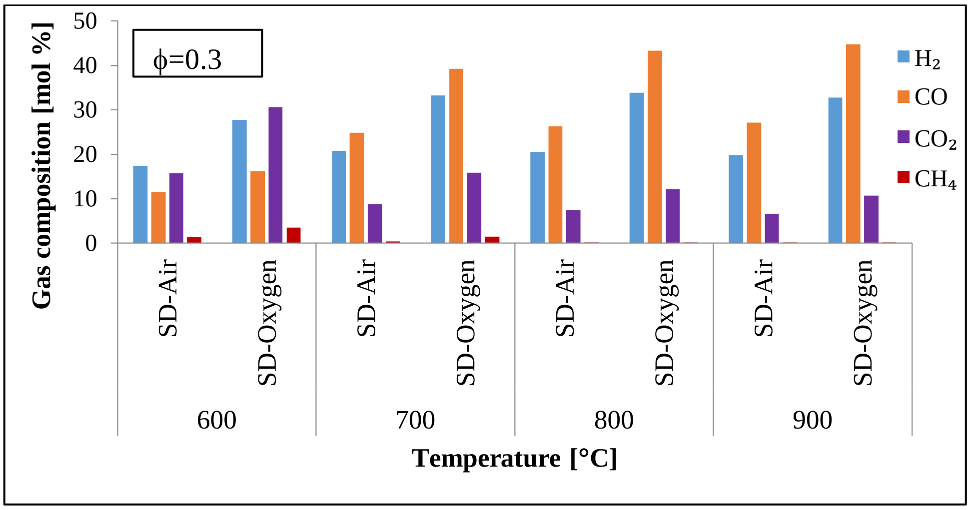


Figure 5. Comparison of sawdust air gasification and sawdust oxygen gasification.

3.3. Comparison of Gasification Performace

Simulation of rice husk air gasification, rice husk steam gasification, sawdust air gasification and sawdust oxygen gasification were carried out to study the effect of simulation conditions on the final gas composition. Maximum hydrogen and carbon monoxide production, gas heating value and gasification efficiency details are discussed in this section.

3.3.1. Maximum hydrogen and carbon monoxide values

Sawdust oxygen gasification has produced higher quantity of hydrogen next to rice husk steam gasification. Rice husk air gasification produced least hydrogen due to its elemental composition. Maximum values of H_2 and CO for different gasification processes are shown in Fig. 6. Gasification results indicate the higher influence of the gasifying medium in hydrogen production in relation to fuel composition [23-25]. The maximum amount of carbon monoxide formation was observed in sawdust oxygen gasification. High CO formation was due to the absence of nitrogen dilution. The formation of CO in rice husk steam gasification was the lowest due to the consumption of CO in the water-gas shift reaction. Higher CO formation was observed in rice husk air gasification.

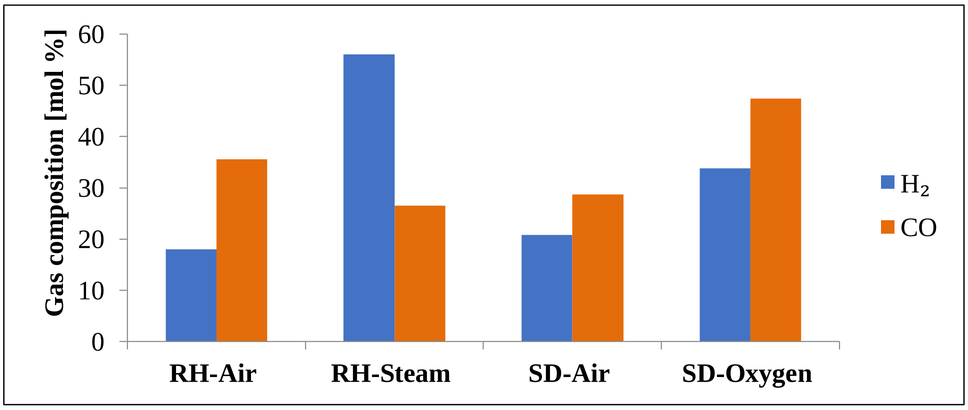


Figure 6. Comparison of hydrogen and carbon monoxide content.

3.3.2. Gas heating value and gasification efficiency

The maximum gas heating value was obtained in sawdust oxygen gasification in relation to rice husk and sawdust air gasification due to higher combustible gas formation. Gas heating values are shown in Fig. 7. In air gasification, nitrogen presence dilutes the concentration of combustible gases. An increase in temperature enhances gas heating value mainly due to the large production of CO. At $\phi = 0.35$, change in temperature from 600 °C to 700 °C increases gas heating value by 1.98 MJ/Nm^3, 1.19 MJ/Nm^3 and 2.4 MJ/Nm^3 for rice husk air gasification, sawdust air gasification and sawdust oxygen gasification respectively. At $\phi = 0.45$, the increase was 1.02 MJ/Nm^3, 0.34 MJ/Nm^3 and 1.31 MJ/Nm^3 respectively. As light change in heating value was observed for the temperature change in the range 700 – 800 °C. An increase in the equivalence ratio reduces the gas heating value due to the higher CO_2 formation and nitrogen dilution [7, 29].

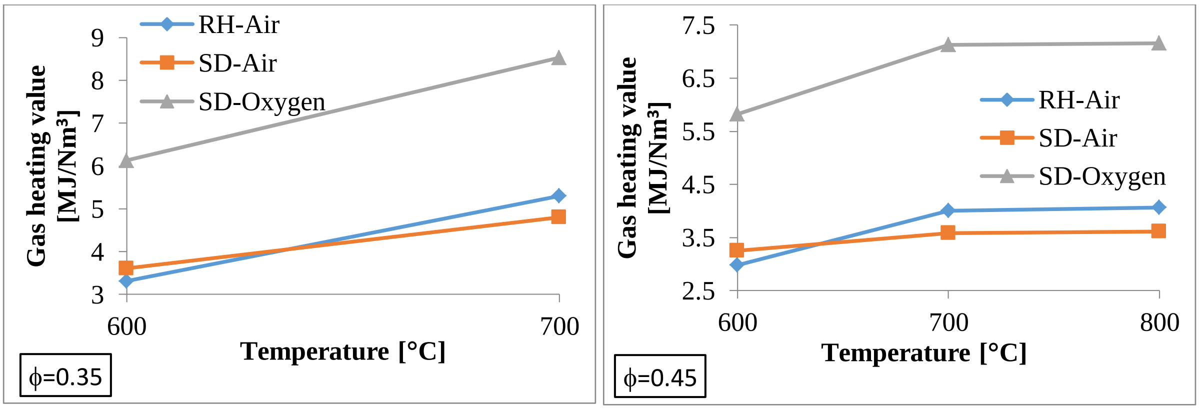


Figure 7. Gas heating value of different gasification process.

At $\phi = 0.35$, maximum gasification efficiency was observed in sawdust air gasification. At $\phi = 0.45$, maximum gasification efficiency was observed in sawdust oxygen gasification except for 600 °C. At $\phi = 0.35$, an increase in temperature enhances gasification efficiency by 25.4 %, 23.29 % and 30.67 % for rice husk air gasification, sawdust air gasification and sawdust oxygen gasification respectively. Gasification efficiency values are shown in Fig. 8.

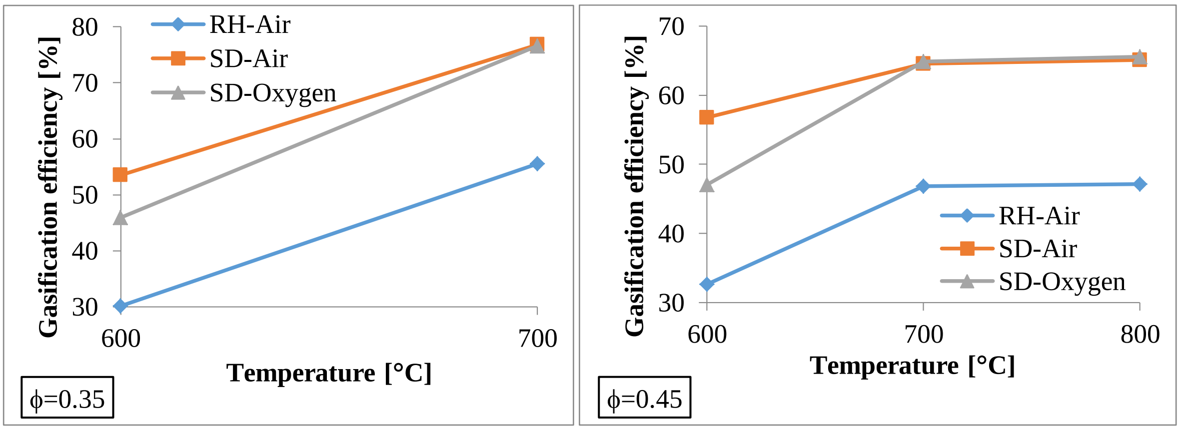


Figure 8. Gasification efficiency of different gasification process.

For ϕ=0.45, efficiency improvement of 14.18 %, 7.79 % and 17.8 % was observed; less than 1% improvement was observed in the temperature range 700 – 800 °C. Gas heating values and gasification efficiencies of rice husk steam gasification are shown in Tab. 3.

Table 3. Gas heating value and gasification efficiency of rice husk steam gasification.

S.No	T [°C]	S/B Ratio	Gas heating value [MJ Nm^{-3}]	Gasification Efficiency [%]
1	690	1.32	8.62	71.23
2	730	1.32	8.71	72.47
3	750	1.32	8.77	73.04
4	750	1	9.21	76.77

4. Conclusion

Rice husk and sawdust gasification has huge potential for power generation through gasification. Gas composition of rice husk air gasification, rice husk steam gasification, sawdust air gasification and sawdust oxygen gasification were determined by the non-stoichiometric equilibrium model. The rice husk air gasification has superior CO and CO_2 formation than sawdust air gasification;biomass elemental composition has the influence on final gas composition. High H_2 and CO_2 formation take place in rice husk steam gasification than rice husk air gasification due to the enhanced water-gas and water-gas shift reaction. Individual gas content of sawdust oxygen gasification is higher than sawdust air gasification due to the absence of nitrogen dilution. The highest H_2formation takes place in rice husk steam gasification at 690 °C and S/B ratio = 1.32. The highest CO formation takes place in sawdust oxygen gasification at 900 °C and ϕ = 0.3. The maximum gas heating value of 9.21 MJ/$Nm^3$was obtained in rice husk steam gasification; maximum gasification efficiency of 84.27 % was obtained in sawdust oxygen gasification at 900 °C. The results of the present work are useful in selection of fuel, gasifying medium and operation condition for the gasification process.

Nomenclature

$LHV_{biomass}$– Biomass lower heating value [kJ kg^{-1}]
LHV_{gas}– Gas lower heating value [kJ Nm^{-3}]
Mass $_{biomass}$– Mass of biomass [kg]
S/B ratio – Steam /Biomass ratio
T – Temperature [°C]
$Volume_{gas}$– Volume of gas mixture [m^3]

Acronyms
RH – Rice Husk
RMS – Root mean square
SD – Sawdust
TGA – Thermogravimetric Analysis

Greek symbol
η – Gasification efficiency [%]

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