Investigating the Effects of Different Operating Parameters on the Performance of Biomass Gasification Mixed with Coal in Multi-Opposite Burner (MOB) Gasifier

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Abstract: The technology of gasification for the Solid fuels has been recognized and used from decades and believed as clean coal technology. There are several configurations have been developed but now a days, popularity of Multiple Opposite Burner (MOB) Gasifiers are being grown for low grade coals. MOB gasifiers are mostly tested for coal gasification whereas few applications for biomass gasification were also available. However, they have not been tested with the biomass mixture with low-grade coal. The current research focused on investigating the performance of MOB gasifier by mixing the biomass and low-grade coal. Commercial CFD software ANSYS FLUENT modeled the MOB gasifier. The energy equations and equation of continuity with Navier-Stoke fluid flow equation have been solved. Standard model of k-ε turbulence was used to anticipate turbulence in flow. The Euler-Lagrangian framework was applied to explain the two phases. Biomass to coal, oxygen to carbon ratio and feed flowrate were changed to observe the gasifier performance. Three biomasses i.e., cotton stalk, rice husk and sugarcane bagasse along with Thar coal compositions were used. As per results, mixing of biomass with coal shown significant effects on the syngas composition, temperature and char conversion. The maximum mole fraction of CO was observed 0.344 with 0.155 mole fraction of H_2 with 90% Rice Husk and 10% Thar coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. O/C ratio has also significant effect on the syngas composition and char conversion. On increasing O/C ratio from 0.8 to 1.2, the mole fraction of CO and H2 increases first and then decrease. The optimized O/C ratio was observed 1.0. At this O/C ratio, the char conversion was also maximum and syngas exit temperature was found minimum.

Keywords: Coal Gasification, Biomass Gasification, Gasifier, CFD, Ansys FLUENT.

1. Introduction

The fossil fuels are considered as essential primary source of energy in the world since decades. As per estimates, in upcoming 40-50 years oil and NG reserves will become empty[1]. On the Other Hand, reserves of coal have much quantity then oil and gas and going to be empty in 100 years. Moreover, the production of energy by coal became the reason of significant ecological and human health problems due to release of SO_x, CO_x and NO_x. These problems related to health and ecology has compelled us to find a technique to utilize the in a clean and safe way. Except coal the energy production from biomass could be applicable [2, 3].

Global supply of energy is round about 11% from the source of biomass [4]. Current around computations for production of energy by biomass shows that about 100EJ might be possible to access till 2050 [5]. The projection of using the biomass for the energy production is high enough but this will still take time to complete. There are different methods by which the biomass can be converted into fuels of different types and these process are extraction, biochemical and thermochemical process. [6]. The reactors used for production of syn gas are generally called gasifiers where the gasification of biomass is carried out.

The features of syngas is influenced by several factors, way the gasifier is designed and properties of fuels [7]. The Key elements that influence the feature of gas produced are pressure, size of particle, temperature, moisture, gasifying medium and equivalence ratio (ER) [8]. Thus, a deep knowledge of the entire changes may be physical or chemical take place throughout gasification of biomass is vital in order to productively operate the gasification unit [9].

Pakistan is listed in the prominent state of the globe following the invention of enormous assets of coal in Sindh at Tharparker district. The estimated assets of coal (175.5 billion tons) shows an essential assets for the economical point of view particularly, at the time of limited electricity supply and limited Natural gas reserves in state and totally relay on outside oil. Sadly, these enough assets of coal are not in use till date, even though they were found in 1989 [10].

The focus of current study is to maximize the energy efficiency in the globe. These Days, industries of power generation have been providing more benefits to the gasification technology for solid fuels due to the fuels effectiveness that may be utilized. Gasification has been vowing method of energy conversion for the consumption of coal as well as biomass since product of syngas may be exploited in several aspects (e.g., combined heat and

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power, automobile fuels etc.). Numerous kinds of gasifiers are here such as fixed bed, fluidized bed, and entrained flow. Entrained flow gasifiers are believed as economic and efficient type of gasifiers. There are several improvements in the basic entrained flow gasifier design has made till today. Entrained flow slagging gasifiers (EFSG) remain key contenders for use in innovative integrated gasification combined cycle (IGCC) power plants [11]. Various types of nozzles are installed to insert solid fuel as well as oxidant in gasifiers on same stage but in reverse ways. Therefore, such gasifiers have named as Multi-opposite Burners' (MOB) gasifiers. Flameless combustion state is formed by MOB gasifiers inside the gasifier cavity and consequently generating temperature is relatively less as compared to conventional entrained flow gasifiers. High carbon conversion within limited time can be attained when EFSG passed at moderate temperature with small particles. The slagging elimination can be attained when molten slag flow ensures most molten slag droplets as well as move out of slag outlet. However, behaviors of gas molecule flow as well as deposition qualities of molten slag/ash droplets are alarmed by uncertainty of EFSG operating system, due to the molten as well as sticky slag/ash particles will evade from slag outlet immediately. Subsequently, the slag/ash fragment behavior command is certified to be main issues for the design and mount-up of the EFSG [12].

The performance of flow particles fluctuates as of the various gas flow for the separate shape gasifiers have[13]. Several extensive efforts have been made to conduct the deep investigations for the behavior of melting ash and the properties of particle in gasifier that is deposited [14, 15]. The quoted expertise be able to help to explain the method of particle buildup in gasifier, though it is harder to reveal flow behavior of complex particle in a gasifier. Since the working condition and the geometry of gasifiers show enormous influence on particle of slag with flow patterns as well as depositions in an EFSG. As a result, an enhanced usage and function of an improved gasification technology requires simulation utensils and accomplishing a decent expertise of aerodynamic. A simulated model in CFD is established to evaluate the deposition quandary for pulverized coal combustors [16, 17]. While the deposition process of ash particles as well as slagging deposit in boiler radiant section is entrained via this tool.

In present research a comprehensive 3D CFD model of Multi-Opposite Burner (MOB) gasifier was developed for biomass gasification. The performance of gasifier at varying feed stocks (biomass and coal), mixing ratio of coal with biomass, Oxygen-Coal ratio and fuel feeding rate was investigated.

2. Development of CFD Model

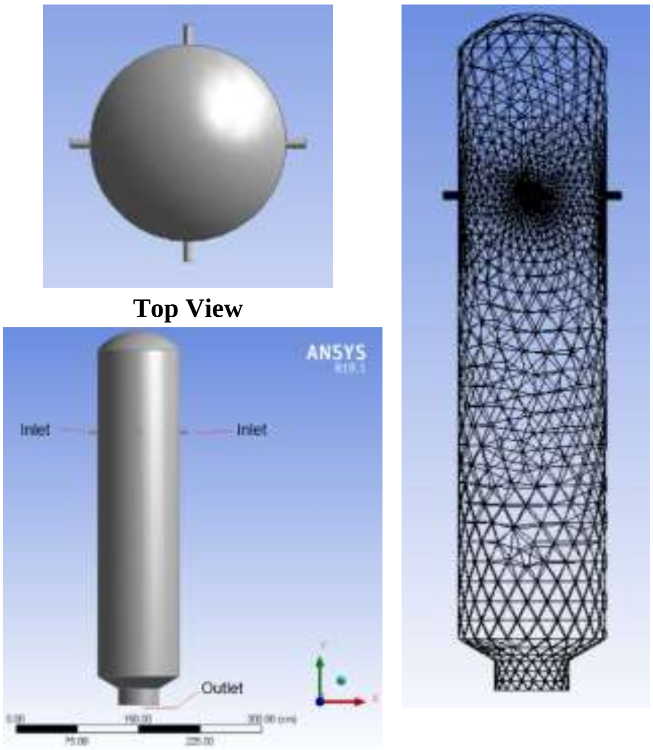
During CFD modeling the concerned governing equations are solved over a defined geometry. In this, there are basically two stages. In first stage the computational domain (meshed geometry) is established. In the second stage, the concerned governing equations are resolved.

2.1 Development of computation domain

ANSYS design modeler for MOB gasifier is used to establish a concentric tube geometry. The simple features of geometry brought from prior literature [18]. The gasifier was of 4.2 m height and diameter was fixed at 1 m wide. Fig. 1(a) demonstrates the 3-dimentional viewpoints of geometry whereas Fig 1(b) reveals the 2D symmetric geometry for meshed domain. The geometry for mesh was made with the tool of ANSYS MESHING. Total 58,382 quadrilateral cells were exploited to established meshed geometry with least possible orthogonal quality 0.689.

2.2 Governing Equations

In current effort, numerical examination was conducted with 3-dimensional, constant and incompressible turbulence flow along heterogeneous and homogenous reactions. Therefore, time-averaged- steady-state Navier–Stokes, mass momentum and energy and species equations have resolved. The regulating equations used in this research are tabulated in Table 1.



Front View

(a) 3D Geometry (b) 2D Meshed Geometry

Figure. 1. Geometry of Multi-Opposite Burner (MOB) Gasifier for Biomass Gasification mixed with Coal.

2.3 Boundary conditions and parametric investigations

There are 58382 quadrilateral cells in a 3-dimentional computational domain. For all input/output streams, the mass-flow inlet and pressure-outlet boundary conditions were considered. In the current model, buoyancy force has been considered. At 800 K, water-cooled walls were meant to maintain a steady temperature. On the surfaces of walls, the no-slip condition (zero velocity) is used. By decoupling the energy and momentum equations, stationary simulation was performed using an absolute pressure-correction scheme When the mass, turbulent kinetic energy, and momentum residuals were all10^{-3}, and the energy and radiation residuals were all10^{-6}, the solution was said to be converging.

Four different feedstocks were used in this analysis. Cotton stalk, rice husk, and sugarcane bagasse are the first three biomasses, while Thar coal is the fourth. Tables 2 and 3 show the proportions of all feedstock materials. The Oxygen-to-Carbon ratio, or O/C ratio for short, is a critical parameter in gasification. Changing the fuel flow rate or the oxygen flow rate will change the O/C ratio. The oxygen flow rate is tweaked in the current study while the feed flow rate is kept constant. In this analysis, the O/C ratios of 0.8, 0.9, 1.0, 1.1, and 1.2 were used. In this analysis, feedstock flow rates of 0.1, 0.2, 0.3, 0.4, and 0.5 Kg/sec were used. 100 percent biomass, 90 percent biomass + 10% coal, 80 percent biomass + 20% coal, and 70 percent biomass + 30% coal are the mixing ratios for biomass and coal 100 percent biomass, 90 percent biomass + 10% coal, 80 percent biomass + 20% coal, and 70 percent biomass + 30% coal are the mixing ratios for biomass and coal.

3. Result and Discussion

Multi-Opposite Burner (MOB) gasifier was numerically simulated for investigating the gasification of biomass with coal at different mixing ratios in this research. The efficiency of the gasifier was calculated by altering the biomass to coal ratio, as well as the O/C ratio and feedstock flowrate. The results are discussed in subsequent paragraphs.

Table 1: Governing Equations

Physical Quantity	Equation	Eq. No.
Mass	$\frac{\partial}{\partial x_i}(\rho u_{ij}) = S_m$	(1)
Momentum	$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \rho \bar{g}_j - \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i}(\tau_{ij} - \rho \overline{u_i^{'} u_j^{'}}) + S_j$	(2)
Energy	$\frac{\partial}{\partial x_i}(\rho c_p u_i T) = \frac{\partial}{\partial x_i}\left(\lambda \frac{\partial T}{\partial x_i} - \rho c_p \overline{u_i^{'} T'}\right) + \mu\Phi + S_h$	(3)
Specie	$\frac{\partial}{\partial x_i}(\rho u_i C_j) = \frac{\partial}{\partial x_i}\left(\rho D_i \frac{\partial C_j}{\partial x_i} - \rho \overline{u_i^{'} C_j{'}}\right) + S_r$	(4)
Standard k-ε Turbulence Model	$\frac{\partial}{\partial x_i}(\rho u_i k) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k - \rho\varepsilon$ $\frac{\partial}{\partial x_i}(\rho u_i \varepsilon) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + C_{1\varepsilon} G_k \frac{\varepsilon}{k} - C_{2\varepsilon} G_k \frac{\varepsilon^2}{k}$	(5)
Radiation Model (P1)	$-\nabla q_r = aG - 4aG\sigma a^4$	(6)

Table 2: Proximate and Ultimate Analysis of Thar Coal [19][19][19][19][19][19][19][19]

Proximate Analysis		Ultimate Analysis	
Element	**Value (Wt. %)**	**Element**	**Value (Wt. %, MF)**
Moisture Content	44.3	C	38.17
Fixed Carbon	19.21	H	7.93
Volatile matter	29.55	N	0.23
slag	6.83	S	1.87
Sulfur	1.68	O	6.84
		slag	6.84

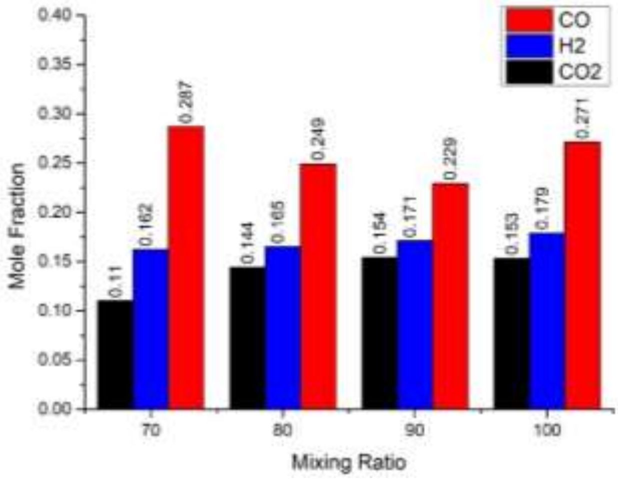
Table 3: Proximate, Ultimate and Calorific Analysis of Selected Biomass [3]

Biomass Type	Sugarcane Bagasse	Rice Husk	Cotton Stalk
Proximate Analysis (Wt%, dry basis)			
Moisture	5.8	6.10	5.58
Volatile Matter	74.87	63.39	69.98
Fixed Carbon	14.93	15.96	16.31
Ash	4.40	14.55	8.13
Ultimate Analysis (Wt%, dry basis)			
C	44.1	43.33	41.73
H	5.96	5.36	5.82
N	0.36	0.29	0.10
O	49.39	50.43	52.05
S	0.19	0.59	0.30
HHV (MJ/Kg)	17.33	13.86	16.22

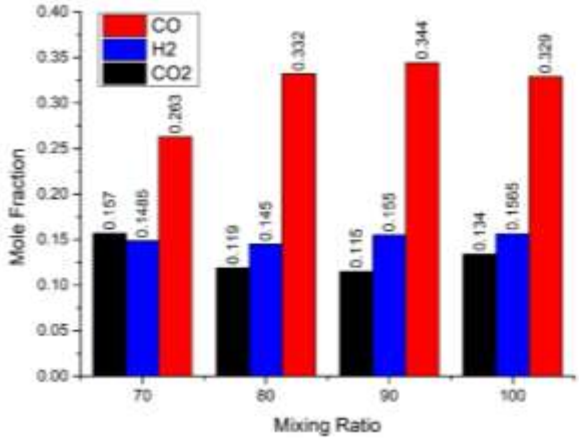
3.1 Effects of Mixing Ratio for biomass to coal

Three selected biomasses were separately gasified with coal at different mixing ratios keeping the O/C ratio and feed flowrate fixed at 1.0 and 0.1 Kg/sec respectively. Fig. 2(a) showing the effect of mixing ratio of cotton talk with coal on the syngas composition. The composition of syngas is clearly influenced by changing the mixing ratio, as shown in the figure. The mole fractions of CO and H_2 with 100% cotton stalk were estimated 0.271 and 0.179. On mixing of coal with cotton stalk the mole fraction of CO is first decreases then increased up to 0.287 with slightly decrease in H_2 mole fraction i.e., 0.162 at 70% cotton stalk and 30% coal.

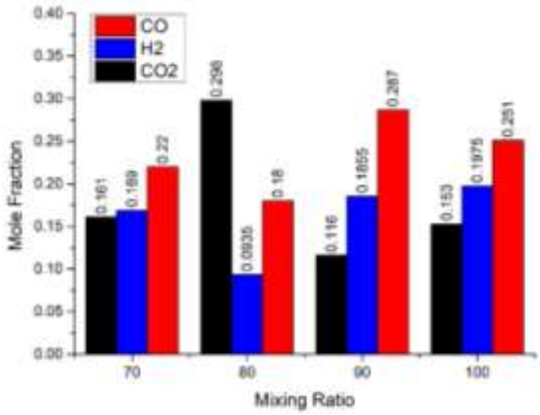
Similarly, Fig. 2(b) and 2(c) are showing the effect of mixing ratio of rice husk and sugarcane bagasse with coal on syngas composition. The maximum CO mole fraction 0.332 was achieved with 80% cotton stalk and 20% coal with 0.145 mole fraction of H_2. One the other hand the maximum CO mole fraction 0.287 was obtained with 90% sugarcane bagasse with 10% coal with 0.18852 mole fraction of H_2. Maitlo has worked on individual biomasses and found similar increase of CO hence the results are consistent with the study[3].



(a) Biomass = Cotton stalk



(b) Biomass = Rice Husk

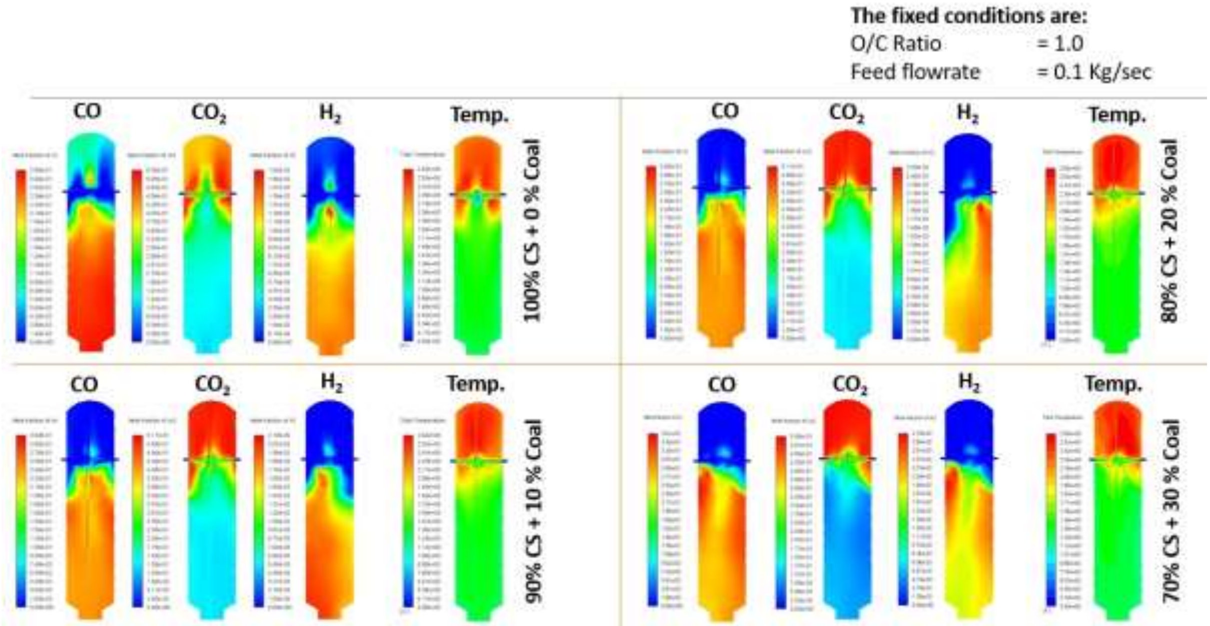


(c) Biomass = Sugarcane Bagasse

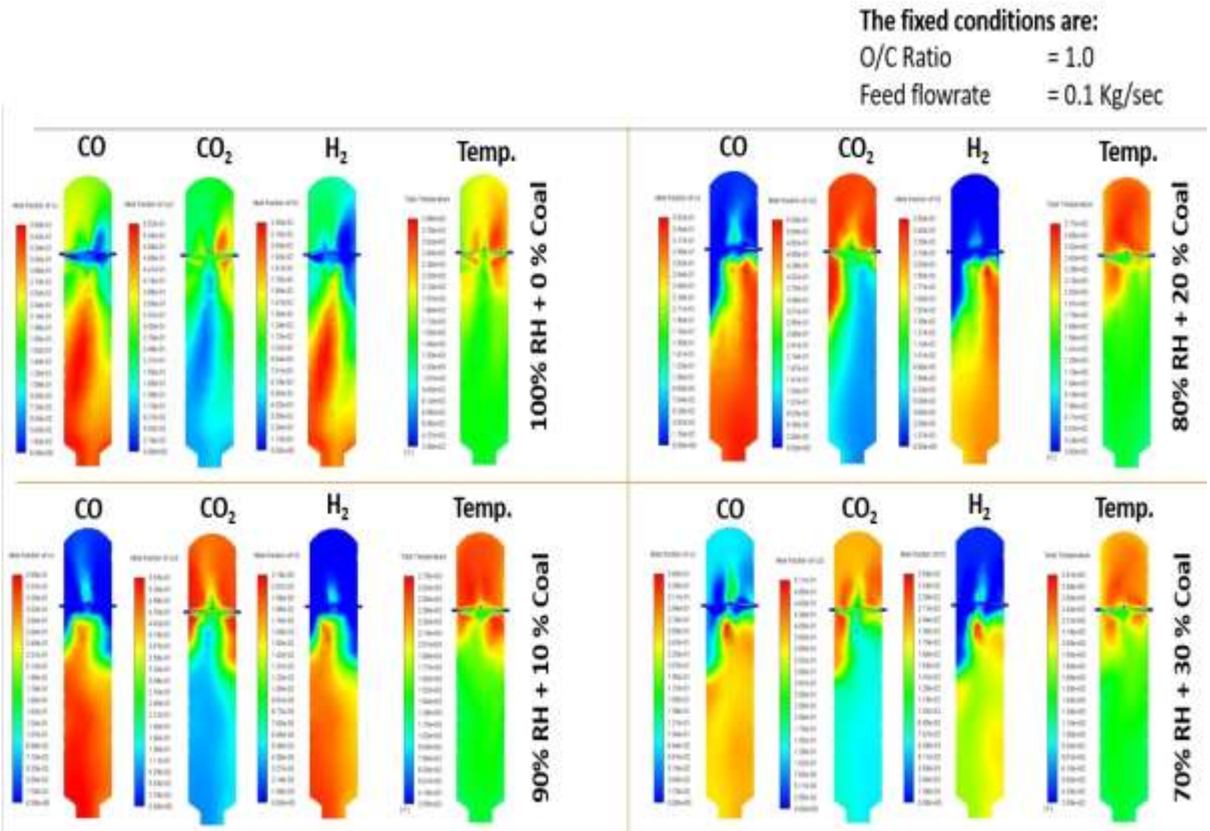
Figure 2: Mole fraction of CO, CO_2 and H_2 in the Syngas using Selected Biomasses at different mixing ratios with Thar Coal

Fig. 3(a), (b) and (c) are showing the mole fraction contours at various simulated cases. In the contours the red color shows the maximum value of particular specie or temperature whereas blue color shows the lowest value of particular species or temperature. From the figure, it is clear that the multi-opposite injection zone of the gasifier the CO and H2 are now of higher quantity but as the combustion products flow down in the gasifier, their production increase and eventually reach at some significant appreciable level up to the exit. For the temperature it is almost revers situation as at the upper section, combustion scenario enhanced as explained by previous research [18] and as the reaction proceed in towards downward direction, gasification reactions occurs and hence temperature decreases.

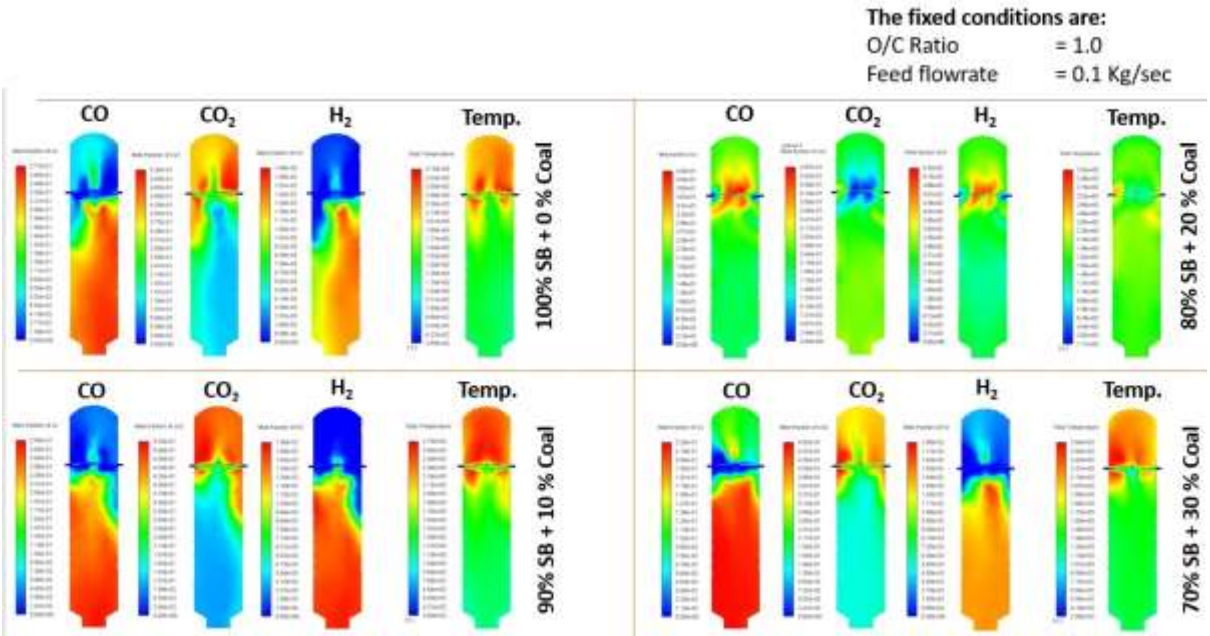
Fig. 4(a), (b) and (c) are showing the temperature of syngas and char conversion for cotton stalk, rice husk and sugarcane bagasse respectively. The maximum char conversion 96.88% was obtained with 80% cotton stalk and 20% coal. The maximum char conversion 99.92% was obtained with 90% rice husk and 10% coal. Similarly, the maximum char conversion 98.5% was achieved with 80% sugarcane bagasse and 20% coal. The maximum exit syngas temperature was observed 1969 K with 80% sugarcane bagasse + 20% coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. The results are very consistent if compared with previous research [3, 9, 10].



(a) Biomass = Cotton Stalk

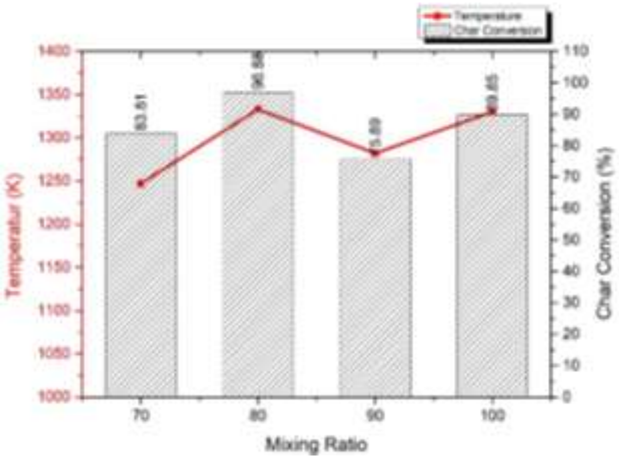


(b) Biomass = Rice Husk

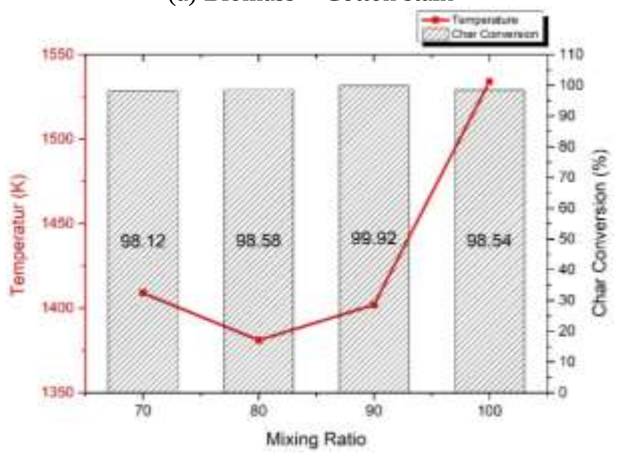


(c) Biomass = Sugarcane Bagasse

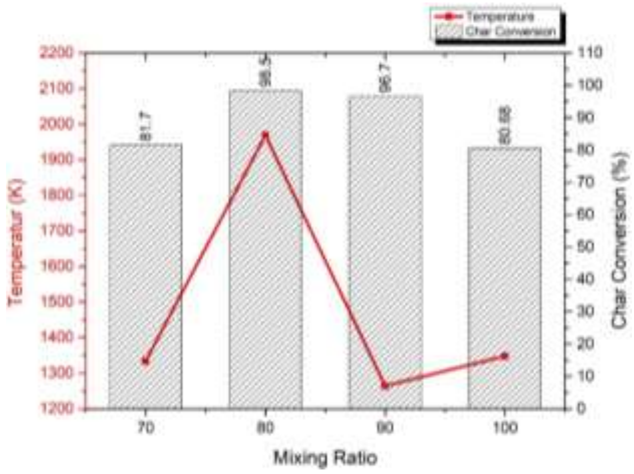
Figure 3: Contours for Mole fraction of CO, CO_2, H_2 and Temperature using Selected Biomasses at different mixing ratios with Thar Coal



(a) Biomass = Cotton stalk



(b) Biomass = Rice Husk



(c) Biomass = Sugarcane Bagasse

Figure 4: Syngas Exit Temperature and Char Conversion using Selected Biomasses at different mixing ratios with Thar Coal

3.2 Effects of O/C Ratio with Different Feedstocks on syngas composition

For gasification, the most important results are the syngas composition. Fig. 5 shows the mole fraction of CO, H_2 and CO_2 in produced syngas at varying O/C ratio with 90% rice husk and 10% Thar coal at fixed feed flowrate of 0.1 Kg/sec. Fig. 6 shows the conversion and temperature of syngas at varying O/C ratio with similar feedstock. From Fig. 5, it was observed that CO (the main product of gasification) produced about 0.281 at 0.8 O/C ratio which increased maximum up to 0.344 at 1.0 O/C ratio and then it decreases and reached up to the value of 0.274 at 1.2 O/C ratio. The prime reason of this variation was the occurrence of char with CO_2 reaction, and it shows that this reaction was maximum at 1.0 O/C ratio. After this the combustion reaction (reaction of char with O_2) become dominant which is as according to previous research [7] . Similarly, the production of H_2 was found 0.142 at 0.8 O/C ratio which increased maximum up to 0.155 at 1.0 O/C ratio and then goes decreasing and reaches up to 0.127 at 1.2 O/C ratio. The reason of this variation was the occurrence of char reaction with steam (produced during initial combustion reactions) which was found at 1.0 O/C ratio and then combustion reaction (reaction of H_2 with O_2) become dominant. The trend of CO2 production was inverse as compared with production of CO or H_2. CO_2 was maximum 0.182 at 0.8 O/C ratio and it was minimum 0.115 at 1.0 O/C ratio. Hence 1.0 O/C ratio was considered as most optimum O/C ratio for 90% rice husk and 10% Thar lignite in terms of getting maximum CO and H_2. According to Fig. 6, the maximum char conversion 98.73 and minimum temperature 1402 K were obtained at 1.0 O/C ratio.

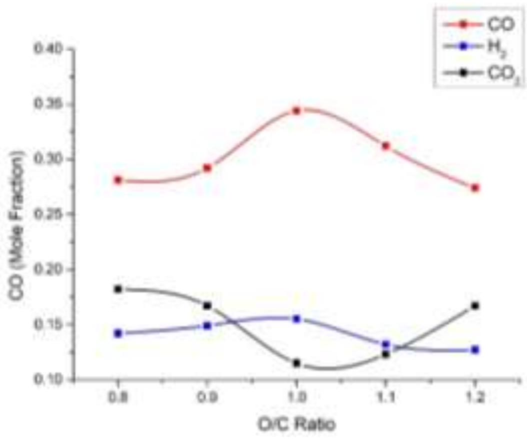


Figure 5: Mole fraction of important components of syngas using 90% rice husk and 10% Thar Coal as feedstock at fixed varying O/C ratio

3.3 *The impact of the fuel inlet rate on the composition of syngas*

Previous research evaluated the improved O/C ratios for both of the selected feedstocks. The fuel feed rate was adjusted from 0.1 Kg/sec to 0.5 Kg/sec while maintaining an O/C ratio of 1.0 for 90 percent rice husk+10 percent Thar coal feedstock. The effect of mole fractions of essential syngas components such as CO, CO_2, and H_2 was investigated, and the results are plotted and shown in Fig. 7. It was seen that the mole fraction of CO and H2 is decreasing with increasing fuel feed rate as explained by Guo [8]. The mole fraction of CO_2 rises directly as fuel feed rate rises. As a result, the fuel feed rate of 0.1 kg/sec was thought to be optimal for the new gasifier. Figure 8 depicts char conversion and syngas temperature as a function of feedstock flow rate. It was confirmed that as the feed flowrate increases, the char conversion decreases and the temperature rises.

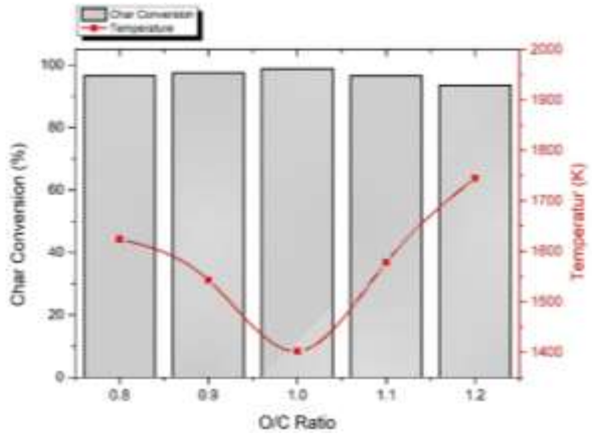


Figure 6: Char conversion and syngas temperature using 90% rice husk and 10% Thar Coal as feedstock at fixed varying O/C ratio

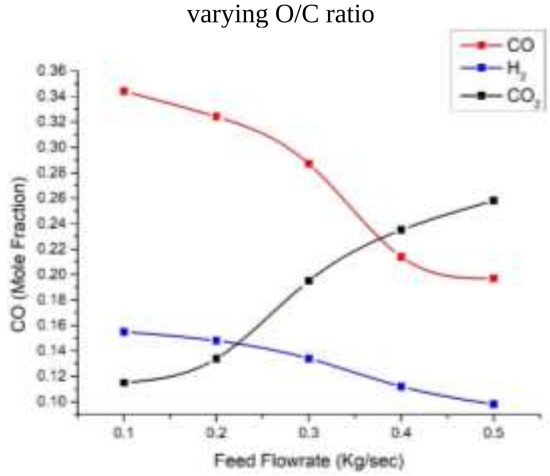


Figure 7: Mole fraction of important components of syngas using 90% rice husk and 10% Thar Coal as feedstock at fixed varying feed flowrate

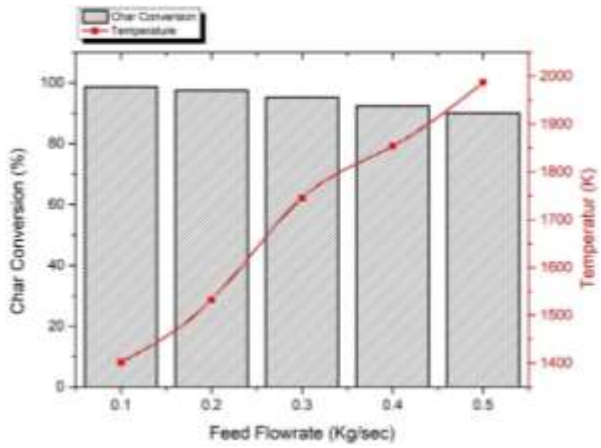


Figure 8: Char conversion and syngas temperature using 90% rice husk and 10% Thar Coal as feedstock at fixed varying feed flowrate

4. Conclusion

CFD Model of MOB gasifier was built with Euler-Lagrangian Framework for investigation the effects of biomass gasification mixed with Thar lignite. It was concluded that mixing of biomass with Coal has significant effects on the syngas composition, temperature and char conversion. The maximum mole fraction of CO was observed 0.287 with 0.162 mole fraction of H_2 with 70% cotton stalk and 30% Thar coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. The maximum mole fraction of CO was observed 0.344 with 0.155 mole fraction of H_2 with 90% rice husk and 10% Thar coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. The maximum mole fraction of CO was observed 0.287 with 0.185 mole fraction of H_2 with 90% sugarcane bagasse and 10% Thar coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. The maximum char conversion was achieved for rice husk i.e., 99.92% with 90%RH+10%Coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate.

The maximum exit syngas temperature was observed 1969 K with 80% sugarcane bagasse + 20% coal at 1.0 O/C ratio and 0.1 Kg/sec feed flowrate. O/C ratio has also significant effect on the syngas composition and char conversion. On increasing O/C ratio from 0.8 to 1.2, the mole fraction of CO and H_2 increases first and then decrease. The optimized O/C ratio was observed 1.0. At this O/C ratio, the char conversion was also maximum and syngas exit temperature was found minimum. Increase in feed flowrate decreases the mole fractions of CO and H_2 and increases the mole fraction of CO_2. It has also negative effect on char conversion.

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