

# Investigation of Performance for Entrained Flow Gasifier Through Simulations

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## ABSTRACT

Pakistan has proven huge coal reserves but still unable to harvest the energy due to unavailability of ingenious technology. Coal gasification is robust, efficient and environmental friendly technology but it is highly sensitive to the coal characteristics. Scant literature is available on the development of the coal gasification technology which suits the characteristics of indigenous coal reserves. This paper presents the simulation of entrained flow gasifier for using indigenous coal through process modeling software namely Aspen Plus® to evaluate various system flow steps within an entrained flow gasifier. General techniques have also been discussed for creating the equilibrium-based simulations of gasification systems. Peng-Robinson equation was used to correlate the volume of species with respect to state variables (temperature and pressure). The effects of composition of different indigenous coals like Thar, Lakhra and Sonda were investigated through simulations along with O/C (Oxygen-to-Carbon) ratio. Parametric study revealed that the O/C ratio along with other related system parameters have great influence on the performance. Sulfur could be available in different forms in coal like pyrite, sulfate or organic sulfur so appropriate form of sulfur in feedstocks should be corrected for better accuracy of model results. The highest percentages of CO i.e. 44.2, 37.8, and 46.6% were obtained from Thar coal (air dried form), Lakhra coal and Sonda coal respectively at the 0.3 O/C ratio. The decrease in LHV and HHV (Lower and Higher Heating Values) of syngas was observed on increase of O/C ratio for all coal types. The composition of as received Thar coal gave maximum LHV ( $1.5 \times 10^4$  KJ/Kg) and HHV ( $1.78 \times 10^4$  KJ/Kg) at the 0.3 O/C ratio. The future work could be extended by simulating biomass composition in the developed model of gasifier in transient simulations.

**Key Words:** Entrained Flow Gasifier, Aspen Plus, and Equilibrium Modeling.

## 1. INTRODUCTION

Sustainable development requires the efficient and economic conversion of coal due to its major utilization for electricity production across the globe [1]. Gasification is considered to be one of the most efficient technologies to convert raw, low-cost coal into

clean and highly priced chemicals, fuels, and power. Gasification provides an alternate source for producing valuable chemicals and energy at the time where conventional fuel cost fluctuates on routine basis. There is about 175 Billion tons of lignite coal available in Thar

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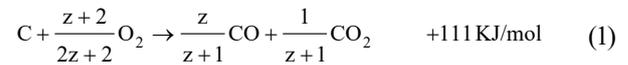
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coal reserves which is a huge amount [2] and could be a breakthrough for country through exploitation of gasification technology for producing energy and other chemicals from abundant ingenious resource [3]. Fundamentally there are three basic configurations for gasifiers, namely fixed bed gasifier, fluidized bed gasifier and entrained flow gasifier. The fundamental difference in these configurations is the fuel and oxidizing agent feeding style and form of fuel. Entrained flow gasifiers are found most efficient but complex in operations.

In entrained-flow gasifier, the gasifying agents such as oxygen/air and steam including the mixture of gas products flows counter currently with solid feedstock like coal [4]. The whole process in entrained flow gasifier carried out at the temperatures below than the ash fusion point for avoiding the clinking issues. The coals with none clinking properties are usually preferred for entrained flow gasifiers. The size of coal being used that ranges from 6.35-38.1mm with oxygen enter from the top of the reactor and from the reactor bottom steams are blown. The coal particles travel from different zones within the reaction chamber of entrained flow gasifier usually known as devitalization zone, drying zone, combustion zone, and gasification zone. Drying zone is at start where the moisture of coal gets evaporated. Generally, drying process occurs its reaction under 300°C but it also depends on moisture content available in the coal [5]. The drying process ends up then devolatilization process begins. The coal is transferred into elevated temperature so that it produce the gases char and tar. The product gases formation, char and tar composition depend on the category of coal, heating rate, pressure, and temperature. The size of particles largely affects the overall reaction rate, quantity and quality of product syngas due to slow heat transfer rate and slow reaction time [6].

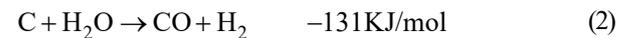
After the devolatilization, combustion of char and volatiles starts which is controlled by limited oxygen supply. The general combustion reaction is described by reaction Equation (1) [7].



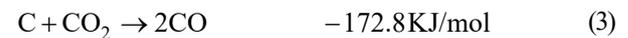
Where ‘z’ is the stoichiometric coefficient and defines the complete or partial combustion of carbon in the fuel.

After the limited combustion the temperature of the chamber reaches above 800°C and filled with enough combustion product gases like CO<sub>2</sub> and H<sub>2</sub>O. At this stage gasification reactions which are endothermic in nature start as described by reaction Equations (2-6).

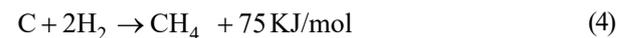
Char-Gasification Reaction



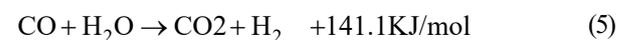
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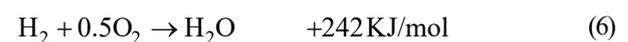
Reaction of Methanation:



Reaction of Water-gas shift:



Reaction of Hydrogen combustion:



The principal advantages of entrained flow gasifier is its ability to produce tar-free gas from the coal used as feedstock along with production of ash in frit or inert slag form. Consumption of high amount of oxygen as compared

to other configurations, particularly for high moisture or ash content feedstocks and extra efforts for preparing coal for feeding are some consequences of this technology. Entrained flow gasifiers can give up to 99% conversion efficiency with high carbon content fuels. Likewise, the quality of syngas produced from entrained flow gasifier is of high quality because it contains less methane and higher CO and H<sub>2</sub> mole fractions. The feed systems, chamber of vessels and its internals, entrance of fuel and oxidant are varying in different designs of entrained-flow gasifiers [8].

Watanabe and Otaka [9] studied reaction gasification of coal, and calculated performance of gasification in entrained flow gasifier. Carbon conversion efficiency, amount of product char, calorific value of syngas produced and cold-gas efficiency were used as performance indicators and effects of air ratio on these indicators were studied through simulations. Darmwanet. al. [10] developing a thermodynamic model of entrained flow gasifier in an IGCC (Integrated Gasification Combined Cycle) using Aspen Plus software. They utilized mass and energy balance for evaluating the performance of gasification system using black liquor as feedstock. Zhuo et. al. [11] developed a numerical model for understanding the performance of entrained flow gasifier for important operating parameters like oxygen-to-coal and oxygen to carrier gas ratio. Troiano et. al.[12] worked on compartmental model of entrained-flow slagging gasifiers for solid fuels. The model was evaluated for sensitive operating parameters for investigating the overall performance of entrained flow gasifiers. Conclusively it was observed that the performance of entrained flow gasifier is highly sensitive towards the coal composition, oxygen to coal ratio and amount of oxidant supplied. Very scant literature is available for investigations of performance of entrained flow gasifiers with indigenous coal characteristics [13].

Hence this research is focused on studying the effects of varying feedstocks on overall performance of entrained flow gasifier through simulations. The composition of four indigenous coal types i.e. Thar AD (Air Dried), Thar AR (As Received), Lakhra and Sonda were used as primary model inputs. The performance of gasifier was evaluated by variation in an important operating parameters i.e. O/C.Plant from natural gas to coal, while power generation at the same time.

## **2. DEVELOPMENT OF MODEL**

This section provides the development of kinetic model for downdraft entrained flow gasifier in Aspen Plus® software. The model approach was proposed by Chaung and Wen [14].

The model features are enlist below:

- The model of steady state.
- The occurring physical and chemical processes in gasifier are accounted for in this modeled, char gasification, coal pyrolysis and volatile combustion.
- The consideration of char in the gasification is defined by the kinetics reaction.
- The time of residence solids is calculated by the hydrodynamics is taken into account.
- The solid segment and gas segment is mixed with each other promptly and flawlessly.
- The pressure drop is negligible in the gasifier.
- The coal particles size is supposed to be spherical as well as uniform.

- The coating formed of ash leftover on the particle at the time of reaction depends upon the model shrinking core unreacted.
- The coal particle temperature inside is assumed to be unchanged.

The process containing the species of chemicals are presented in Table 1.

### 2.1 Explanation of Process

Fig. 1 shows the simulated gasifier typically entrained flow type. The gasifier is divided into two internally sections. The heightened section is used for gasification. When the pulverized coal is mixed with water it forms the slurry of water coal which is typically about 500 μm and then oxygen and slurry together are introduced simultaneously into the highest section. Later production of the syngas take place by reactions that is coal pyrolysis, char and volatile combustion. In this unit, to bear the severe environment functions, the refractory material is

lined separately. The temperature of operating is typically more than usually 1000°C at 20-50atm pressure.

The slake bowl is lower unit. The lowest part of the gasifier is sustained for water tank to cool down by water inoculation nonstop. The syngas exit and slag upper unit of gasifier. The syngas and slag leaving the upper component of gasifier permit over a pipe water dip cooled into tank of the water. The residue of slag persist in the water and then it is removed. The saturated syngas along with water is removed by the space gas above the water [15].

### 2.2 Physical Properties of Model

The method used RK-SOAVE property in the model to calculate the conventional mixed physical properties and components of CISOLID. The HCALGEN and DCOALGT are models used to calculate the components of density and non-conventional enthalpy respectively. The simulation of HCALGEN model requires three features

TABLE 1. THE USED OF COMPONENTS IN MODEL

Symbol	Category	Title	Formula
CO	Conventional	Carbon Monoxide	CO
O <sub>2</sub>		Oxygen	O <sub>2</sub>
CO <sub>2</sub>		Carbon Dioxide	CO <sub>2</sub>
H <sub>2</sub>		Hydrogen	H <sub>2</sub> O
H <sub>2</sub> S		Hydrogen-Sulfide	H <sub>2</sub>
N <sub>2</sub>		Nitrogen	N <sub>2</sub>
H <sub>2</sub> O		Water	H <sub>2</sub> S
C <sub>6</sub> H <sub>6</sub> *		Benzene	C <sub>6</sub> H <sub>6</sub> *
CH <sub>4</sub>		Methane	CH <sub>4</sub>
S		Solid	Sulfur
C	Carbon-Graphite		C
Coal	Conventional	-	-
Char1*		-	-
Char2*		-	-
Ash		-	-

Components for sulfur analysis belong to “SULFANAL”, for ultimate analysis belong to “ULTANAL” and for proximate analysis belong “PROXANAL”. With the help of proximate analysis the contents of weight, moisture,

fixed carbon volatile matter, and ash are evaluated. The coal composition weight is given by the sulfur, nitrogen, oxygen, carbon, hydrogen, ash and chlorine. The pyritic sulfur and organic sulfur division analysis is obtained by the fraction weight of sulfur. The SULFANAL and ULTANAL attributes components are required for the model DCOALIGT. The compositions of different indigenous coal types taken from literature [16-18] are shown in Tables 2-5. The gasifier dimensions and data of feed stream derived from the literature [14], as shows in the Tables 6-7. With the help of those analyses the results are calculated of density and enthalpy of coal respectively. The char and ash characterization are generated by the coal conversion and also enthalpy and density of coal calculated with this model and methodology applied. The char and ash results are calculated in accordance with original coal and gaseous amount products in mass balance relation by the method of ultimate, sulfur and proximate analysis [19].

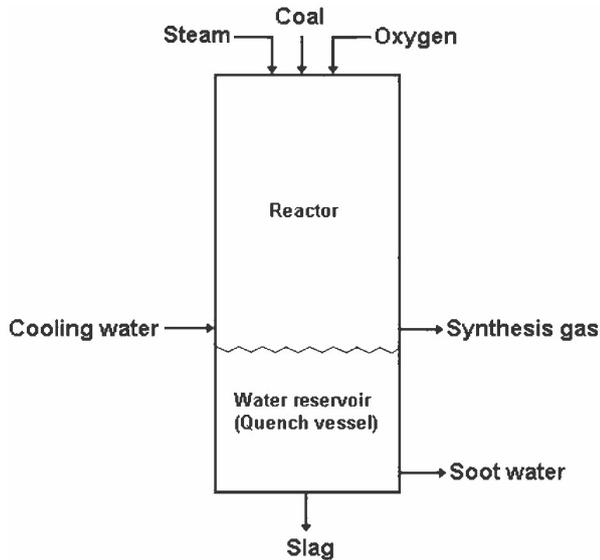


FIG.1. TEXACO DOWN-FLOW SCHEMATIC DIAGRAM OF ENTRAINED FLOW GASIFIER

TABLE 2. PROPERTIES OF LAKHRA COAL FIELD [16]

Proximate		Ultimate		Sulfur analysis	
Element	Value (wt.%)	Element	Value (wt.%, MF)	Element	Value (wt. %, MF)
Moisture Content	17.6	C	46.39	Pyritic	2.06
Fixed Carbon Dry Basis	27.59	H	5.4	Sulfonate	2.06
Volatiles on Dry Basis	34.04	N	0.98	Organic	2.05
Ash Dry Basis	38.37	S	6.17		
		O	9.45		
		ASH	31.62		

TABLE 3. PROPERTIES OF SONDA COAL FIELD [17]

Proximate		Ultimate		Sulfur analysis	
Element	Value (wt.%)	Element	Value (wt.%, MF)	Element	Value (wt. %, MF)
Moisture Content	10.6	C	58.92	Pyritic	1.16
Fixed Carbon Dry Basis	29.3	H	5.83	Sulfonate	1.16
Volatiles on Dry Basis	61.9	N	0.29	Organic	1.17
Ash Dry Basis	9.07	S	3.49		
		O	23.36		
		ASH	8.11		

TABLE 4. PROPERTIES OF THAR (AIR DRY BASIS) OF LAKHRA COAL FIELD [18]

Proximate		Ultimate		Sulfur analysis	
Element	Value (wt.%)	Element	Value (wt.%, MF)	Element	Value (wt. %, MF)
Moisture Content	15.86	C	62.54	Pyritic	1
Fixed Carbon Dry Basis	34.65	H	6.04	Sulfonate	1
Volatiles on Dry Basis	53.17	N	0.39	Organic	0.99
Ash Dry Basis	12.18	S	2.99		
		O	18.09		
		ASH	10.25		

TABLE 5. PROPERTIES OF THAR (AS RECEIVED BASIS) COAL FIELD [18]

Proximate		Ultimate		Sulfur analysis	
Element	Value (wt.%)	Element	Value (wt.%, MF)	Element	Value (wt. %, MF)
Moisture Content	44.35	C	38.17	Pyritic	0.62
Fixed Carbon Dry Basis	34.56	H	7.93	Sulfonate	0.62
Volatiles on Dry Basis	53.15	N	0.23	Organic	0.63
Ash Dry Basis	12.29	S	1.87		
		O	44.96		
		ASH	6.84		

TABLE 6. DATA FEED STREAMS OF OXIDANT, STEAM AND FUEL [14]

Feedstock	Parameters	Value
Coal	Velocity	3 (m/s)
	Flow rate	76.66 (g/s)
	Diameter of particle	350 (m)
	Pressure	24 (atm)
	Temperature	505.22 (K)
Oxygen	Pressure	24 (atm)
	Temperature	298 (K)
	Ratio of oxygen to coal flow rates	0.866 (Dimensionless)
Steam	Temperature	696.67 (K)
	Ratio of steam to coal flow rates	0.241 (Dimensionless)
	Pressure	24 (Atm)

TABLE 7. PARAMETERS OF DIMENSIONAL AND OPERATING [14]

Parameter	Value
<u>Diameter</u>	<u>1.5 (m)</u>
<u>Length</u>	<u>3.25 (m)</u>
<u>Pressure</u>	<u>24 (atm)</u>

### 2.3 Simulation Method

The model is developed in Aspen Plus®V10 for whole process of gasification is shown in Fig. 2 flowsheet. In this gasification model the slake section of cooling the hot gas is not simulated.

Process of coal pyrolysis simulation is carried by the blocks of PRESCORR and PYROLYS. The process of combustion of volatiles in the model used the block of COMBUST. The process of char gasification is followed with the GASIFIER block. And the process of above three blocks is carried out with the help of other blocks [20].

The state variables were calculated using PR (Peng-Robinson) equation of state. Mathematical expression of PR equation is given in Equation (7) as explained by previous research [21].

$$P = \frac{RT}{\hat{v} - b} - \frac{a}{\hat{v}(\hat{v} + b) + b(\hat{v} - b)} \quad (7)$$

where P is pressure, R is general gas constant, T is temperature, Z is compressibility factor of real gas and  $\hat{v}$  is specific volume.

### 2.4 Measuring Performance of Gasifier

There are two ways in which the performance of gasifier is measured that is efficiency and heating value of syngas.

Commonly efficiencies of gasifier are of three types well-defined by Silaen[22]:

- The calculation of efficiency by the method of carbon total conversion
- The calculation of efficiency by the method of carbon into CO (CO) conversion
- The calculation of efficiency by the method of (CO + H<sub>2</sub>+CH<sub>4</sub>) into useful fuel conversion.

The efficiency of conversion of fuels from above efficiencies is defined in Equation (8). It elaborate the

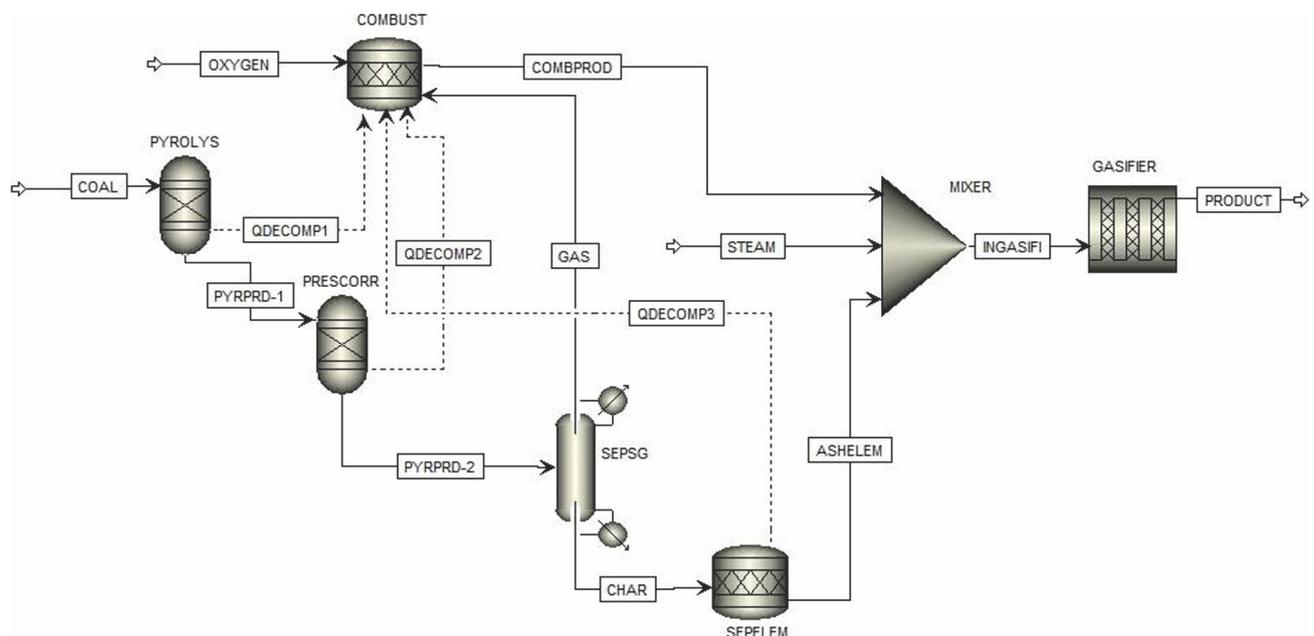


FIG. 2. THE DEVELOPED MODEL OF ENTRAINED FLOW GASIFIER IN SOFTWARE ASPEN PLUS®V10 SHOWS THE FLOW SHEET PROCESS

gasifier’s correct performance hence has been used in current research to measure the complete performance of entrained flow developed model for gasification.

$$\text{Fuel Conversion Efficiency} = \frac{\text{Total Moles of CO} + \text{H}_2 + \text{CH}_4 \text{ in Exitit Gas}}{\text{Total Moles of C} + \text{H}_2\text{O} + \text{O}_2 + \text{Volatiles at Inlet}} \quad (8)$$

The produced syngas quality is analyze by the heating value which is prime factor of gasifier. The calculation of HHV and LHV using the HYSYS®8.4 aspen by stream defining in the HYSYS Aspen and stream converged by putting the achieved composition and conditions.

### 2.5. Cases of Simulation for Various Inputs

The simulation conditions input are given in Table 8. In this simulation two types of variables are used which are independent i.e. feed types (composition of four different indigenous coal types) and the ratio of O/C range of 0.3-0.7.

### 3. RESULTS AND DISCUSSION

The Aspen Plus®8.4 software, a standard flow-sheeting, is used in current research work for development of entrained-flow gasifier using coal as

TABLE 8. THE CASE PARAMETERS OF VARYING INPUT FOR ALL SIMULATIONS

Case No.	Varying Parameters	
	Type of Feedstock	O/C Ratio
1	Thar Coal AR (As Received)	0.3
2		0.4
3		0.5
4		0.6
5		0.7
6	Thar Coal AD (Air Dried)	0.3
7		0.4
8		0.5
9		0.6
10		0.7
11	(Air Dried)	0.3
12		0.4
13		0.5
14		0.6
15		0.7
16	(Air Dried)	0.3
17		0.4
18		0.5
19		0.6
20		0.7

feedstock. The heating value of syngas and fuel conversion efficiency was calculated for four types of indigenous coal composition for investing the performance of gasifier. As explained earlier, there were twenty simulated cases, converged with different types of feed coal and (O/C) ratios. Several effects are discussed in next paragraphs.

### 3.1 Effects of O/C Ratio and Type of Feedstock on Syngas Composition

The significant components of produced syngas from four type of coal inputs are plotted against varying O/C ratio and shown in Fig. 3-6. It was observed that increase in O/C ratio decreases the CO mole fraction as shown in Fig.3 for all type of coals except Thar coal (AR) because of high moisture in parent coal from Thar coal field. Thar (AD), Sonda and Lakhra coals produced maximum mole fraction of CO of about 44.2, 46.6 and 37.8% respectively at O/C ratio 0.3 whereas maximum CO produced by Thar as received conditions (AR) of about 15% at 0.5 O/C ratio because of high moisture presence. At O/C ratio of 0.3, the maximum H<sub>2</sub> was produced from Thar(AR), Thar(AD), and Sonda coals of about 29, 30 and 35% respectively. The highest H<sub>2</sub> i.e. 33% was produced from Lakhra coal at 0.5 due to presence of high carbon.

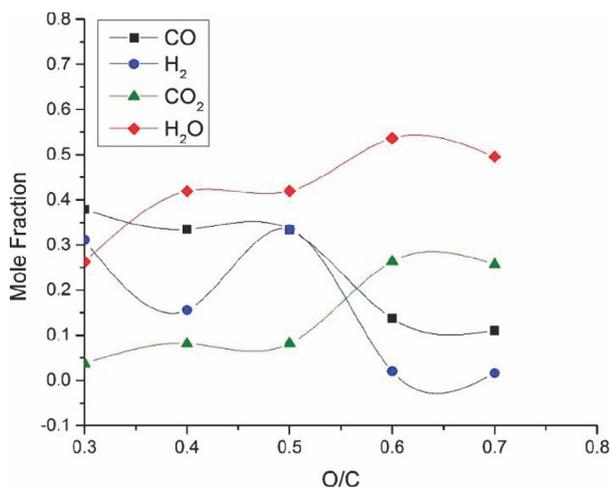


FIG. 3. LAKHRA COAL SYNGAS MOLAR COMPOSITION AT VARYING O/C RATIOS

Maximum 26% CO<sub>2</sub> was produced from Thar (AD) and Lakhra coals at 0.6 O/C ratio. For Thar (AR) and Sonda coal the maximum CO<sub>2</sub> was achieved at O/C ratio of 0.7 i.e. 21 and 26% respectively. The results are in agreement with previous findings [9].

### 3.2 Effects of O/C ratio and type of feedstock on Temperature of Syngas

The outlet temperature of product syngas from different feedstocks was also recorded during the simulations of gasification at varying O/C ratio and is shown in Fig.7. The maximum syngas temperature was observed at O/C ratios of 0.3, 0.4 and 0.5 for Lakhra coal i.e.(2500-3100K) in

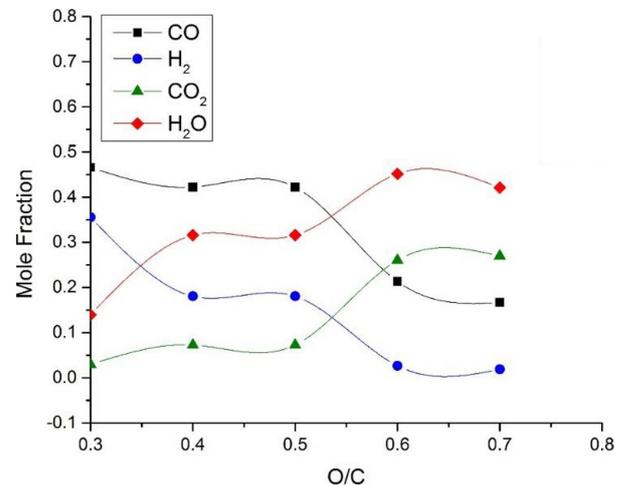


FIG. 4. SONDA COAL SYNGAS MOLAR COMPOSITION AT VARYING O/C RATIOS

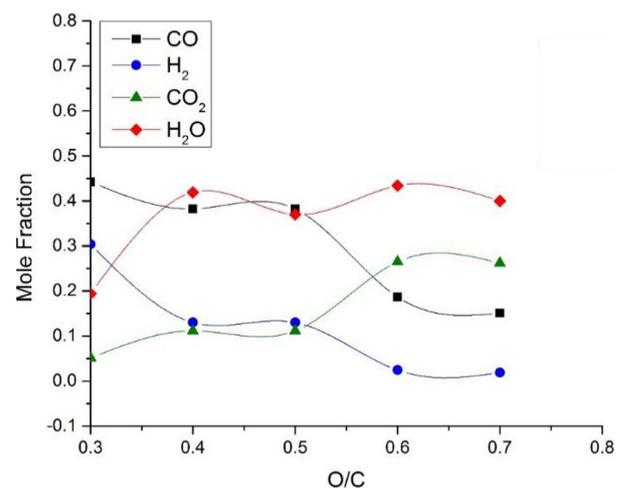


FIG. 5. THAR COAL (AD) SYNGAS MOLAR COMPOSITION AT VARYING O/C RATIOS

gasification but at higher O/C ratios i.e. 0.6 and 0.7, Sonda coal produced high temperature of about 3500K. The lower range of produced syngas temperature of Thar air dried samples was observed when compared with Sonda coal and Lakhra coal at respective O/C ratio. Thar as received coal samples produced lowest temperate in the range of 900-2500K ranges. It was observed that increasing the O/C ratio increases in the temperature of syngas produced for all type of coals and confirms the finding by previous research [11]. The main cause of this performance is due to the converting gasification into the combustion at greater O/C ratios.

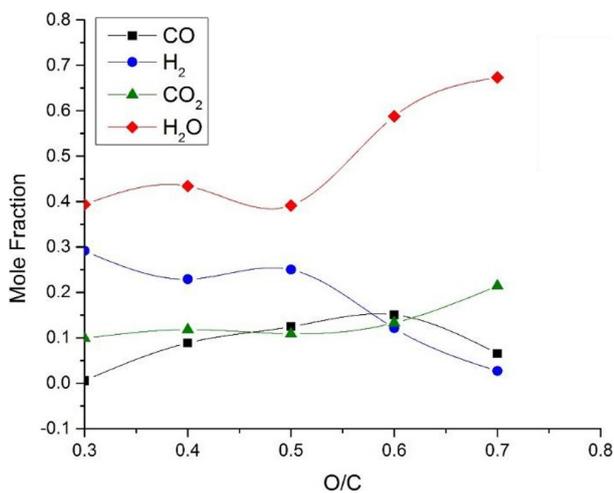


FIG. 6. THAR COAL (AR) SYNGAS MOLAR COMPOSITION AT VARYING O/C RATIOS

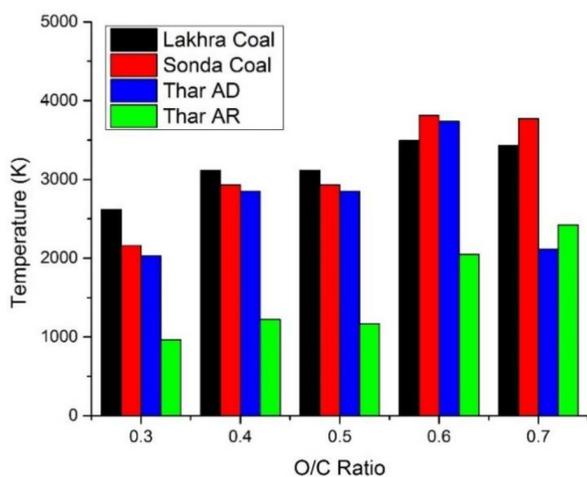


FIG. 7. TEMPERATURE OF EXIT SYNGAS FOR VARIOUS FEED STOCKS

### 3.3 Fuel Conversion Efficiency

The efficiency of conversion of all fuels was calculated using Equation (8) by inserting the composition of syngas and feedstock types and plotted against varying O/C ratio as shown in Fig. 8. Above 60% fuel-conversion efficiency was observed at O/C ratio of 0.3 and 0.4 for the Sonda, but a decreasing trend was noticed in fuel conversion efficiency beyond 0.4 O/C ratio for all types of feedstock. This is due to dominance of combustion reaction over gasification reactions Equations (2-3) at higher O/C ratios as explained by literature [7,23].

### 3.4 Quality of Syngas

The heating value would be the term for measuring the quality of syngas. The syngas composition, pressure, and temperature was utilized in each case to calculate the LHV and the HHV using material stream convergence method in Aspen HYSYS. Fig. 9(a-b) show the comparisons of HHV and LHV for various coal types and O/C ratios respectively. A decreasing trend for HHV and LHV was observed on increasing O/C ratios with all four types of coal. A plausible reason is decrease of combustible components in syngas like CH<sub>4</sub>, CO and H<sub>2</sub> with increase in the O/C ratio as explained by previous research [13]. It was observed that at 0.3 O/C ratio, the maximum HHV (1.78x10<sup>4</sup> KJ/Kg) and LHV (1.5x10<sup>4</sup> KJ/Kg)

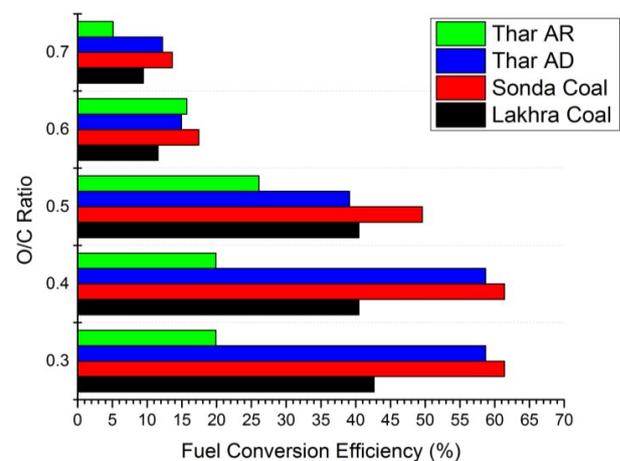


FIG. 8. EFFICIENCY OF VARIOUS FEEDSTOCK FUEL CONVERSION

was achieved from Thar as received composition. Thar coal (as received) produces a syngas with 19% CH<sub>4</sub> at 0.3 O/C ratio, which is highest amount and for that factor, the unexpected higher HHV and LHV values are obtained. In other type of coals there is less moisture than the Thar (AR) and for that reason the highest amount of methane is obtained because moisture work in the gasifier as the steam and producing more methane. The Sonda coal produced second best quality of syngas, which is  $1.36 \times 10^4$  KJ/Kg HHV and  $1.24 \times 10^4$  KJ/Kg LHV at the O/C ratio of 0.3. The other types of coal contain the heating values in the ranges  $.12 \times 10^3$ -  $2.5 \times 10^3$  KJ/Kg HHV and  $1.11 \times 10^3$ -  $1.88 \times 10^3$  KJ/Kg LHV and at O/C ratio 0.7 the minimum quality achieved.

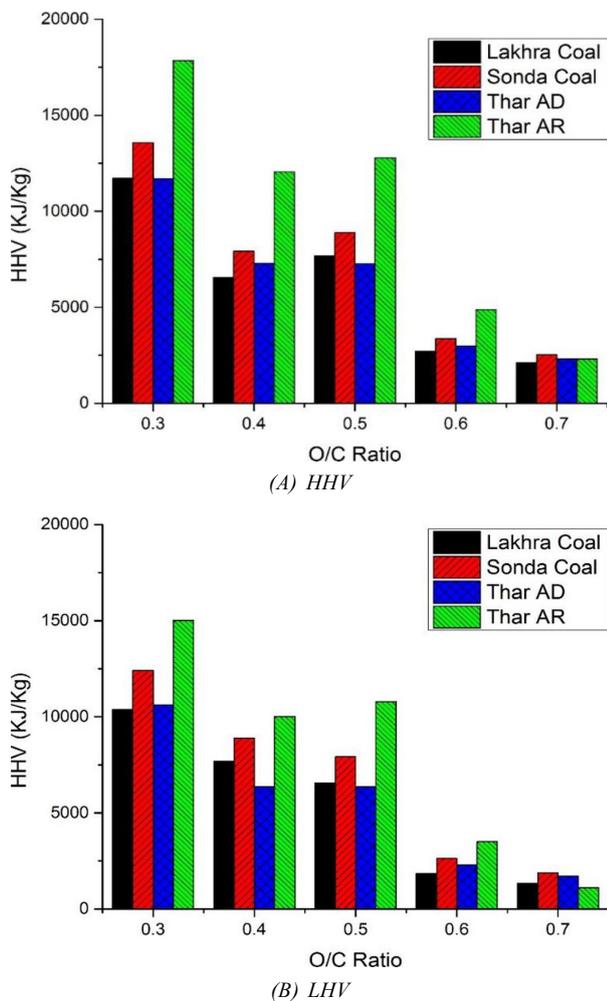


FIG. 9. VARIOUS TYPES OF COAL AND THEIR O/C RATIOS PRODUCED SYNGAS HEATING

#### 4. CONCLUSION

The gasifier of Entrained Flow Coal model is developed in this research which is steady state type by using the Aspen Plus®8.4 which is software of flow sheeting standard. This gasifier model can perform depolarization or coal pyrolysis, drying, combustion and lastly gasification, because this model gasifier is based on the major chemical and physical of processes occurring. For the gasification of char there was a consideration of reaction Kinetics. It was assumed to be the gas phase mixed with the solid phase immediately and flawlessly. In the gasifier there was no any consideration of pressure drop. The spherical and uniform particles of coal were assumed in the simulations. The developed model of gasifier was tested for four different types of indigenous coals used as feedstock of gasifier by inserting the composition of Sonda Coal, Lakhra Coal, Thar Coal (AR) and Thar Coal composition of (Air dried). The O/C ratios from 0.3-0.7 were inserted in the gasifier model for evaluating the performance of developed model based on the efficiency of fuel conversion, syngas quality and syngas composition. The conclusions drawn from detailed discussion on results in previous sections are as under:

- (i) The highest percentages of CO i.e. 44.2, 37.8, and 46.6% were obtained from Thar coal (AD), Lakhra coal and Sonda coal respectively at the 0.3 O/C ratio.
- (ii) The maximum CO of Thar coal (AR) was achieved about 15%, which is quite less as compared to other coal feedstocks due to the great amount of moisture present in Thar coal (AR) composition.

- (iii) The maximum percentage of H<sub>2</sub> found in Lakhra feedstock was 33% on the O/C ratio of 0.5 and other feedstocks of Thar AR, Sonda, and Thar AD the maximum percentage of H<sub>2</sub> obtained was 29, 35 and 30% on the O/C ratio of 0.3 respectively.
- (iv) For the Thar AD and Lakhra coal the highest percentage of CO<sub>2</sub> obtained on the 0.6 O/C ratio was 26% of each feedstock and for other two feedstocks of Thar AR and Sonda field the maximum CO<sub>2</sub> obtained was 21 and 26% on the O/C ratio of 0.7 respectively.
- (v) It was found that increase in the ratio of O/C increased the produced syngas temperature because it was observed in the O/C ratios of (0.3, 0.4 and 0.5) the maximum temperature was obtained in the Lakhra coal that was (2500-3100 K).
- (vi) The maximum efficiency of fuel conversion was found that was 60% for the Sonda coal at the lower O/C ratio 0.3 and when it was increased in the O/C ratio there was decrease in the efficiency of fuel conversion for the all feedstock types of coals.
- (vii) It is observed that when O/C ratios are increasing than there is reduction in the LHV and HHV because H<sub>2</sub>, CO, and CH<sub>4</sub> components of combustible are decreasing when increasing the O/C ratio of all coal types. The composition of as received Thar coal gives the maximum LHV (1.5x10<sup>4</sup> KJ/Kg) and HHV (1.78x10<sup>4</sup> KJ/Kg) at the same O/C ratio i.e. 0.3.

The following are the recommendations for future work:

- (i) The developed entrained flow model could be further tested for its performance on the biomass or composition of mixed waste or biomass inserting.
- (ii) The different effects of dynamics of operating parameters could be investigated by using transient simulations model.
- (iii) Experimental confirmation could be approved for validate the model outcomes in future.

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