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Process Simulation Of Co-Combustion Of Coal And Biomass In Fluidized Bed Combustor

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Abstract- *With ever-increasing usage of biomass to curb environmental pollution, it is imperative to develop new insights into coal combustion processes, for efficient and optimal usage. Many process models have been developed for combustion process, including fixed and fluidized bed combustion for different types of coal; however, they are designed for specific process and lack generality. More recently, Aspen Plus has introduced new tools, and particularly featured a built-in unit operation model, to design fluidized bed processes. Herein, a process simulation model has been developed to simulate and predict the condition of co-combustion of coal and biomass in fluidized bed combustor (CFBC) based on Aspen Plus with considering gas-solid hydrodynamics via Aspen Plus in-line FORTRAN codes and combustion reaction kinetics via some external FORTRAN subroutines simultaneously. In this study, a novel hybrid approach for modelling coal combustion has been implemented to comprehensively design a model for conversion of low-grade coal under various operating conditions. The proposed model combines sequential modeling of drying/pyrolysis (devolatilization) and combustion of coal by means of conventionally used units (RYIELD and RGIBBS), & a newly used unit (FLUIDBED) in Aspen Plus. The model validation was performed by experiments on the combustion of low-grade coal in a pilot-scale circulating fluidized bed reactor (CFBR). Experimental data were used to further calibrate the Aspen Plus model and decrease model uncertainties. The results obtained from the developed simulation model were found to be in good agreement with the experimental data. Discrepancies of less than 15% were observed, in most of the predictions of molar fractions for the resultant flue gas composition, including NO_x & SO_x, emissions which were at ppm levels. As a result, the model can easily be used for design, scale-up, and simulation of coal combustion as well as for other feedstock like biomass in fluidized bed with process optimization based on sensitivity analysis.*

Index Terms- *Co-combustion, Coal/Biomass, circulating fluidized bed reactor, Aspen Plus.*

I.INTRODUCTION

AS a result of the accelerated economic growth in Asian countries, the International Energy Agency (IEA) projects nearly 50% increase in world energy consumption by 2050 [1]. This increase in the global energy consumption, and its associated impact on the environment, has become one of the most debated issues. While renewable energy is important, combustion of different fuels such as coal, crude oil, and gas are likely to remain to be a common source of energy for the upcoming decades. Moreover, almost half of the world's electricity, and a quarter of the primary energy demand, is still provided by combustion of coal [2]. Approximately 9.45% of the world's coal reserves are located in India, which suggests that coal consumption will still continue to remain as one of the dominant sources of energy supply in this country for the foreseeable future [3]. According to World Coal Association, India was ranked amongst top 3 coal producers in 2016 [4]. At present, the combustion of medium and high ash content bituminous coals typically occurs using pulverized-coal boilers (PC) for electricity and district heating [5]. More than half of the total electricity in India is produced by the combustion of high ash coal in thermal power plants, and moreover such plants are highly inefficient due to the use of old technologies and lack of investment [6]. Moreover, the aging technology used by India coal-fired power plants translates to low thermal efficiencies [4][6]. The process and economics of coal combustion is further complicated with increasing constraints from various national and international institutions and regulations set on the emissions of SO_x, NO_x, particulate matter, and other pollutant emissions. The above-mentioned considerations provide encouragement to develop thermal processes further and explore ways to minimize pollution [7]. Circulating fluidized bed reactors (CFBRs) is an alternative technology for the conversion of low-grade solid fuels at relatively low temperatures, and typically has lower SO and NO_x emissions. Moreover, CFBRs can also utilize a variety of feedstock without

major modifications, i.e., they are fuel flexible [8]. Over the last two decades, several models for CFBRs have been developed, at times, using specialized process simulation tools, to understand them and to optimize their operating conditions [7, 9-13]. Most of these models are based on the commercial Aspen Plus process modeling software, owing to its accuracy and reliability. For example, Dong et al. [14] described the modeling of the coal combustion in a circulated fluidized bed boiler. They used series of different reactors available in Aspen Plus to simulate the fluidized bed reactor unit such as RYield for decomposition, RGibbs for Gibbs equilibrium, cyclones, and heat exchangers. Their model was based on the following assumptions, which are commonly used in the literature [8, 11, 12]: (a) the process is isothermal and steady state, (b) coal is decomposed into its constituent components as hydrogen, nitrogen, oxygen, water, sulfur, and char, which consists of fully reactive carbon and inert ash [12]. However, bed hydrodynamics was neglected in their model. Chen et al. [15] recently modeled a 50 kW CFBR using computational fluid-particle dynamics and validated the model with experimental results on flue gas concentrations. These authors later proposed optimized conditions for using chemical looping combustion of coal. However, this model is highly specific to the type of the coal and conditions studied, and did not adequately consider bed hydrodynamics. Hydrodynamic parameters affect the conversion of coal in CFBR and hence, both hydrodynamic and reaction kinetics must be treated simultaneously. In this regard, earlier, Nikoo and Mahinpey [16] modeled biomass gasification in fluidized bed reactor using Aspen Plus. Their model consisted of three steps: biomass decomposition, devolatilization, and the char gasification. The gasification reaction included both bubbling fluidized bed hydrodynamics parameters and kinetic parameters for coal combustion. However, the version of Aspen Plus, available at that time, did not have the necessary libraries to support bed hydrodynamics modelling and hence the authors modeled hydrodynamics separately using FORTRAN subroutines [14]. This model was validated using the lab-scale pine gasifier and the authors determined the effect of varying temperature on the reactivity of the carbon and hydrogen. Likewise, Nayak and Mewada [17] and Jurado et al. [18] modeled coal gasification via Aspen Plus using a series of RYield, RGibbs, RStoic reactors and performed analysis on oxy combustion and co-combustion of coal and biomass mixtures. Using their model, which was validated with the experimental data obtained from a pilot-scale pulverized coal combustor [18], these authors pointed out that the heat flux during the oxy-combustion was three times higher than in conventional air-based combustion. While several such efforts have been made to model coal combustion in CFBR with varying models, most of them employ Aspen Plus and, case-specific FORTRAN subroutines [19]. Over time, Aspen Plus has become a recommended method for dealing with the solid handling processes owing to its strong solid databanks as well as its superior capabilities for determining solid characteristics (such as PSD) together with Property Methods for a wide range of solid fuel compounds. While Aspen plus offers flexibility in modeling, the subroutines that have been employed in the literature are specific to a given process, coal and bed type, and the governing equations used, thereby reducing the flexibility of the overall model for other applications.

Biomass is a carbon–neutral fuel and considering the overall life-cycle, biomass conversion has a potential to be a carbon negative process [22]. Co-firing of coal with biomass also claims to reduce emissions of SO_x and NO_x due to low content of sulfur and nitrogen in the biomass [23], while maintaining a comparable heating value [24]. Experiments conducted by Kommalapati et al. [25], demonstrated a decrease in life cycle emissions for CO2 (by 13.45%) and NOx (by 11.70%) for the blend fuel with 15% of biomass. However, along with advantages, certain technical issues of biomass/coal co-firing, such as growth of soot deposition in the reactor, ash composition, and morphology changes, needs to be considered [23, 26]. In addition, limited literature is available on comprehensive analysis of efficient integration of biomass into existing coal firing systems. Even though biomass has a great capacity in the energy sector, especially when coupled with coal, increased cost of operation and pretreatment for biomass fuel brings challenges to quick fuel [24, 27, 28]. Therefore, an understanding of the behavior of the conversion process at different biomass to coal ratio in blended fuel is of current interest.

Optimization through modelling requires thorough analysis and validation. Most of the coal/biomass combustion models in the literature are built on Computational Fluid Dynamics (CFD), using Eulerian–Eulerian or Eulerian–Lagrangian approach. The approach often takes into consideration combustion

reaction kinetics and reactor hydrodynamics, as a part of holistic modelling [28, 29]. However, results based on the CFD models strongly depend on the grid selection and assumption, including improper modeling of the complex momentum equations. In addition, the simulation using CFD cannot be referred to as a user-friendly approach for optimization execution.

Being one of the leading chemical process modeling software, Aspen Plus incorporates various attributes required for comprehensive process modeling along with the user-friendly interface. However, limited studies are available for coal/biomass co-firing processes models built in Aspen plus, especially the ones occurring in Fluidized Bed Reactor (FBR) unit. Complex hydrodynamics of the combustion reactor and chemical reaction kinetics bring some challenges to the models and their optimization. A FLUIDBED unit has been available since version 8 of Aspen Plus and is an obvious choice to model FBR. The unit includes a variety of governing equations for the incorporation of reactor hydrodynamics along with kinetics and the heat and mass balances. However, it has never been used for design of combustion process due to several modeling related issues.

The purpose of this work is to develop a comprehensive and, at the same time, flexible model for co-combustion of coal and biomass in the CFBR, using the built-in FLUIDBED unit by Aspen Plus (version 11). In this work, the combustion model is designed to implement FLUIDBED unit with a broader reaction set including NO_x, SO_x and tar combustion including the effect of volatiles and further incorporate co-combustion of biomass and coal in the CFBR unit. In the following sections, the development of the model is discussed in details, followed by the validation using the well-established literature data provided by researchers [20, 21] on co-combustion of coal and biomass.

II.METHODOLOGY

Arocess development

Combustion of the solid fuel particles in the fluidized bed reactors under goes three key steps: drying, devolatilization/pyrolysis, and combustion, each of which is modeled separately in Aspen Plus [32]. The explanation of each step pathway is demonstrated in Table 1.

Table 1 Stages of Coal/Biomass combustion in FBR [32]

Drying	Wet coal/biomass → dry coal/biomass + moisture (H2O)
Pyrolysis	Dry coal/biomass → ash + volatiles + fixed carbon (char)
Devolatilization	Volatiles → CH_4 + H2O + H_2 + CO2 + CO + H_2S + HCN + NH_3 + tar ($CH_{1.84}O_{0.96}$)
Combustion	According to combustion kinetics

At drying and pyrolysis steps moisture entrapped in the fuel is evaporated [33, 34, 35]. Further, pyrolysis proceeds with a decomposition of the dry fuel particles to volatiles, char, and ash. The composition of resulting compounds depends on the proximate analysis and operating conditions, as we discuss later. Lastly, devolatilization occurs wherein the obtained volatiles are disintegrated into tar, CH4, CO, CO2, H2, H2O, HCN, and NH3 [34]. In the current work, the composition of volatiles was calculated using the theory of the functional-group dependence on the ultimate analysis for coal [35]. The selected approach is based on the experimental results for the volatile composition of six different coal types during pyrolysis that are shown in Table S1 in Supplementary Material. Using the data set, a linear regression as performed to obtain a separate equation for each volatile component as a function of structural elements (Table S2 in Supplementary Material). The data set consists of loosely coupled and tightly coupled molecules, like H2O; however, these are combined together during the regression analysis.

Finally, the oxidation of the char and volatile gases in the reactor develops at 1123–1273 K. The combustion kinetics were adapted from several papers published on the burning of the pure coal/biomass and their mixtures, and the main criterion for the selection was the presence of the validation on the experimental results (Serio et al. 1987; Zhou et al. 2011; Gu et al. 2020; Liu et al. 2020b). Table 2 demonstrates the reaction set utilized in the fuel combustion.

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Table 2 Set of reactions describing the combustion process in FBC

R1	$CH_4 + 1.5O_2 \rightarrow CO + 2H_2O$
R2	$H_2 + 0.5O2 \rightarrow H_2O$
R3	$H_2S + 1.5O2 \rightarrow H_2O + SO_2$
R4	$HCN + 0.75O_2 \rightarrow CNO + 0.5H_2O$
R5	$NH_3 + 1.25O_2 \rightarrow NO + 1.5H_2O$
R6	$NO + CO \rightarrow 0.5N_2 + CO_2$
R7	$CO + 0.5O_2 \rightarrow CO_2$
R8	$CNO + 0.5O_2 \rightarrow NO + CO$
R9	$C + (1/\Phi)\ O_2 \rightarrow (2 - 2/\Phi)\ CO + (2/\Phi - 1)\ CO2$
R10	$C + CO_2 \rightarrow 2\ CO$
R11	$Tar + 0.48O_2 \rightarrow 0.92H_2O + CO$
R12	$CNO + NO \rightarrow N_2O + C$

Model Assumptions

The model was designed considering the following assumptions:

(1) Drying and pyrolysis occurs instantaneously and the process is under steady-state.

(2) The temperature across the FBR is uniform.

(3) The produced tar is reactive, and the produced char is 100% carbon (Merrick 1984).

(4) Functional group distribution of volatiles is correlated to the ultimate analysis of the fuel.

(5) Coal and biomass have similar volatile components.

(6) Heat transfer throughout the process is not considered.

Instantaneous drying and pyrolysis can be justified by its relatively fast decomposition rates at high temperatures present in the FBR. Furthermore, the uniform temperature distribution in FBR has been observed, for example, by Zhou et al. (2011) [36], wherein the riser temperature varied only slightly (within 50 K). The produced tar during the combustion has often been neglected in developing the process model, due to its complexities; however, herein we account for tar combustion using reaction kinetics.

Process Simulation

The developed flowsheet of the simulation, designed in Aspen Plus v11, is shown in Fig. 1. Coal, biomass, volatiles, ash, and tar were declared as non-conventional components and details were specified using HCOALGEN and DCOALIGT property methods. The COALPROC thermodynamics model was chosen for the simulation. A different approach was utilized for the tar treatment to avoid the material balance issues, arising from the fact that molecular weight of non-conventional solids is specified as 1 g/mol in Aspen Plus. Hence, tar was specified twice; a) in DEVOL ("TAR") block, as a non-conventional component produced after VM devolatilization and b) in FLUIDBED ("TAR2") as a pseudo component that is involved in kinetics governed combustion.

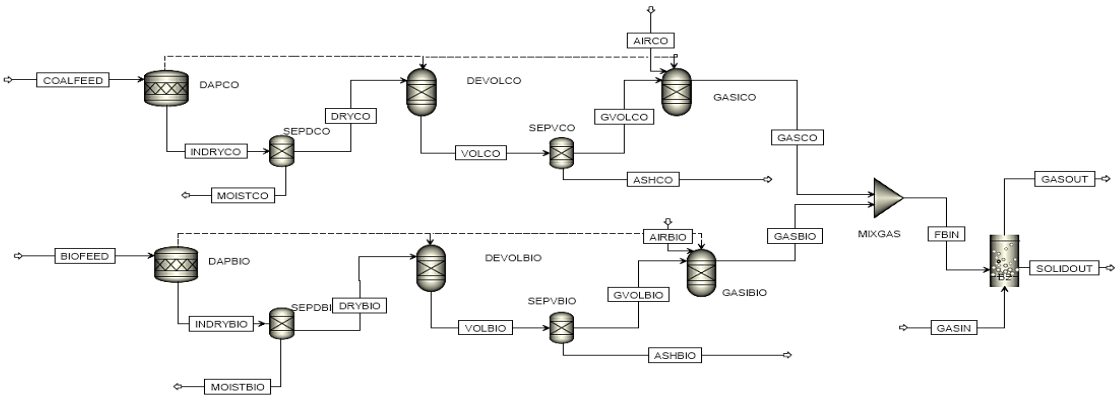

Fig. 1 The combustion model designed in Aspen Plus v11 for co-firing of Coal /Biomass in FBC

A calculator block was added to convert "TAR" to TAR2, with proper molecular weight of 29.2 g/mol and chemical composition of CH1.84O0.96 [37]. The CNO component involved in the reaction set was also declared as a pseudo component with a molecular weight 42.02 g/ mol to eliminate incorrect properties estimations. A summary of key sub-processes used for process development is represented in Table 3.

Description of unit model

The units are specified with "C" indicates coal and with "B" indicates biomass. Since coal and biomass undergo similar process stages, the units for fuel flows are in parallel and perform equivalent tasks. The process model consists of three main units: Drying and Pyrolysis (DAPC and DAPB), Devolatilization (DEVOLATC and DEVOLATB), and Combustion (FLUIDBED). In addition, two supportive units include: Moisture separator (SEPC and SEPB) and Tar exchanger (TAREX) and two logical connectors include: Devolatilization yield calculator (C-1 and C-2) Tar declaration calculator (C-3). The function of each block is discussed in the sections below. DAPC & DAPB are modeled by a RYield reactor, based on proximate analysis of each component in the outlet. Since the drying and pyrolysis are assumed to have 100% conversion and occur instantaneously, all coal and biomass are converted to FC, Ash, VM, and H2O (Serio et al. 1987). The reactors work at standard operating conditions, namely 101.325 kPa and 298 K. DEVOLATC & DEVOLATB are modeled by another RYield reactor based on the mass yield of each component using the correlation (incorporated into calculator blocks C-1 and C-2) between ultimate analysis of the fuel and composition of volatiles. Ash and FC are taken as inert in these reactor units. H2O extracted from fuel at the drying stage is separated via SEPC and SEPB, respectively, for each fuel train and added back to the mainstream at the FLUIDBED inlet. Moisture Separator (SEPC and SEBC) were used to separate moisture from the fuel, apart from H2O from the volatiles. Tar exchanger (TAREX) exchanged non-conventional TAR to pseudo component TAR2. Lastly, FLUIDBED is based on FLUIDBED unit with the dimensions are based on the literature and governed by combustion reactions stated in Table 2.

Table 3 Fuel properties for Coal and Biomass [20]

Item	Coal	Biomass
Proximate Analysis (wt% as received)		
FC	29.26	15.4
VM	29.36	80.17
MOIST	12.98	4.03
ASH	28.4	0.4
Ultimate Analysis (wt% as received)		
C	44.4	49.6
H	2.92	5.92
N	0.52	0.13
S	5.72	—
O	13.83	43.93
ASH	32.64	0.42
HHV, kJ/kg (as fired)	14600	18900

Reactor Hydrodynamics

Selected FLUIDBED unit requires a multiple parameter adjustment. Firstly, the pressure drop over bed is defined according to Kunii and Levenspiel (1991) [38]

$$\Delta P_b = (\rho_s - \rho_g) \times L_{mf} \times (1 - \varepsilon_{mf}) \times {}^{g}/_{g_c}$$

where ρ_s is a density of the solid particles, ρ_g is a density of gas, L_{mf} is the height of bed at minimum fluidization velocity, ε_{mf} is the voidage. Further next, minimum fluidization velocity was defined based on the Wen & Yu correlation [38]:

$$U_{mf} = \frac{{d_p}^2(\rho_s - \rho_g)g}{150\mu} \times \frac{{\varepsilon_{mf}}^3 {\emptyset_s}^2}{1 - \varepsilon_{mf}}, Re_{p,\ mf} < 20$$

where ρg is a density of gas, L_{mf} is a viscosity of gas, and $\emptyset$ is the sphericity of particles (0.86 for sand). The Reynolds number herein is defined as:

$$Re_{p,\ mf} = \frac{d_p U_{mf} \rho_g}{\mu}$$

The proposed approach is generally recommended for fine particle evaluation [38]. Considering that the particle size used is typically less than 200 μm and that the density of the available sand/coal is 1.6 g/cm3, B type Geldart classification was selected. Lastly, George and Grace model was utilized for determining the transport disengagement height (TDH) and Tasirin and Geldart's model was selected to estimate the elutriation.

III.RESULTS AND DISCUSSIONS

Model Validation

In order to validate our process model, we begin with the data available in the recent literature. Varol et al. (2018), have performed experiments for coal and coal/biomass combustion on a fluidized bed reactor with diameter 0.1 m and height 5.1 m and operating under bed temperature of 1123 K, results of which were presented in Table S5 in Supplementary Material, along with properties of coal and biomass. Their results reveal molar fractions of the flue gases for different fuel ratios, which were taken as a basis for validating in the current model. The operating conditions and the geometry of the rector was kept the same in the current developed model, as noted above. The model was further executed for the four runs under same operating conditions and inlet flows, but with varying fuel composition (1) 3.88 kg/h of coal flow rate and 18.1 kg/h of air feed, (2) 3.08 kg/h of coal, 0.47 kg/h of biomass, and 18.5 kg/hr of air feed, (3) 2.36 kg/h of coal, 1.38 kg/h of biomass, and 19.2 kg/h of air feed and (4) 1.48 kg/h of coal, 2.02 kg/h of biomass, and 22.1 kg/h of air feed. The model results in terms of CO_2, CO, NO, SO_2 emissions were compared with the experimental data and are presented in Table 4.

It can be noticed that the model results are in a reasonable agreement with the experimental data. The mean-absolute deviation between the emissions of CO_2, CO, NO, and SO_2 are 1.4%, 5.0 ppm, 6.0 ppm, and 20 ppm, respectively. Given that results are comparable, the model further was used to observe behavior of coal and coal/biomass fuel combustion under different conditions.

CO_2 Emission

The results interestingly reveal that CO_2 concentration does not vary significantly with a change in composition of the fuel (Fig. 2). These results are consistent with those obtained by Varol et al. [21], wherein the authors have observed that biomass concentration in blend fuel combustion under air conditions do not result in notable changes in CO_2 emissions. The compositions were in the range of 16.0%–17.1%, because of the low air flow rate. CO_2 concentration reduces with an increase of biomass fraction for GHG reduction. Moreover, at temperatures lower than 1100 K the rate of CO_2 concentration growth is lower than at higher temperatures. The highlighted pattern is a result of interconnection between the rapid decrease of CO and increase of CO_2 concentration in the flue gases and has been discussed earlier [26, 27, 39]

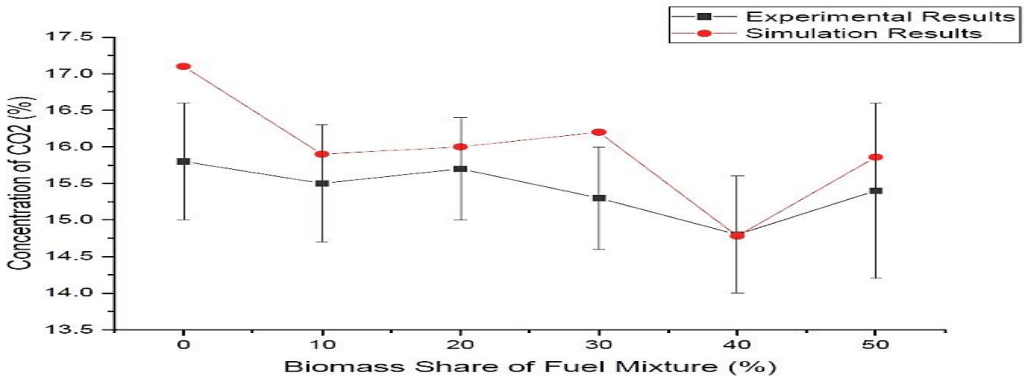

Fig. 2 Effect of Biomass fraction on CO2 concentration

Table 4 The emissions of the gases from the co-firing of Coal/Biomass in FBC obtained from simulation and compared with the experiments [20]

Test	Run Designation	Firing Mode	Biomass Share of Fuel Mixture (% by wt.)	Nomical O_2 (% by vol.)	CO_2 (vol %)		CO (PPM)		NO_x (ppm)		SO_2 (ppm)	
					Exp	Simu	Exp	Simu	Exp	Simu	Exp	Simu
1	C-1	Air Firing	0	21	15.8 ± 0.8	17.7	86 ± 12	80	131 ± 13	127	977 ± 130	938
2	CB-1	Air Firing	10	21	15.5 ± 0.8	15.9	59 ± 5	60	144 ± 13	140	806 ± 72	808
3	CB-2	Air Firing	30	21	15.3 ± 0.7	16.2	30 ± 7	35	120 ± 7	125	410 ± 87	448
4	CB-3	Air Firing	50	21	15.4 ± 1.2	13.4	56 ± 15	48	120 ± 19	131	303 ± 83	304
5	CB-5	Oxy-Firing	50	25	83 ± 7.1	87	316 ± 261	363	116 ± 18	125	2354 ± 287	2323
6	CB-6	Oxy-Firing	50	30	81.1 ± 5.5	78	410 ± 289	433	121 ± 25	137	779 ± 288	795

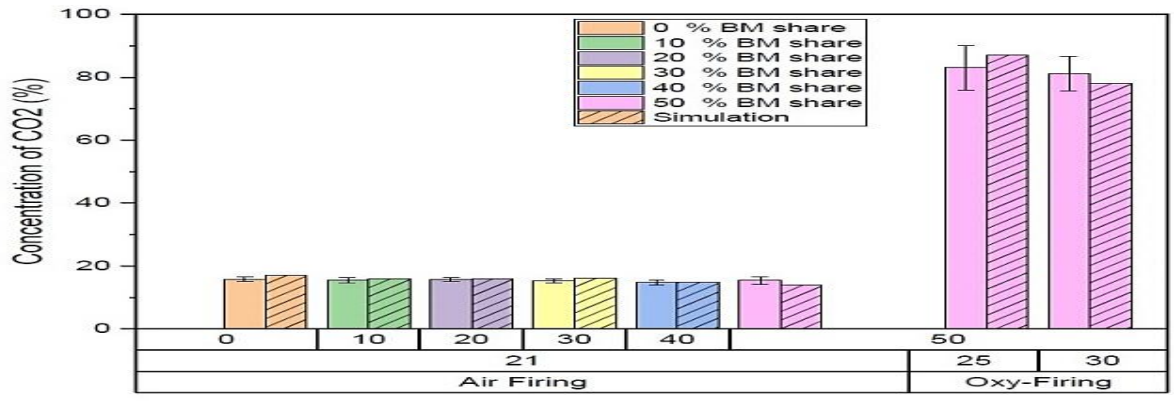

Fig. 3 Effect of Firing mode (Air/Oxy) and Oxygen concentration with Biomass fraction on CO2 at emission

It is observed that with the increase in the biomass fraction in the infeed for the co-firing along with the coal, the CO_2 (%vol) remains constant throughout the range of 15-17%. The lowest % concentration is about 14% with BM fraction from 0.3 to 0.4. In case of Oxy-firing condition, the CO_2 concentration is much higher than the Air-firing condition, because the CO_2 is recycled in the system and it carries the O_2 in fluidized bed.

CO Emission

Figure 5 indicate the sharp growth of the CO content in flue gas with increased biomass content in the blend fuel. This increase is attributed to the fact that the Biomass has a higher content of volatile gases in the riser, which contributes significantly to the CO concentration [40, 41]. Earlier literature (Khan et al. 2009) underlined that short freeboard and insufficient residence time are the reasons for high CO concentration during the operation on small-scale fluidized bed reactors. To optimize the CO emissions, it is recommended to design a FBRs with a long riser and supply extra oxygen as it was mentioned in the literature [42, 43].

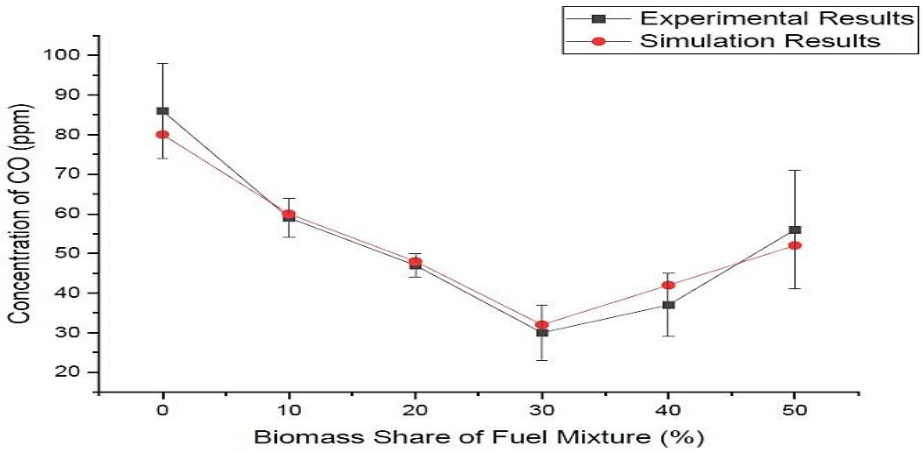

Fig. 4 Effect of Biomass fraction on CO concentration

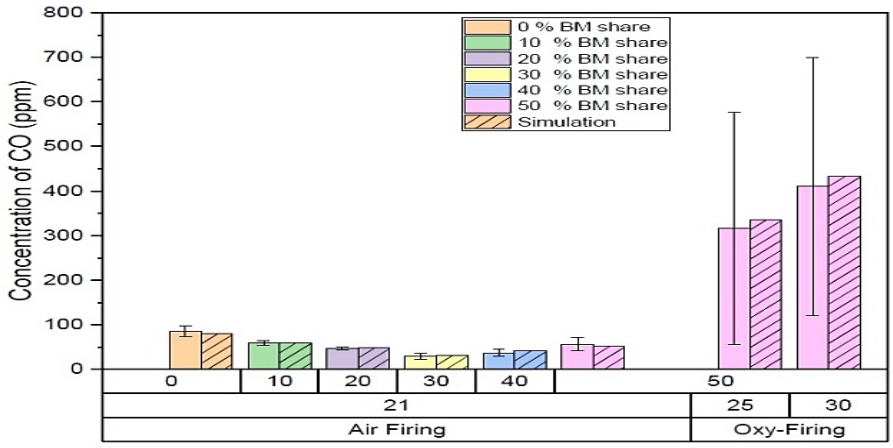

Fig. 5 Effect of Firing mode (Air/Oxy) and Oxygen concentration with Biomass fraction on CO at emission

It is also observed that the minimum CO level is achieved when the % sharing of biomass rage from 0.3 to 0.4. The minimum value of CO concentration is about <50ppm for Biomass sharing of 30%. This concentration is higher for Oxy-firing condition, but ultimately it results in to higher CO_2 conversion efficiency. It is noticeable that the minimum value of CO concentration is shifted to BM sharing 25%.

NO Emission

Figure 6 showed a slight increase of NO molar fraction, when the mass fraction of biomass extends in the blend fuel. The same behavior is detected with a temperature increase. However, after 1173 K in all analyzed

B/C ratios NO content starts to decrease. As stated in literature [43, 44, 45] the fluidized bed reactors typically operate at temperatures between 1073 and 1198 K, thus the formation of the thermal and/or prompt NO gases can be neglected. Hence, the fuel nitrogen is predominant for analyzed cases. The above-mentioned trend can be justified by the intensified formation of NH_3 and HCN (devolatilization stage) that depends on the volatile content in fuel and furnace temperature [46].

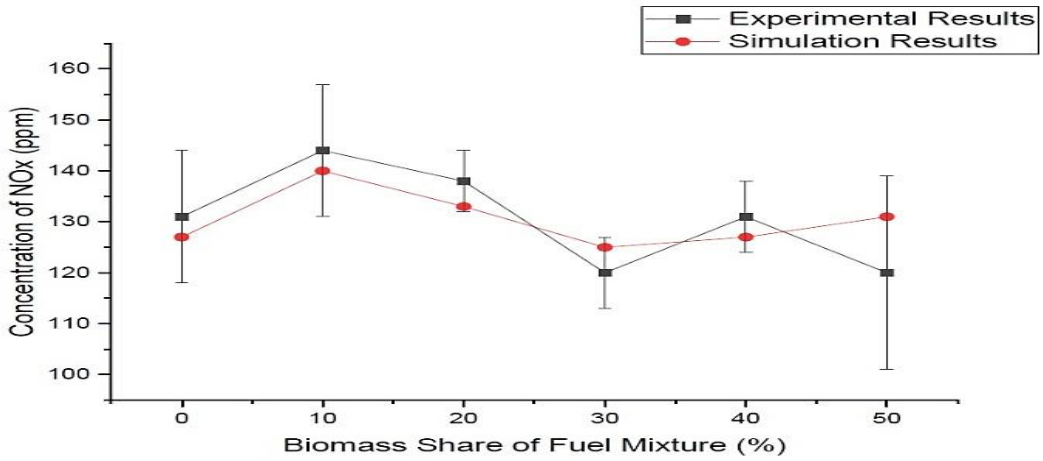

Fig. 6 Effect of Biomass fraction on NOx concentration

Further intensification of the combustion process is observed at higher furnace temperatures and subsequently, the radical production is increased resulting in higher conversion of fuel nitrogen in NO [47, 48, 49]. As the biomass contains more nitrogen as mentioned in the ultimate analysis, NO emission also increased along with the increase in % sharing of biomass, as represented in fig. 6. NO emissions were consistently between 100ppm and 150ppm irrespective of firing condition.

The optimal parameters for FBR can be proposed based on the sensitivity analysis results. In the selected range of temperature, the rate of CO decrease is faster than the rate of NO increase while the SO_2 concentration does not change significantly. Thus, it can be recommended to keep the optimal reactor temperature at 1148 K, because among the examined range, the lowest concentration of CO was observed despite the relatively high NO concentration. CO_2 and SO_2 emissions did not change significantly at the proposed FBR operating temperature. Moreover, the analysis of the flue gas composition at different blend fuel ratios demonstrated that at 1/3 and 1/1 biomass/coal ratios: (1) CO concentration is 26% and 60%, and (2) NO is 50% and 160% higher than in case when biomass presence not exceed 20% of total feed. Thus, for the FBR with abovementioned geometry, the optimal operation temperature is 1148 K while the recommended B/C ratio is 1/4.

IV.CONCLUSION

A versatile model has been established in Aspen Plus for co-combustion coal and biomass in a fluidized bed reactor. The flexibility of the model has been validated primarily using the recent experiments of co-combustion of Spanish lignite and biomass. The model has numerous novel features including (1) the composition of volatiles which was calculated using the theory of the functional-group dependence on the ultimate analysis for coal, (2) Adaptation of the FLUIDBED unit in Aspen plus to include hydrodynamics, which has often been neglected, along with the reaction kinetics, and (3) detailed kinetics of twelve reactions were used for the simulation of the combustion process during co-combustion. While the model works well in predicting the flue emissions, it needs to be further developed to account for heat transfer within the system. Evaluation of the heat generation and its dependence on the moisture content is an interesting field to explore further. Lastly, the sensitivity analysis presented on co-combustion of local biomass and Coal provides detailed guidelines for designing optimum experiments.

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