Sensitivity Analysis of Coal and Bagasse Co-Firing in an Integrated Gasification Combined Cycle Power Plant

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ABSTRACT: *Integrated Gasification Combined Cycle power plants generate electricity by utilizing the syngas obtained from the carbonaceous materials via gasification. These systems commonly use coal fuel; however, biomass fuels like bagasse could be a more environmentally friendly option. This study was aimed at analyzing the effects of varying operating parameters (such as temperature, pressure,* O_2*/fuel, and water/fuel ratios), and fuel feedstocks (i.e., coal, bagasse, and coal-bagasse co-firing) on the syngas composition. Based on the data obtained from a commercial power plant, an equilibrium model was developed and validated using the Aspen Plus® software. Sensitivity analysis was carried out by varying the considered operating parameters and selected fuel feedstocks. The results of this study have manifested that low temperatures, low* O_2*/fuel ratio, and high water/fuel ratio produce syngas with a comparatively higher* H_2*/CO ratio. The highest* H_2*/CO ratios of 1.16, 0.99, and 0.84, were obtained for bagasse, co-firing, and coal, respectively at operating parameters of 1200°C temperature, 0.5* O_2*/fuel, and 0.6 water/fuel ratios. Furthermore, bagasse and co-firing of coal-bagasse feedstocks could provide a better quality of syngas as compared to that of coal feedstock. The results of this study would also help to operate the Integrated Gasification Combined Cycle plants at optimum performance by utilizing different fuels and by appropriately adjusting the operating parameters.*

KEYWORDS: *Coal; Bagasse; Aspen Plus®; Sensitivity Analysis; Gasification.*

INTRODUCTION

In order to utilize coal more efficiently, the process of gasification has emerged as a potential substitute for direct combustion to reduce airborne emissions and net station heat rates. Moreover, gasification has gained interest in power production due to the intrinsic potential feature of CO_2 removal — practiced at large scales in the ammonia industry — via pre-combustion at reasonably low rates [1]. On the other hand, gasification of biomass is considered

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one of the most promising routes — due to the potential for higher efficiency cycles — to produce syngas and/or combined heat and power generation [2]. However, a comparative assessment should be conducted to analyze the effects of co-firing the fossil fuels (i.e., coal), and biomass (i.e., bagasse) on the quality of syngas in an integrated gasification combined cycle power plant.

As compared to solid fuels, the gaseous fuels are considered more efficient, versatile, controllable, and environmentally friendly; furthermore, the combustion units are also relatively simple. In gasification, the carbonaceous materials (e.g., coal or biomass such as bagasse) is converted to the gaseous product (i.e., syngas, also known as producer gas, product gas, synthetic gas, or synthesis gas) with the help of gasifying agents. One of the prime objectives of this entire process is to convert the entire non-ash feed to syngas while conserving the heat of combustion value of the feedstock [3]. The syngas is mainly composed of CO, H_2, N_2, CO_2, and hydrocarbons (e.g., CH_4, C_2H_4, and C_2H_6, etc.); and it may also include traces of H_2S, NH_3, and tar. Depending upon the gasifying agents used in the process, biomass gasification can further be classified as air gasification, oxygen gasification, steam gasification, carbon dioxide gasification, and supercritical water gasification, etc. [4].

In Integrated Gasification Combined Cycle (IGCC) systems, solid fuel is gasified, and the gas is cooled and then cleaned. The cleaned syngas is fired in a combustion turbine and the exhaust gas from the combustion turbine is used in a Heat Recovery Steam Generator (HRSG). The steam from HRSG is used to produce additional electricity through the steam turbine. The IGCC systems have emission levels comparable to natural gas-fired combined cycle systems and show better environmental performance than direct burning of liquid and solid fuels in power plants by lowering SOx, NOx, and dust emissions. They also discharge 30% less wastewater than conventional coal-fired power plants. Moreover, they are economical, consuming far less amount of water in treating a high pressure and low volume flue gas. IGCC power plants can reduce CO_2 emissions by approximately 15% as compared to conventional coal-fired power plants [5]. The flexibility of feedstock and supply of commercial by-products (such as gasification slag and elemental sulfur) makes IGCC a competitive substitute among other power-producing technologies [6]. Coal gasification in IGCC power plants has already been developed and many plants are being operated successfully on a commercial scale around the globe [4].

The GE Energy gasification process is one of the foremost names in coal gasification processes for IGCC power generation applications. In this process, the coal feed is crushed and turned into slurry in wet rod mills. The slurry water consists of recycled condensate coming from raw gas cooling along with makeup water. The coal-water slurry is pumped into the gasifier burner in the presence of oxygen. At temperatures greater than 1260°C, the coal is rapidly converted to H_2, CO, and CO_2 *via* gasification [7].

To evaluate the economics and quality of syngas, there are two significant parameters: fuel reactivity and the H_2/CO ratio. Power plants generally require H_2/CO ratios in the range of around 1.5 to 2 for good quality syngas [8]. Some other value-added chemicals may also require almost the same range (i.e., H_2/CO ratio of 1 to 2). However, syngas produced in IGCC plants has a much lower H_2/CO ratio owing to the high pressure and temperature. To enrich the H_2 content and remove impurities, the gas — before entering the combustion turbine to generate electricity — is passed through water-gas-shift reaction and other processes. Thus, the capital and operational costs of the plant can be reduced by using the feedstocks producing higher H_2/CO ratio syngas.

Bagasse, a byproduct of sugarcane, is considered as a promising source of renewable energy worldwide [9]. According to estimates, 1 tonne of crushed sugarcane produces around 0.3 tones of bagasse [10]. Sugarcane producing countries like Brazil, India, Thailand, Reunion Island, Mauritius, and Pakistan have established highly successful energy projects using the co-firing of bagasse [11]. The utilization of sugarcane bagasse for power generation offers a sustainable, cost-effective, competitive, and profitable renewable energy option [12]. This could help to achieve highly desirable environmental goals by providing an environmentally friendly source of energy.

The biomass fuels are considered to reduce the greenhouse gas emission because the biogenic CO_2 from their burning is considered to have been absorbed from the atmosphere during the growth of plants from which they are produced. Coal and biomass co-firing power plants are gaining attention around the world as they offer a short-term solution for keeping greenhouse gas emissions within acceptable levels [13]. A coal-fired power plant with an integrated biomass co-firing produces lesser net CO_2 emissions than a conventional power plant [14].

For instance, *Restrepo* and *Bazzo* [15] developed an exergo-environmental analysis scheme to compare global warming impact of burning only coal with coal-rice straw (i.e., biomass) co-firing schemes. The result indicated that co-firing would reduce the impact value by around 25% than that of only coal. Another study conducted by *Chen et al.* [16] reported that the best coal-bagasse blend to be used as a fuel is 80/20 by weight.

To design an optimum and efficient gasification process, mathematical modelling and simulation studies are very important [17]. Several researchers have designed models based on coal and biomass gasification systems and have simulated them for parametric studies. For instance, *Akhlas et al.* [18] performed a simulation of steam gasification of coal with pre-combustion that enabled cleaner coal combustion. *Saha et al.* [19] worked on modelling and simulation of gasification of cow manure using the R-Gibbs model in Aspen Plus® based on minimization of Gibbs free energy. Another study conducted by *Uddin et al.* [20] also used the Aspen Plus® software to evaluate the feasibility of the operation and the effects of different operating parameters, such as temperature and pressure, on the working and performance of a gasifier. They employed pine sawdust biomass as a feedstock in their study. Recently, several studies have been reported on the simulation of biomass gasification process using the Aspen Plus® software [21]. Additionally, economic analysis of biomass IGCC power plants and economy-based comparison between lignite and biomass IGCC power plants have also been carried out in another previous study [22].

Tupsakhare et al. [23] investigated the impacts on gasification performance and applications of liquid CO_2 as a slurry fluid for solid carbon feedstock (coal and biomass sludge) in an IGCC plant using Aspen Plus® simulations. From the obtained results, it was revealed that co-feeding CO_2 into the gasifier yields higher cold gas efficiency. The two cases (in which CO_2 was added) showed cold gas efficiency values of 83.22 and 81.13%; however, the baseline cold gas efficiency using steam gasification (with no CO_2) was only 78.46%. With the addition of 30% CO_2 at 1000 °C, the carbon conversion in the process increased from ~50% to ~68%.

In another study conducted by *Niu et al.* [24], the performance of biomass gasification and power generation under various operating conditions was evaluated using Aspen Plus®. In this study, the considered parameters included oxygen percentage of enriched air, gasification temperature, compressor pressure ratio, and excess air ratio. It was revealed that the syngas quality and gasification efficiency could be improved by increasing the oxygen percentage of the enriched air. In an IGCC, the maximum fuel utilization efficiency could be obtained at an oxygen percentage of enriched air of 40%. To maintain the designed gas turbine inlet temperature for efficient IGCC operation, the excess air ratio should be below 3.5.

Ge et al. [25] designed a new system by integrating biomass-based IGCC with chemical looping gasification for power generation which included biomass gasification, gas cleaning, heat recovery steam generator, and gas/steam turbine. The simulation was carried out using Aspen Plus® software. In this simulation, 860 °C was proved to be an optimal gasification temperature and 1.0 was the most suitable steam-to-biomass ratio, where the power efficiency was relatively higher. The overall power efficiency of the designed plant was 33.51%.

Two process models were developed and analyzed by *Ahmed et al.* [26] in Aspen Plus® software. The conventional IGCC process was compared with the integrated reforming model (with the gasification unit) to enhance the syngas yield. It was observed that integrated reforming model can increase the process performance by 4.77% and reduce the cost of electricity by 5.9% compared to the conventional process.

A proposed configuration of the integrated combined cycle power plant was analyzed by *Parvez* and *Khan* [27]. The performance of the system was examined associated with various components and operating variables (e.g., change in biomass materials, gas inlet temperature to heat recovery steam generator, and steam turbine pressure, etc.). The exergy loss was found to be maximum in the combustion chamber of the cycle followed by gasifier, heat recovery steam generator, gas turbine, and steam turbine, respectively. Furthermore, during the analysis, solid waste was proved to be a better option than bagasse.

Therefore, this study is aimed at providing a comparative overview of the syngas composition comprehensively by varying the operating parameters and fuel feedstocks. This work is unique as it used the real time high pressure IGCC power plant data for validation of the gasification model. Also, as compared to the previous similar studies, this study focuses on the quality of syngas produced specifically by co-firing low-rank coal and sugarcane bagasse. This could help the designers and engineers to design and operate their IGCC power plants

Table 1: Input data from ELCOGAS IGCC power plant [28]

Parameter	Value
Feed (t/day)	2600
O_2/ Feed ratio	0.71
O_2 (t/day)	1859
H_2O/feed ratio	0.13
H_2O (t/day)	338
Gasifier temperature (°C)	1600
Gasifier pressure (bar)	25

Table 2: Proximate, ultimate & sulfur analysis of coal

Proximate Analysis (on dry basis)	
Components	Value (%)
Volatile matter	17.66
Fixed carbon	56.66
Ashes	25.68
Ultimate Analysis	
Components	Value (%)
Carbon	62.94
Nitrogen	3.53
Hydrogen	2.99
Chlorine	0
Sulfur	3.41
Oxygen	1.45
Ash	25.68
Sulfur Analysis	
Component	Value (%)
Pyritic	1.57
Sulfate	0.26
Organic	1.57

at optimum parametric conditions for environmentally friendly operations and produce higher quality syngas. It will be equally valid for both the coal and bagasse-based plants, to adjust the parameters or blend the respective fuels in the plant. Additionally, the ranges of parameters such as temperature, pressure, and feed ratios, etc., contemplated in this study are considerably high which makes the results robust for the high-pressure power plants.

EXPERIMENTAL SECTION

In this study, the operating data were taken from the ELCOGAS IGCC Power Plant in Madrid, Spain. The data from the power plant is shown in Table 1.

The proximate, ultimate, and sulfur analysis of coal used in the IGCC power plant are shown in Table 2 [28].

Table 3: Proximate and ultimate analysis of bagasse

Proximate Analysis (on dry basis)	
Components	Value (%)
Volatile matter	82.19
Fixed carbon	12.41
Ashes	5.41
Ultimate Analysis	
Components	Value (%)
Carbon	43.07
Nitrogen	1.41
Hydrogen	6.6
Sulfur	0.16
Oxygen	43.31
Ash	5.41

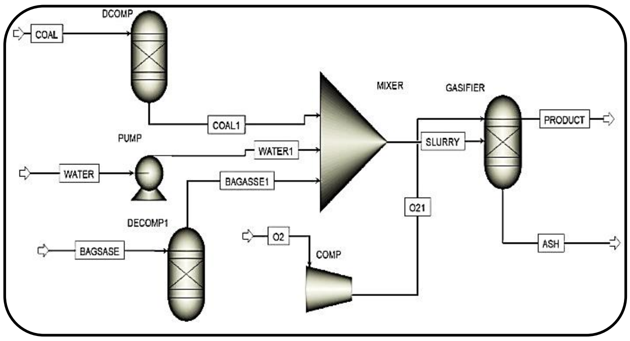

Fig. 1: Process flow diagram for coal and bagasse co-firing in Aspen Plus®

Likewise, the proximate and ultimate analysis of bagasse added in the simulation after model validation are shown in Table 3 [29].

Model description

The assumptions made in this study while performing the simulation are given as follows [30]:

- The gasification process is carried out at steady state.
- There is perfect mixing and uniform temperature distribution in the gasifier.
- Devolatilization takes place instantaneously and the products include H_2, CO, and CO_2 with negligible by-products.
- The process is isothermal and isochoric.
- Tar and char formation are negligible and ignored in the simulation.

Aspen Plus® simulation model for coal, bagasse, and co-firing are shown in Figure 1.

Hydrocarbon systems with gases such as CO_2, N_2, and H_2S are usually modelled using equations of state.

Table 4: Description of blocks used in the simulation

Unit	Aspen Plus® model	Description
DCOMP	RYield	Simulates fuel decomposition based on elemental analysis
DCOMP1	RYield	Simulates fuel decomposition based on elemental analysis
PUMP	Pump	Increases pressure of water and pumps it to the mixer
COMP	Compressor	Increases pressure of O_2/air and sends it to the gasifier
MIXER	Mixer	Mixes fuel and water
GASIFIER	RGibbs	Simulates equilibrium reactions of gasification

For the present analysis, the Peng-Robinson equation of state was used for the simulation as it is recommended for gas-processing, petrochemical, and refinery processes [18, 28]. For Non-Conventional solid components, density and enthalpy were also calculated. Furthermore, HCOALGEN and the DCOALIGT models were used to calculate the enthalpy and density of coal and ash. Details of models used in Aspen Plus® are provided in Table 4.

Carbon was added as a solid component while ash and coal as NC components. Ash in the feed remains unconverted and is shown as the bottom product from gasifier. However, in IGCC plants, ash is mostly removed as slag for slagging gasifiers or partly as dry bottom ash for non-slagging gasifiers. The remaining ash and char are entrained in syngas and removed using wet scrubbing, cyclones, candle filters or combinations of these. Heat in the gasifier liquefies the ash. The molten ash is then quenched and crushed at the bottom of the gasifiers before being dewatered for disposal. Centrifugal pump was used to increase the pressure of water. The models were simulated with isentropic efficiencies ranging from 0.850 to 0.869 and the mechanical efficiency ranging from 0.98 to 1. Pump efficiency was assumed as 0.9 and driver efficiency as 0.98. The compressor was used to compress oxygen at a pressure of 10 bar to the reactor pressure of 25 bar. The Yield Reactor (R-Yield model) was used as a decomposer. Coal was fed to the decomposer and the products were distributed according to elemental analysis. RGibbs reactor is used for multiphase chemical equilibrium based on Gibbs free minimization energy. Main gasification reactions taking place in the gasifier along with their heat contents are as follows [31]:

$$\mathrm{C(s)} + \mathrm{O_2(g)} \leftrightarrow \mathrm{CO_2(g)} \quad \Delta\mathrm{H} = -393.98\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{1}$$

Table 5: Operating parameters in the simulation model

Feed	Flow rate (tones/day)	2600
	Temperature (°C)	25
	Pressure (bar)	1
Water	Flow rate (tones/day)	338
	Temperature (°C)	25
	Pressure (bar)	1
O_2	Flow rate (tones/day)	1859
	Temperature (°C)	25
	Pressure (bar)	1
Pump	Isentropic efficiency	0.85-0.87
	Mechanical efficiency	0.98-1
	Driver efficiency	0.98
	Pressure (bar)	1
Compressor	Isentropic efficiency	0.85
	Mechanical efficiency	0.98
	Pressure (bar)	25
Decomposer	Temperature (°C)	25
	Pressure (bar)	1
Gasifier	Temperature (°C)	1600
	Pressure (bar)	25

$$\mathrm{C(s)} + \mathrm{CO_2(g)} \leftrightarrow 2\mathrm{CO\ (g)} \quad \Delta\mathrm{H} = 172.5\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{2}$$

$$\mathrm{C(s)} + \mathrm{H_2O(g)} \leftrightarrow \mathrm{CO\ (g)} + \mathrm{H_2(g)} \ \Delta\mathrm{H} = 131\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{3}$$

$$\mathrm{CO(g)}+\mathrm{H_2O(g)}\leftrightarrow\mathrm{CO_2(g)}+\mathrm{H_2(g)} \ \Delta\mathrm{H}=-41\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{4}$$

$$\mathrm{C(s)}+2\mathrm{H_2O(g)}\leftrightarrow\mathrm{CO_2(g)}+2\mathrm{H_2(g)} \ \Delta\mathrm{H}=90.2\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{5}$$

$$\mathrm{C(s)} + 2\mathrm{H_2(g)} \leftrightarrow \mathrm{CH_4} \qquad \Delta\mathrm{H} = -75\,\frac{\mathrm{kJ}}{\mathrm{gmole}} \tag{6}$$

Syngas composition was calculated assuming that chemical equilibrium goes to completion. Operating parameters in the model are shown in Table 5. The composition yield for both coal and bagasse in the RYield decomposer and the product composition of the gasifier are shown in Tables 6 and 7, respectively.

After validating the model, a parametric study was carried out with coal, bagasse, and co-firing of coal-bagasse in equal percentage by weight.

Model validation

The model was validated by comparing the predicted syngas composition by the model with experimental results.

Table 6: Composition yield of coal and bagasse in the RYield reactors

Component	Composition of coal (Mass basis)	Composition of bagasse (Mass basis)
Carbon	0.6168	0.4264
Ash	0.2517	0.0529
Hydrogen	0.0293	0.0653
Nitrogen	0.0346	0.0139
Oxygen	0.0142	0.4287
Sulfur	0.0334	0.00158
Water	0.02	0.01

Table 7: Product composition of the gasifier

Gas Composition	Mass Flowrates (lb/hr)	Mass percent
CO	336300	76.3
H_2	9714	2.2
CO_2	10112.8	2.29
Others	24414	5.5
Ash	60107.2	13.64

The mean error was calculated by taking square root of the mean-root-sum-squared value described in a previous work [32]. The comparison is shown in Table 8.

The simulation results are in reasonably good agreement with the plant data as indicated by the low mean error. However, the percentage error in H_2 concentration is high. In a similar simulation study on gasification of palm kernel shell, percentage errors of 25% and 27% for CH_4 and CO_2, respectively, were observed [30]. The difference may be caused by a combined effect of several simplifications that this model relies on, such as the gasification process is at steady-state conditions, the reaction occurs isothermally and at constant volume, etc.

RESULTS AND DISCUSSION

After the validation of the model, a sensitivity analysis was performed in Aspen Plus® by varying temperature, pressure, O_2/feed, and water/feed ratios using the coal, bagasse, and co-firing of coal-bagasse. The model analysis tool in Aspen Plus® was used to perform a sensitivity analysis. Ratio of 1:1 for coal and bagasse mixture was selected for the sensitivity analysis.

Effect of temperature

The temperature was varied from 1200-1600°C keeping the other parameters constant and its effect on syngas composition was analyzed. It was found that the production of approximately 7 MJ/kg syngas energy will require almost 0.053-0.074 MJ/kg of energy to raise the temperature of gasifier feed to 1200-1600°C. Operating gasifier at lower temperatures can lead to tar formation whereas at higher temperatures there is a high possibility of slag formation. The temperature range is also dependent on the gasifier design. Since the base value of temperature in validated model is 1600°C, the temperature range 1200-1600°C was selected as a reasonable operating temperature range in IGCC power plants [33].

Table 8: Comparison of plant and simulation data

Gas Composition	Actual plant results (Volume %)	Simulation Results (Volume %)	Mean Error
H_2	21.11	27.9	0.17
CO	62.06	65.9	
CO_2	1.43	1.15	
Others	15.41	5	

The results of the simulation are shown in Figure 2. In the case of coal, H_2 concentration increases slightly with an increase in temperature while in the case of bagasse and co-firing, it decreases. The average molar composition of H_2 for coal, bagasse, and co-firing was 0.28, 0.16, and 0.24, respectively. CO concentration was higher than H_2 concentration for all feedstocks with average molar composition reported as 0.68, 0.28 and 0.48 for coal, bagasse, and co-firing, respectively. These results agree with Le Chatelier's principle which says that an increase in temperature should increase the concentration of CO in the syngas. H_2/CO ratio for coal remains almost constant in the entire temperature range but decreases for bagasse and co-firing. The difference in H_2/CO ratio between bagasse and coal goes from 0.24 at 1200°C to 0.08 at 1600°C. In the temperature range of 1200-1600°C, H_2/CO ratio for bagasse and co-firing is significantly higher than for coal. Coal is thermally more stable than bagasse because of its complex cross-link structure and as a result undergoes relatively fewer composition changes. Since bagasse has a higher volatile content than coal, it has a lower gasification temperature. As temperature increases, H_2 decreases and CO increases reducing the H_2/CO ratio as is evident from Figure 2.

Since the ELCOGAS plant operates at 1600°C, using bagasse instead of coal can produce syngas having H_2/CO ratio of 0.5 as compared to 0.41 for coal.

Effect of pressure

The effect of pressure on H_2/CO ratio is an important

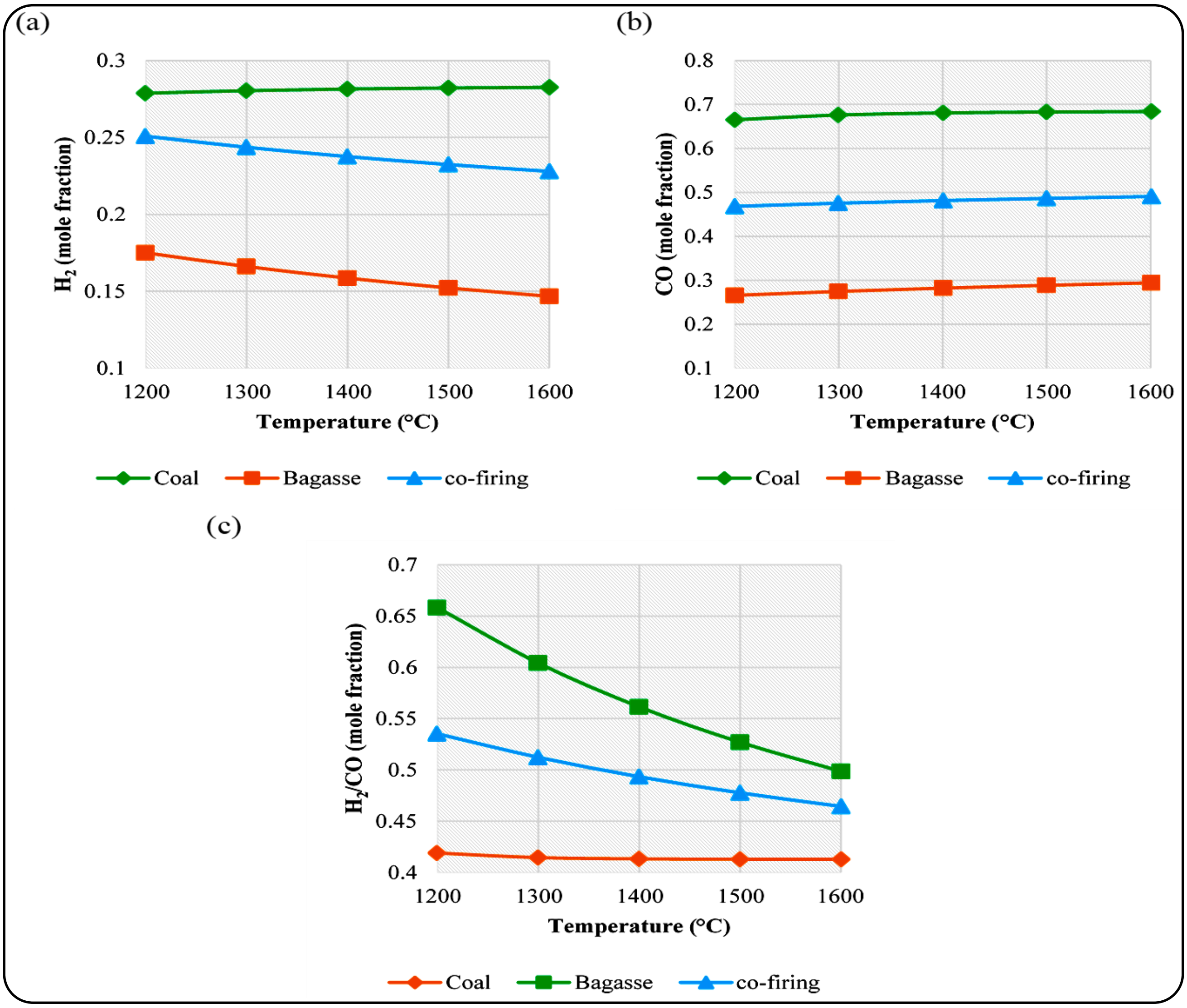

Fig. 2: Effect of temperature on syngas composition (a) H_2 (b) CO (c) H_2/CO (P=25 bar, O_2/fuel=0.71, water/fuel=0.13)

parameter with regards to gasifier design. To investigate the effect of pressure, it was varied from 20 to 110 bar, and the compositions of CO, CO_2, and H_2 were analyzed. There are IGCC plants already operating at this pressure, for instance, an IGCC plant is operating up to 100 bar in Malaysia [34]. The energy required to increase the pressure to 110 bar is 6 MJ/kg. Since the syngas energy produced is higher, the process remains viable at the highest pressure investigated in the study. Other parameters such as temperature, airflow rate, and water flow rate were kept constant. The resulting graph is shown in Figure 3.

The results show that higher pressures can affect the syngas composition. H_2 and CO compositions significantly dropped going from 20 bar to 110 bar pressures. These results once again comply with Le Chatelier's principle that increase in pressure reduces H_2 and CO since maximum extraction of H_2 takes places at atmospheric pressure [34]. Ultimately, the change in pressure will also change the H_2/CO ratio, and it is in the order of bagasse >s co-firing > coal with molar ratio values range between 3.6 to 4.2 for bagasse, 3.3 to 3.8 for co-firing, and 2.9 to 3.3 for coal, respectively. The result is expected as the concentration of biomass is directly proportional to H_2 production.

Effect of O_2/fuel ratio

The O_2/fuel ratio was changed in the range of 0.5-1 by changing the air flow rate between 1300-2600 tones/day. The results are shown in Figure 4. The results show that as the ratio increases, the amounts of CO and H_2 decrease which is due to the complete combustion because of excess

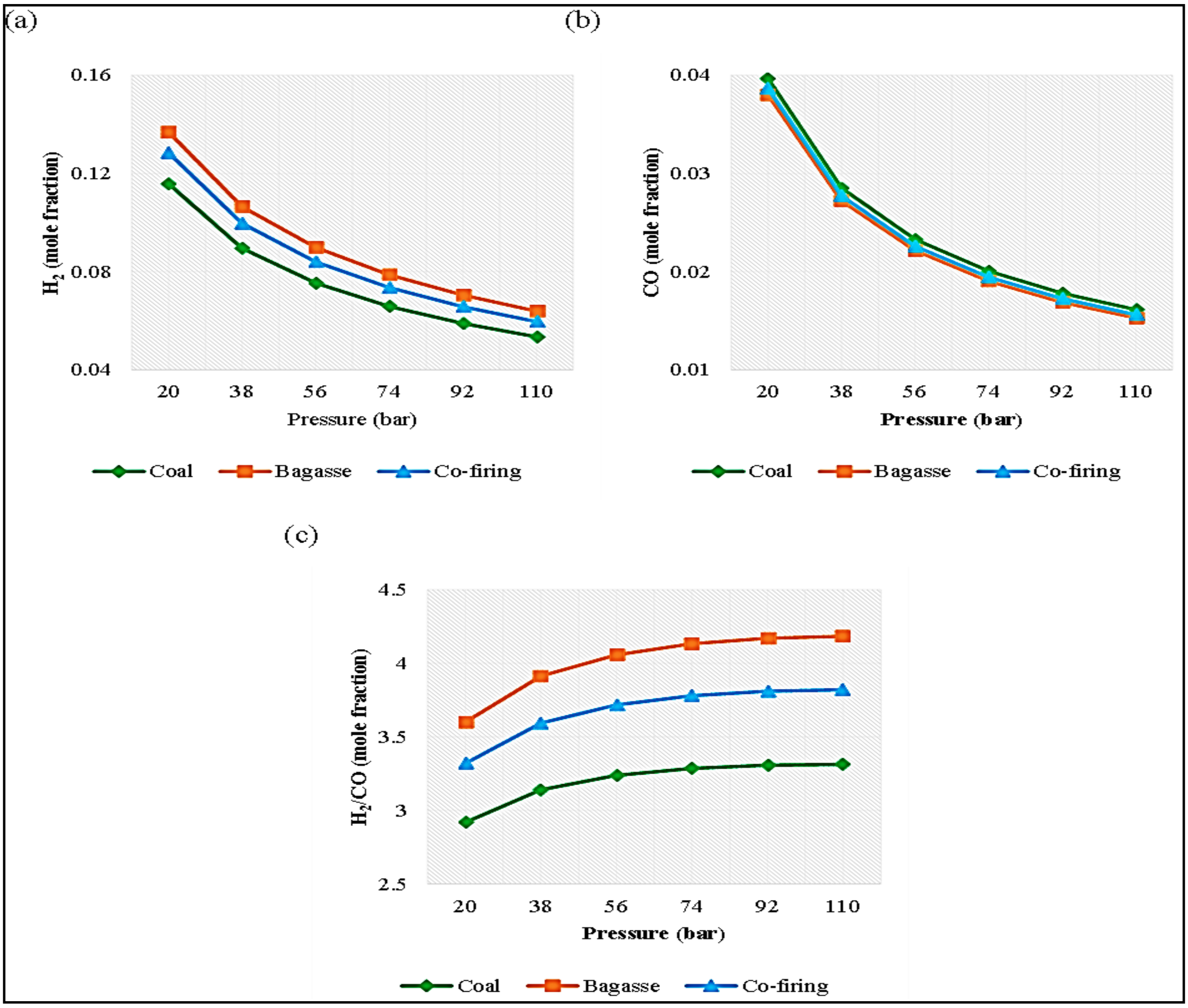

Fig. 3: Effect of pressure on syngas composition (a) H_2 (b) CO (c) H_2/CO (T=1600 °C, O_2/fuel=0.71, water/fuel=0.13)

air. CO concentration for coal increases with O_2/fuel ratio from 0.5-0.7 but then starts decreasing at higher ratios as the quantity of O_2 supplied becomes sufficient to bring about complete combustion resulting in production of CO_2 instead of CO. Comparatively, H_2 and CO produced were much lower for bagasse than coal with a higher CO_2 concentration at various O_2/fuel ratios due to lower carbon content in bagasse as compared to coal. The H_2/CO ratio showed a decreasing trend with O_2/fuel ratio for the three feedstocks considered, with higher values for bagasse followed by co-firing and coal, respectively.

For the O_2/fuel ratio range studied, average H_2/CO ratios were 0.42, 0.49, and 0.46 for coal, bagasse, and co-firing, respectively. From the results, a low O_2/fuel ratio is recommended for better gasification performance.

Effect of water/fuel ratio

In this analysis, the effect of water to coal ratio was also investigated by changing the ratio in the range of 0.1-0.6 by keeping the water flow rate between 260-1560 tones/day as shown in Figure 5.

The results showed that the formation of H_2 increases in the beginning for coal with an increase in water flow rate up to 0.4 and then starts to decrease. For co-firing, H_2 concentration slightly decreases, whereas it remains constant throughout for bagasse. CO concentration decreases for all the fuels tested with the highest values for coal and lowest for bagasse. Consequently, H_2/CO ratio increases linearly with steam/fuel ratio. This is due to water-shift in the gas reaction (4). At a lower value of steam/biomass ratio, there was less steam present to react

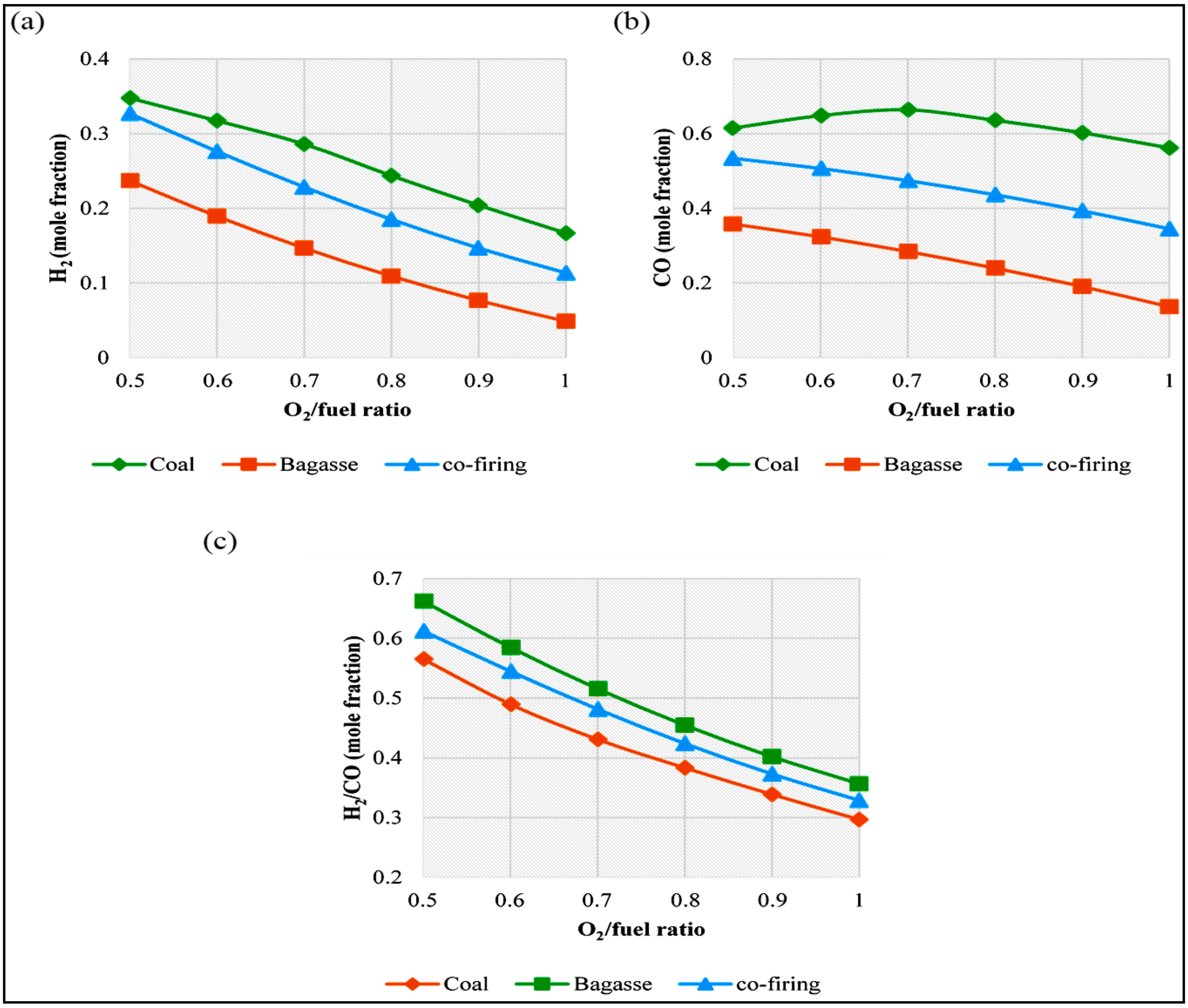

Fig. 4: Effect of O_2/fuel ratio on syngas composition (a) H_2 (b) CO (c) H_2/CO (P=25 bar, T=1600 °C, water/fuel=0.13)

with the coal. Subsequently, it terminates water-gas shift reaction. However, at high values, the water-gas shift reaction occurs which results in the higher formation of H_2.

The previous studies have found that as the water flow rate increases, the formation of CO_2 and H_2 also increases, while that of CO decreases [36, 37]. However, these simulations were conducted at lower temperatures. At very high temperature, H_2 concentration does not increase much. Fig. 5 (c) shows a direct relationship between water/fuel and H_2/CO ratio for the three feedstock types in the order as bagasse>co-firing>coal. Therefore, for higher H_2/CO ratio, higher water/fuel ratio is recommended.

Overall results

It is obvious from previous results that low temperature, low O_2/fuel ratio, and high water/fuel ratio produce syngas having higher H_2/CO ratio. Therefore, to optimize the performance of IGCC power plants for the concerned feedstocks, overall results have been compiled within the range of 1200-1600°C, O_2/fuel ratio within 0.5-0.6, and water/fuel ratio 0.5-0.6 as shown in Figure 6. The H_2/CO ratios have been represented for each fuel (i.e., coal, bagasse, and their co-firing) considering the varying parameters as mentioned above. Results have shown that on all the parametric conditions, the highest H_2/CO ratio was obtained for bagasse followed by co-firing and coal fuels, respectively. Higher H_2/CO ratios for coal, bagasse, and co-firing feedstocks (i.e., 0.84, 1.16, and 0.99, respectively) were obtained at 1200°C temperature, 0.5 O_2/fuel, and 0.6 water/fuel ratio.

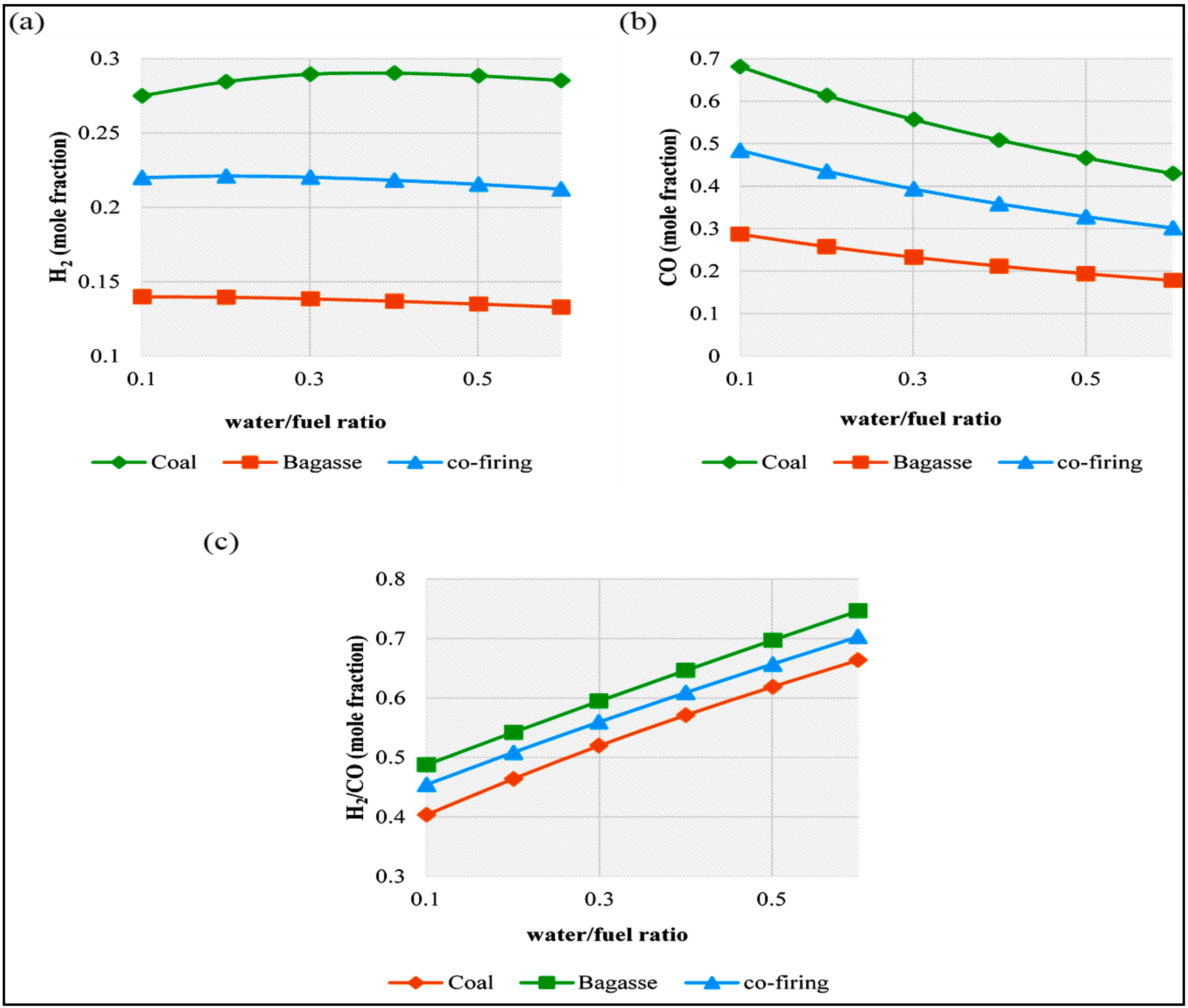

Fig. 5: Effect of water/fuel ratio on syngas composition (a) H_2 (b) CO (c) H_2/CO (P=25 bar, T=1600 °C, O_2/fuel=0.71)

CONCLUSIONS

In this study, a comparative assessment was carried out to analyze the quality of syngas used in an IGCC Power Plant for electricity generation by using coal, bagasse and coal-bagasse as a feedstock. For this analysis, the data used to develop an equilibrium model in Aspen Plus® software were taken from a commercial power plant. Then, the validated model was used to compare the quality of syngas produced from coal, bagasse, and coal-bagasse co-firing by changing various parameters (such as temperature, pressure, O_2/fuel and water/fuel ratio). Finally, H_2/CO ratios were calculated at optimized parameters for the three selected feedstocks. The simulation results revealed that lower temperature, higher O_2/fuel, and water/fuel ratio can produce syngas having a higher H_2/CO ratio for the three studied feedstocks. Highest H_2/CO ratios of 0.84, 1.16 and 0.99 were obtained for coal, bagasse, and co-firing, respectively at 1200°C temperature, with 0.5 O_2/fuel and 0.6 water/fuel ratio. From the obtained results, it can be concluded that higher H_2/CO ratio can be obtained using bagasse or coal-bagasse co-firing as compared to coal which can save cost for purifying the product gas before its use as a fuel in turbines. Furthermore, the study would also be helpful to operate the plants at optimum performance by adjusting the various parameters and by utilizing different fuels. In the future, a sensitivity analysis can also be conducted for various biomass other than bagasse (such as wheat straw, corn cob, rice husk, etc.) by following a similar model. The linking of process optimized constraints with the economics evaluation is

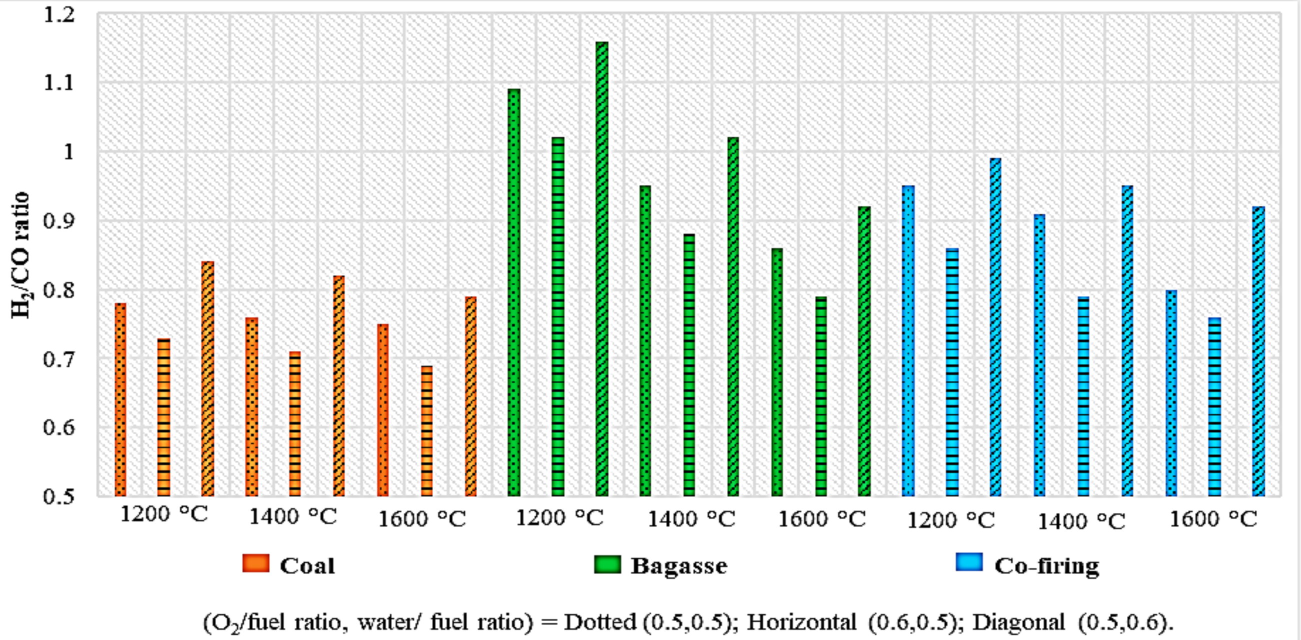

Fig. 6: Overall results at optimized parameters for the studied feedstocks

important, therefore, an economics assessment is suggested to be conducted in the future. Furthermore, for a highly efficient process, a techno-economic analysis of the system should also be performed using Aspen Plus® or similar software by optimizing the operating parameters.

The overall mass balance is provided in the appendix.

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