Reduction of emission gas concentration from coal based thermal power plant using full combustion and partial oxidation system

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ABSTRACT

Rapid growth in industrialization has led to high dependency on reliable electric power source for its operation. On the contrary, thermal power plants expel pollutants consisting of hazardous gases that result in degradation of environment and ecosystem. Thus, utmost importance is to generate clean and efficient energy from power plant. This current article resolves the problem of sustainable power production using coal-based thermal power plants, by integrating gasification technologies to the system. The performance of thermal power plant in terms of emission is numerically analysed with varying gasifier pressure, air-fuel ratio, steam-fuel ratio, and flue gas-fuel ratio. Numerical simulation of the gasification cycle with varying parameters is carried out using MATLAB. Optimum performance at a gasifier pressure of 2 bar and a steam-fuel ratio of 0.25 was observed with relative air-fuel of 0.075. With increasing flue gas-fuel ratio from 0.25 to 1.00, although the mole fractions of components of syngas do not differ much, the heating value and cold-gas efficiency of syngas produced decrease for each fuel. Considering the emissions, simulated results present co-gasification as a better option over conventional systems. A reduction of two-thirds in kg of CO_2 released per kg of fuel was observed with almost three-fourth decrement in kg of CO_2 per kWh of power produced. Also, zero SO_x and NO_x emissions were observed compared to coal based thermal power plants. An optimum performance of gasification system at gasifier pressure of 2 bar, air-fuel ratio of 0.1, steam-fuel ratio of 0.25, and flue gas-fuel ratio of 1.00 is noticed. The proposed cycle is proven to be suitable for further research and its application to coal based thermal power plants, providing potential towards supplementary power generation and cleaner exhaust. This research would also significantly contribute to achieving sustainable development goals.

Keywords: emission; flue-gas; gasification; steam-fuel ratio; temperature.

NOMENCLATURE

a, b, d, f, g, h, k   coefficients

h specific enthalpy, kJ/kg mol

K dissociation constant

M mass flow, kg/s

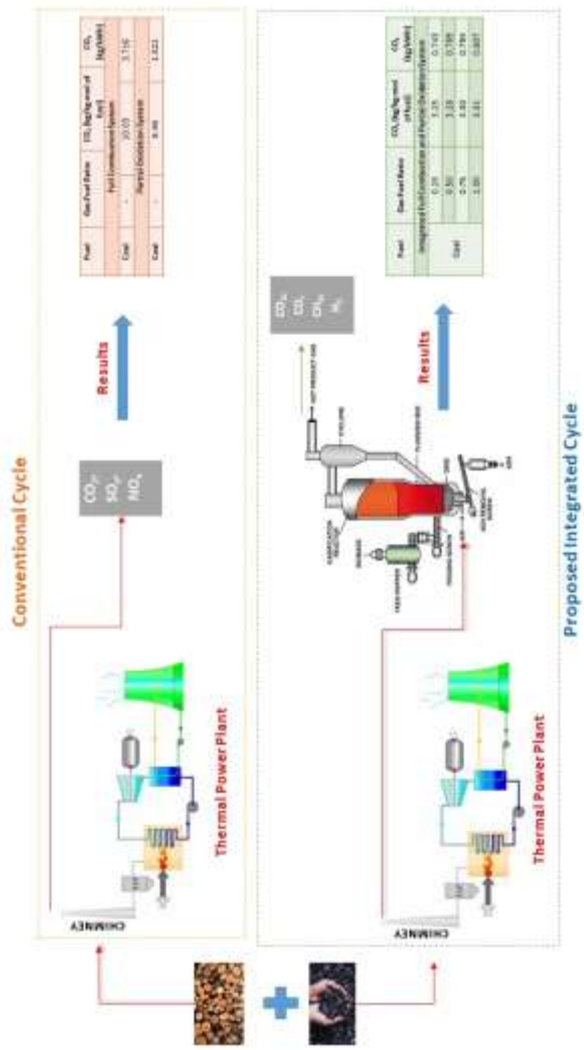
T temperature, K

P gasifier pressure

R universal gas constant

ΔG^o Gibb's free energy (kJ/kg-mol)

GRAPHICAL ABSTRACT



INTRODUCTION

Growth in population and industrialization has led to high demand of electric power. Especially in few parts of the world, in order to bridge the gap between demand and supply of energy, increasing trends towards utilization of renewable energy are noted. Such renewable sources of power include solar energy, wind energy, and biomass energy. However, the intermittent nature of supply for solar energy is one of the major disadvantages. Thus, electricity from fossil fuelled power plants has been the key source of energy and power for most of the developing countries like India. The Indian power sector is caught between the pressure of adding new generating capacities to match the rapid growing demand of power and the environmental challenges encompassing power generation itself. And the coal based power generation will continue to dominate its role in future till the time when other energy sources have not yet succeeded to take its place.

On the other hand, gasification process offers more scope for recovering products from waste than incineration. Gasification can meet concerns of global warming and aid in pollution control, multi-fuel capacity, and energy conservation to achieve sustainable progression (Rezaiyan et al., 2005). Research analysis for both gasification and co-gasification of biomass waste, with varying compositions, was performed. Biomass Integrated Gasification Combined Cycle (BIGCC) technology has the potential to produce electricity at a higher efficiency through the use of combustion turbines and steam turbines (Lapuerta et al., 2008). Gasification technique also finds its application in paper mills (Pio et al., 2020), sugarcane ethanol (Machin et al., 2021) industries, and corn ethanol process industries. Gasification of Argentinean coal chars with carbon dioxide and oxygen investigated by Ochoa et al. (2001) and Gutierrez et al. (1987) presents the reaction kinetics and reactivity of gasification with CO_2 by thermogravimetric analysis for temperatures between 1173 and 1433 K, and for CO_2 concentrations among 50% and 70% v/v done by Micco et al. (2010). The authors obtained syngas with high calorific value of 190 kJ/mol. Research on co-gasification techniques and principles was performed, and results conveyed that co-gasification is much efficient than conventional gasification systems (Brar et al., 2012). The developmental analysis of rice husk based Integrated Gasification Combined Cycle (IGCC) system with gas turbine by Srinivas et al. (2012) presents the advantage of reduced emissions with combined cycles. Following the same principle, the concept of integrated full combustion and partial oxidation systems has been presented.

Coal gasification and coking to methanol (CGCTM) with dry methane reforming (DMR) technology was adopted to improve the carbon conversion and reduce the emission of CO_2 (Chen et al. 2019). Advanced and integrated coal gasification combined cycle with triple bed combined circulating fluidized bed (TBCFB) model was developed by Furusawa et al. (2019), in which the cold gas efficiency (CGE) and heating value were high when compared to those of the IGCC system. The findings also report that the increase in the temperature negatively affects the CGE. A new gasification process for cleaner combustion of coal includes the combination of circulating fluidized preheater with downflow bed gasifier that was proposed (Liang et al. 2018). They also reported that lowering the temperature of gasifier improves the cold gas efficiency and negatively affects the oxygen demand. Experimental study on pilot scale 8 t/d CFB gasifier that was carried out (Wang et al., 2019). In this work, staging injection of AGA is carried out for the unburned solid particles filtered in cyclone separated at 3.75 m, 6.25 m, and 8.75 m. It was noted that when solid particles are fed at height of 6.25 m, there is a significant increase in cold gas efficiency and gas production. Integrated BIGCC with oxy-fuel combustion to reduce the CO_2 emission was proposed (Xiang et al., 2019). Syngas produced from the gasifier is further burned in the oxy-fuel combustion chamber for power generation, and the flue gas emitted is processed for CO_2 capturing by cooling. A numerical investigation on radiation and gas property of the particles in order to predict the formation of NO_x pollutants in pulverised coal was carried out (Huynh et al., 2019).

A numerical system comprising of two reactors to enhance the potential of copper oxides for chemical looping gasification (CLG) was proposed (Sarafraz et al., 2017a). In the system, copper oxide was used as oxygen carrier to improve syngas production. It was observed that H_2/CO slightly decreased with the increase in operating temperature due to increase in CO production. The performance of different liquid oxygen carrier for a chemical looping combustion and chemical looping gasification system, by varying exergy flow, energy flow, and syngas quality, was assessed (Sarafraz et al. 2017b). CLG with liquid bismuth oxide for producing syngas was analysed chemically and thermally by Sarafraz et al. (2019). In the proposed method, feed stock is considered as input, and it is partially oxidized using molten bismuth in gasification reactor, and it was followed by oxidation with air in air reactor. A solar thermochemical cycle depended on coal liquefaction method for producing oil proposed (Kong et al., 2019). Here, the traditional coal liquefaction method for hydrogen generation is swapped by thermochemical cycling method. Thermodynamic simulation model integrated with LCA to find the environmental consequence of supercritical coal fired power plant of 1000 MW operating under partial and low loads was modelled (Han et al., 2019). GSE software opted for thermodynamic simulation and SimaPro for LCA investigation. It is pragmatic from the results that the power plant operating at low power load about 30 % resulted in a rapid increase of environmental impact up to 90 % due to low thermal and NO_x removal efficiency. The catalytic coal gasification process for the preparation of methane was reviewed in detail considering the effects of catalyst, their properties and composition, and the preparation methods (Li et al., 2021). Research work has also been progressed with the study on underground coal gasification technique with effect of temperature and pressure in the formation of hydrogen and methane (Hu et al., 2021)

Numerous works have been carried out by the researchers for reducing the emission from thermal power plant using integrated gasification technologies. In the present work, coal based thermal power plant has been integrated with circulating fluidised bed gasification system. The above literature highlights the application of gasification process to biomass waste, sugarcane ethanol, corn ethanol, and rice husk. Few literatures consolidate the coal gasification with dry methane reforming, and few other researches focused on chemical looping gasification with numerical analysis rather than experimentation. This research paper focuses on integrating coal based thermal power plant with gasification cycle in order to determine the optimized condition for better cold gas efficiency along with complete reduction of NO_x and SO_x for cleaner emission using MATLAB. The conventional gasification system and the integrated cycle were analysed considering coal as fuel. Table 1 shows the cold gas efficiency for the present work compared to the previous research with different biomass. The effects of relative air-fuel ratio, steam-fuel ratio, flue gas-fuel ratio, and gasifier pressure on mole fraction of gases produced during gasification, gasifier temperature, heating value of syngas, and cold gas efficiency of gasifier have been studied.

Table 1: Cold Gas Efficiency of Previous Research Work.

Reference	Biomass	Gas Composition (% by Volume)					Cold Gas Efficiency (%)
		CO	H_2	CH_4	CO_2	N_2	
(Corella & Toledo, 2008)	Saw dust	19.48	18.89	3.96	-	-	62.5
(Bridgwater, 2003)	Wood Chips	26.5	7.0	2.0	-	-	48.7
(Warnecke, 2000)	Hazelnut Shells	16.8	14.12	1.70	-	-	51.5
Present Work	Coal	49	34	0.2	9.7	6.1	63.0

EXPERIMENTAL METHODS

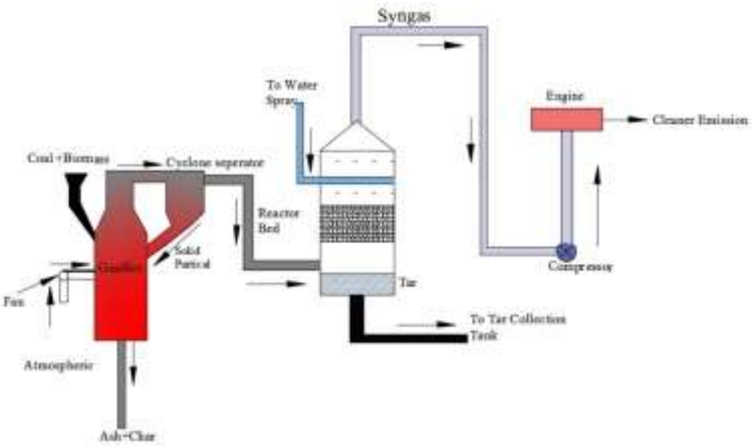


Figure 1: Gasification Process Cycle.

Layout of gasification process cycle considered for numerical simulation is presented in Figure 1. Numerical simulation of the cycle is done using MATLAB. In the gasification layout, coal and biomass are burned in a gasifier in the presence of air, the gas is then filtered in a cyclone separated to remove solid particles, and the solid particles are sent back to the gasifier for complete combustion. Ash and char are extracted from the bottom of gasifier. Gas from cyclone separator passed through a reactor in which water is sprayed for converting the flue gas into syngas. The syngas obtained is compressed and used in engine, which results in cleaner emission with less NO_x and SO_x.

The proposed integrated full combustion and partial oxidation cycle is presented in Figure 2. With combustion of coal in the boiler, flue gas rises and passes through various components resulting in generation of highly pressurized superheated steam that rotates turbine and the coupled generator. Passing through the air-preheater, flue gas heads towards electrostatic precipitator and then enters the gasification chamber at a temperature of about 150 °C. The air-flue gas circuit of the full combustion process ends with the electrostatic precipitator but results in deficient amount of oxygen for gasification. To make over the deficient oxygen, an auxiliary fan provides additional air into the gasifier that facilitates gasification similar to the above cycle.

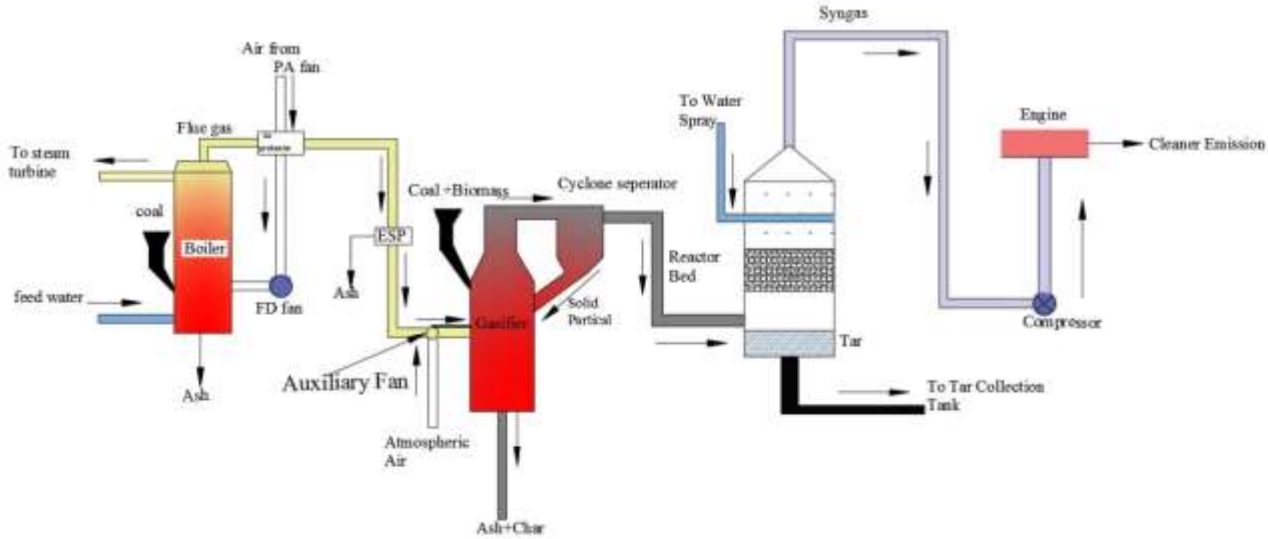


Figure 2: Proposed integrated full combustion and partial oxidation cycle.

NUMERICAL METHOD

For simulation based analysis of complete combustion of fuel, reactions (1) and (2) were used. Reaction (1) presents the combustion reaction for stoichiometric combustion, with no oxygen content after combustion. Reaction (2) presents the combustion reaction when excess is fed into the combustion chamber. Both (1) and (2) were solved using the energy balance method. Considering the combustion temperature of 1673 K, the air-fuel ratio was determined to be 19.543, while the stoichiometric air-fuel ratio was found to be 10.126.

$$C_{a1}H_{a2}O_{a3}N_{a4}S_{a5} + x_s(a_6O_2 + a_7N_2) \Rightarrow b_1CO_2 + b_2H_2O + b_3N_2 + b_4SO_2 \quad (1)$$

$$C_{a1}H_{a2}O_{a3}N_{a4}S_{a5} + x(a_6O_2 + a_7N_2) \Rightarrow b_1CO_2 + b_2H_2O + b_3N_2 + b_4SO_2 + b_5O_2 \quad (2)$$

The model of the present numerical analysis is taken from the analysis performed by Srinivas et al. 2009. The generic formula of the fuel is given as $C_{a1}H_{a2}O_{a3}N_{a4}S_{a5}$. Considering each solitary mole of a fuel, the coefficients a1, a2, a3, a4, and a5 are determined through ultimate analysis. Every single atom of carbon in fuel (coefficient a1) becomes one; similarly, coefficients a1, a2, a3, a4, and a5 are H/C, O/C, N/C, and S/C mole ratio. The authors (Srinivas et al. 2009) neglect only the moisture content present in the coal sample; all other parameters are taken into consideration for the numerical study.

Reaction (3) presents the chemical reaction in gasifier with air, while (4) presents the reaction in gasifier employing exhaust flue gas from combustion systems. For reaction (4), coefficients a_7, a_8, a_9, a_{10}, and a_{11} are determined using the products obtained from combustion reaction (3.10) and making up their sum to single mole. Coefficient a_6 for the reactions (3) and (4) is procured by variation in relative air-fuel ratio. Analysis was done considering one kg-mol of flue gas input, and a_{11} was varied, which gives the relative gas-fuel ratio for equation (4).

$$\begin{aligned}&\left(C_{a1}H_{a2}O_{a3}N_{a4}S_{a5}\right)_{fuel}+\left(a_6\left(a_7O_2+a_8N_2\right)\right)_{air}+\left(a_9H_2O_g\right)_{steam}+\left(a_{10}H_2O_l\right)_{moisture}\\&\quad\Rightarrow d_1CH_4+d_2CO+d_3CO_2+d_4H_2+d_5H_2O+d_6N_2+d_7SO_2\end{aligned}\tag{3}$$

$$\begin{aligned}&\left(C_{a1}H_{a2}O_{a3}N_{a4}S_{a5}\right)_{fuel}+\left(a_6\left(a_7O_2+a_8N_2\right)\right)_{air}+\left(a_9H_2O_g\right)_{steam}+\left(a_{10}H_2O_l\right)_{moisture}\\&+a_{11}\left(a_{12}CO_2+a_{13}H_2O+a_{14}N_2+a_{15}SO_2+a_{16}O_2\right)_{flue\quad gas}\\&\quad\Rightarrow f_1CH_4+f_2CO+f_3CO_2+f_4H_2+f_5H_2O+f_6N_2+f_7SO_2\end{aligned}\tag{4}$$

Taking atom balance on C, H, O, and N for both reactions (3) and (4), a total of six unknowns and four equations were obtained. Thus, using the methane reforming reaction (15) and water shift reaction (16), the dissociation constants k1 and k2 were obtained. k_1', k_1'', k_2', and k_2'' represent the first and second derivatives of dissociation constant for reforming reaction and water shift reaction.

From reaction (3):

C balance: $a_1 = d_1 + d_2 + d_3$ (5)

N balance: $a_4 + 2a_6a_8 = 2d_6$ (6)

S balance: $a_5 = d_7$ (7)

O balance: $a_3 + 2a_6a_7 + a_9 + a_{10} = d_2 + 2d_3 + d_5 + 2d_7$ (8)

H balance: $a_2 + 2a_9 + 2a_{10} = 4d_1 + 2d_4 + 2d_5$ (9)

From reaction (4):

C balance: $a_1 + a_{11}a_{12} = f_1 + f_2 + f_3$ (10)

N balance: $a_4 + 2a_6a_8 + 2 + a_{11}a_{14} = 2f_6$ (11)

S balance: $a_5 + a_{11}a_{15} = f_7$ (12)

O balance: $a_3 + 2a_6a_7 + a_9 + a_{10} + 2a_{11}a_{12} + 2a_{11}a_{13} + 2a_{11}a_{15} + 2a_{11}a_{16} = f_2 + 2f_3 + f_5 + 2f_7$ (13)

H balance: $a_2 + 2a_9 + 2a_{10} + 2a_{11}a_{13} = 4f_1 + 2f_4 + 2f_5$ (14)

Rearranging all the equations from (5) to (14), the equations were brought in terms of a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, d_1, d_2, d_3, d_4, d_5, d_6, and d_7 for equation (3) and in terms of a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12}, a_{13}, a_{14}, a_{15}, a_{16}, f_1, f_2, f_3, f_4, f_5, f_6, and $f_7$for equation (4). Here, all parameters of a, d, and f are constants.

$$CH_4 + H_2O = CO + 3H_2 \tag{15}$$

$$CO + H_2O = H_2 + CO_2 \tag{16}$$

$$k_1' = \frac{P_{CO}P^3{}_{H_2}}{P_{CH_4}P_{H_2O}} = \frac{d_2 d^3{}_4 P^2}{d_1 d_5 n_t{}^2} \quad \text{(for equation 3)} \tag{17}$$

$$k_1'' = \frac{P_{CO}P^3{}_{H_2}}{P_{CH_4}P_{H_2O}} = \frac{f_2 f^3{}_4 P^2}{f_1 f_5 n_t{}^2} \quad \text{(for equation 4)} \tag{18}$$

$$k_2' = \frac{P_{CO_2}P_{H_2}}{P_{CO}P_{H_2O}} = \frac{d_3 d_4}{d_2 d_5} \quad \text{(for equation 3)} \tag{19}$$

$$k_2'' = \frac{P_{CO_2}P_{H_2}}{P_{CO}P_{H_2O}} = \frac{f_3 f_4}{f_2 f_5} \quad \text{(for equation 4)} \tag{20}$$

P in (18) and (19) is gasifier pressure, and n_t is total moles in products for each reaction of (3) and (4). The equilibrium constant was given by

$$\ln(k) = \frac{-\Delta G^o}{RT} \tag{21}$$

Using the numerical method, the constants d_1 and d_2 and f_1 and f_2 are solved. Approximate values are assumed from b_1 and b_2 to begin the iteration in the numerical method technique.

$$f_o + h\frac{\partial f}{\partial b_1} + k\frac{\partial f}{\partial b_2} = 0 \tag{22}$$

$$g_o + h\frac{\partial g}{\partial b_1} + k\frac{\partial g}{\partial b_2} = 0 \tag{23}$$

b_1 and b_2 are replaced by f_1 and f_2, and g_1 and g_2 as per the equation. The numerical values obtained for the constant h and k indicate the degree of accuracy for the coefficient constants b_1 and b_2. If convergence does not occur for the required degree of accuracy, then the iteration process is carried out using new assumed values as given in (28) and (29).

$$b_1 = b_1 + h \tag{24}$$

$$b_2 = b_2 + k \tag{25}$$

STATISTICAL ANALYSIS

Cold gas efficiency (CGE) is a measure of the performance of converting process. It represents the energy preserved in the synthesis gas.

$$\text{CGE}(\%) = \frac{\text{Heating value of Syn gas}*100}{\text{Heating value in the fuel input}} \tag{26}$$

The amount of energy liberated during complete combustion of biomass in the presence of adequate oxygen is known as heating value. Compared to most of the fossil fuels used, the heating value of coal is low on a volumetric basis as its density is very low. In the present research work, the heating value is represented as lower heating value as moisture content is in gaseous state in the producer gas.

Using the above simulated model, the heating value of the produced gas is numerically obtained from MATLAB, and the heating value in the coal and gas-fuel mixture decreases from 23104 kJ/kg-mol based on the percentage of flue gas mixed with fuel. Using the heating value of producer gas and heating value of gas-fuel mixture, cold gas efficiency is determined.

RESULTS AND DISCUSSION

The ultimate analysis data of the coal used as fuel in the present work is carbon 78.58 %, hydrogen 4.41%, oxygen 13.24%, nitrogen 1.52%, sulphur 0.64%, and ash content of 1.61% with enthalpy of -23104 kJ/kg-mol (Eftekhari, 2012). The MATLAB based simulations were done considering 1 kg-mol of fuel input. With varying air-fuel ratio, gasifier pressure, and steam-fuel ratio, plots for mole fraction of components of syngas with gasification temperature were obtained. Figure 3 depicts the mole fraction of emission gas composition for gasification process with steam fuel ratio as 0.25 for gasifier pressure of 2, 4, 6, 8, and 10 bars. Figure 3 (a) presents variation of mole fraction of CH_4 in syngas produced after the gasification process of fuel. Figure 3 (b) presents variation of mole fraction of CO, Figure 3 (c) presents that for CO_2, and Figure 3 (d) presents the variation for mole fraction of H_2. With gasifier pressure, relative air-fuel ratio, and steam-fuel ratio as varying parameters, the variation of mole fractions of gases with gasification temperature presents detailed information about the mole fraction of composition of gases emitted from coal based power plant (Tian et al., 2018). As steam fuel ratio is increased from 0.25 to 1.0 (results with highest mole fraction are shown), the amount of fuel supplied with steam generation decreases, which proportionally reduces the mole fraction of syngas composition, that is, CH_4, CO, CO_2, and H_2, irrespective of the combustion process. Also, the increment in steam fuel ratio affects the temperature of reactor bed. The increment in both relative air-fuel ratio and steam fuel ration decreases the mole fraction of methane, hydrogen, and carbon monoxide due to excess supply of air with constant fuel, and most of the air combines with carbon resulting in formation of excess carbon dioxide with an increase in the relative air fuel ratio. This is justified by the concept that increased amount of air supply to gasifier increases the oxidation effect in fuel, and thus, there is increase in the temperature (Halmann & Steinfeld 2006). An increase in the gasifier pressure increases the temperature of compressed air, resulting in a rise in gasifier temperature. The heating value is determined at the gasifier temperature, and products are cooled to reference temperature of 298.15 K with a theoretically correct air fuel ratio. The heating value of syngas increases with the increase in gasifier pressure but decreases with an increase in both relative air-fuel ratio and steam-fuel ratio. Hydrogen content in syngas decreases at a steady rate with an increase in the relative air-fuel ratio, and thus, the heating value of gas decreases with the increase in the relative air-fuel ratio.

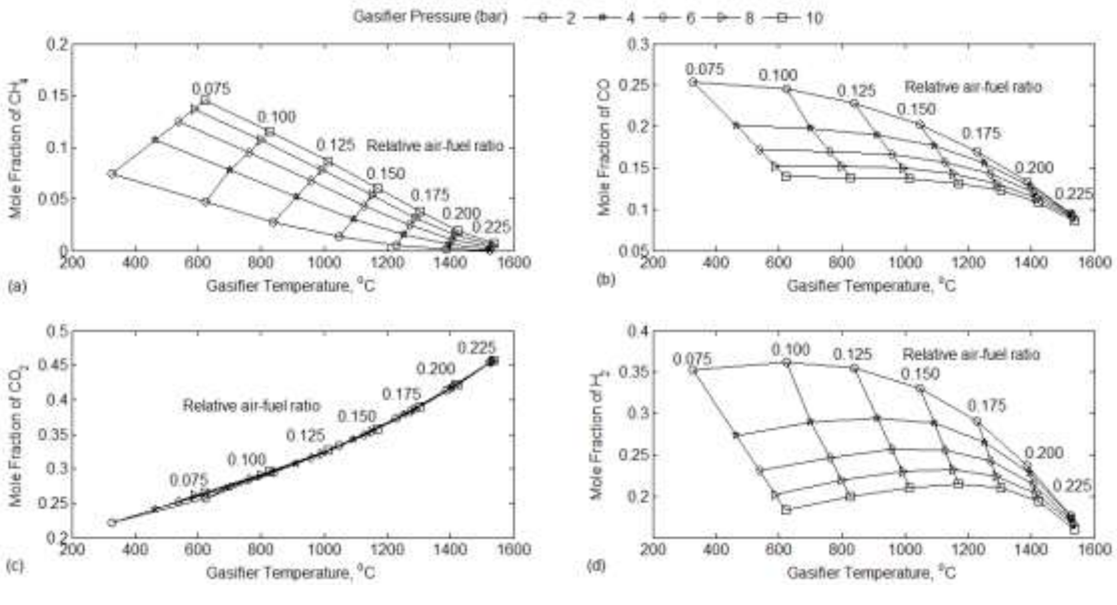


Figure 3: Gasification with steam-fuel ratio of 0.25 and with no flue gas ratio.

Now, on simulating the proposed gasification cycle with integrated full combustion and partial oxidation systems, plots were obtained for varying gasifier pressure, relative air-fuel ratio, steam-fuel ratio, and a new parameter called gas-fuel ratio. Flue gas-fuel ratio is defined as the ratio of flue gas from coal based thermal power plants with fuel input into the gasifier. Figure 4 presents the simulation results for coal gasification with steam fuel ratio as 0.25 and varying flue gas-fuel ratio as 0.25, 0.5, 0.75, and 1.0. The increase in gas fuel ratio is processed by increasing the flue gas supply from thermal power plant with constant fuel supply in the gasifier. The higher the flue gas supply for constant fuel is, the better the combustion is, and thus, the composition of syngas decreases as the fuel supply is maintained constant with an increase in the gas fuel ratio. And there is an increase in the gasifier pressure, which increases the gasifier temperature drastically due to high moment of air particles at elevated pressure. Similarly, Figure 5, Figure 6, and Figure 7 present results for coal gasification with steam fuel ratio as 0.50, 0.75, and 1.00 and varying gas-fuel ratios. However, it is also observed from the results that, for constant pressure, gas fuel ratio, mole composition of methane, carbon monoxide, and hydrogen tend to decrease drastically for the increase in steam fuel ratio as the fuel composition fed is reduced.

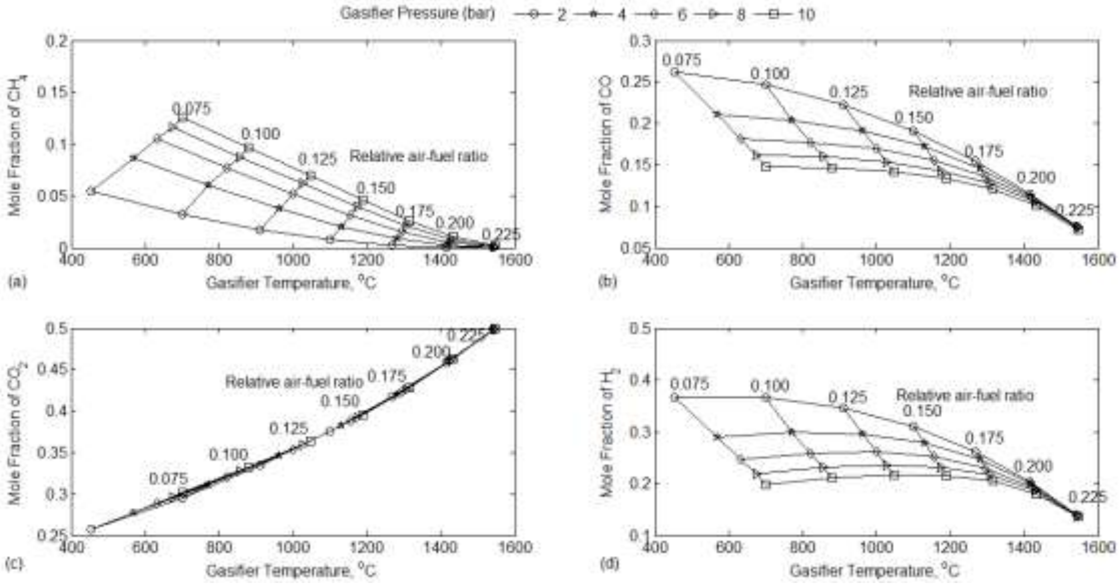


Figure 4: Gasification with steam-fuel ratio of 0.25 and flue gas-fuel ratio of 0.25.

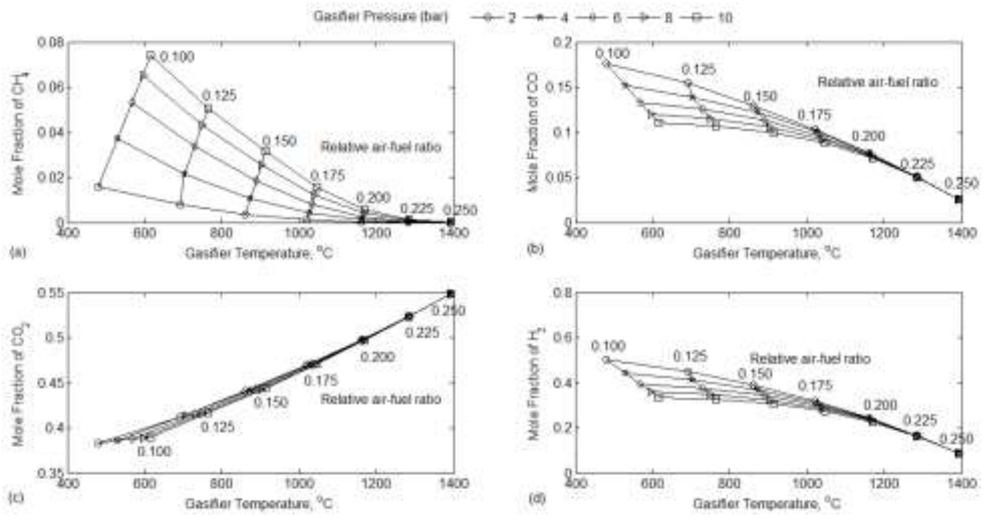


Figure 5: Gasification with steam-fuel ratio of 0.50 and flue gas-fuel ratio of 0.25.

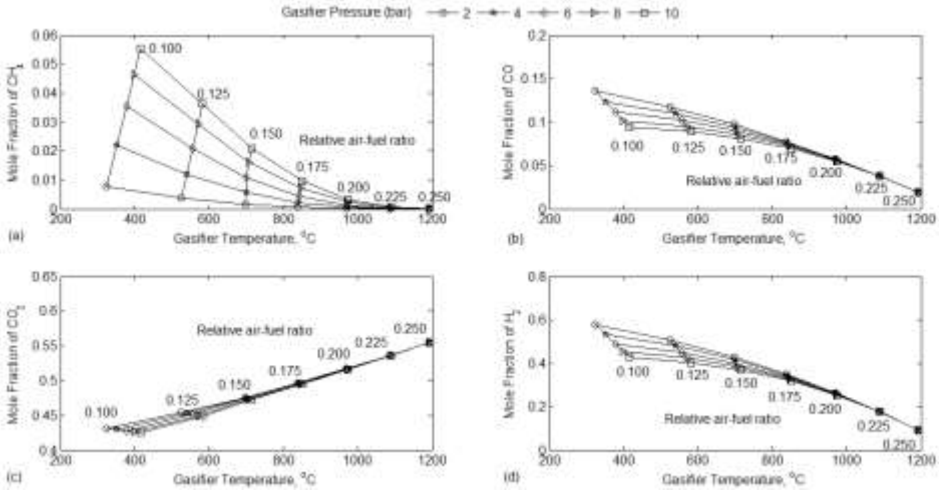


Figure 6: Gasification with steam-fuel ratio of 0.75 and flue gas-fuel ratio of 0.25.

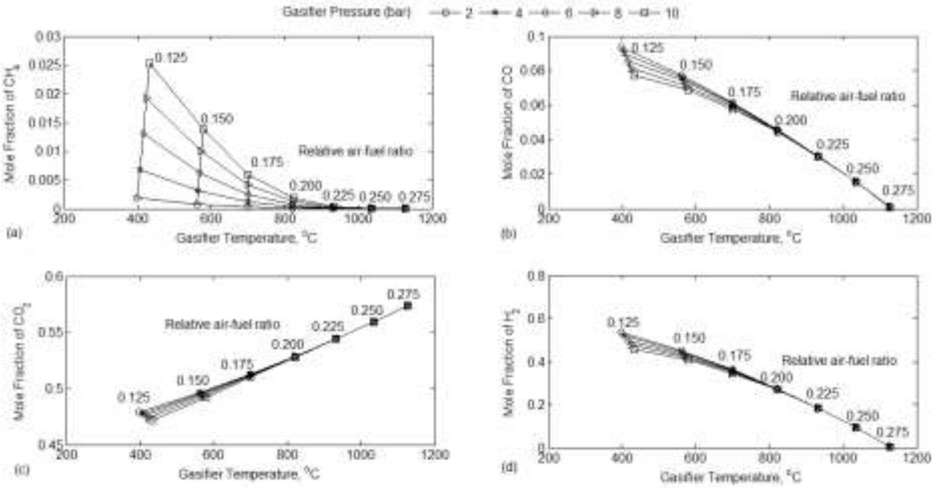


Figure 7: Gasification with steam-fuel ratio of 1.00 and flue gas-fuel ratio of 0.25.

Simulated results for gasifier pressure of 2 bar and steam-fuel ratio of 0.25 presented the results with highest mole fraction for various combinations of relative air-fuel ratio and gas fuel ratio. For introduction of exhaust flue gas with atmospheric air, the results of mole fraction of syngas components were nearly close to those obtained by gasification using air only. It was also observed that the variation in gas-fuel ratio does not affect mole fractions of CO and H_2 significantly. Figure 8 presents the result for the effect on gasification temperature with varying relative air-fuel ratio for different gas-fuel ratios at gasifier pressure of 2 bar and steam-fuel ratio of 0.25. The mixture of coal fuel with air shows a steady increase in temperature with the increase in relative air-fuel ratio irrespective of gas fuel ratio, as the flue gas is not taken into account in the case. The excess supply of air contributes to the combustion and increases the temperature of the gasifier, whereas the mixture of coal fuel with air and flue gas increase in gas fuel ratio increases the flue gas concentration, which enters the gasifier with high temperature and results in an increase in the gasifier temperature (Taba et al., 2012).

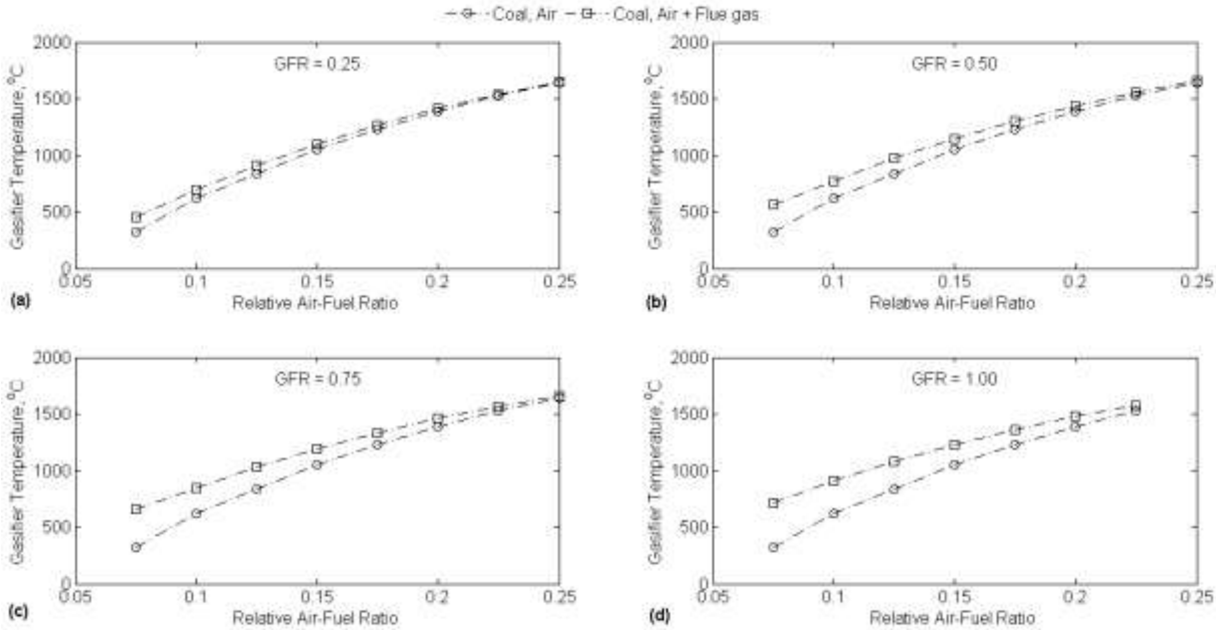


Figure 8: Variation in gasification temperature for gasifier pressure of 2 bar and steam-fuel ratio of 0.25.

Figure 9 presents the effect on mole fraction of gases at gas-fuel ratio of 0.25 with gasifier pressure of 2 bar and steam-fuel ratio of 0.25. It is evident from the mole fraction composition graph of 2 bar pressure, 0.25 steam fuel ratio, and 1.0 flue gas fuel ratio with an increase in relative air fuel ratio the percentage of oxygen supply for combustion increases, which improves the burning and tends to decrease methane, carbon monoxide, and hydrogen as excess oxygen combine with carbon dioxide and increase its composition alone. For every composition of syngas, with the mixture of flue gas along with air, there are slight increase and decrease in the value of mole fraction; this occurs due to the mixture of flue gas, as they add onto the syngas mixture.

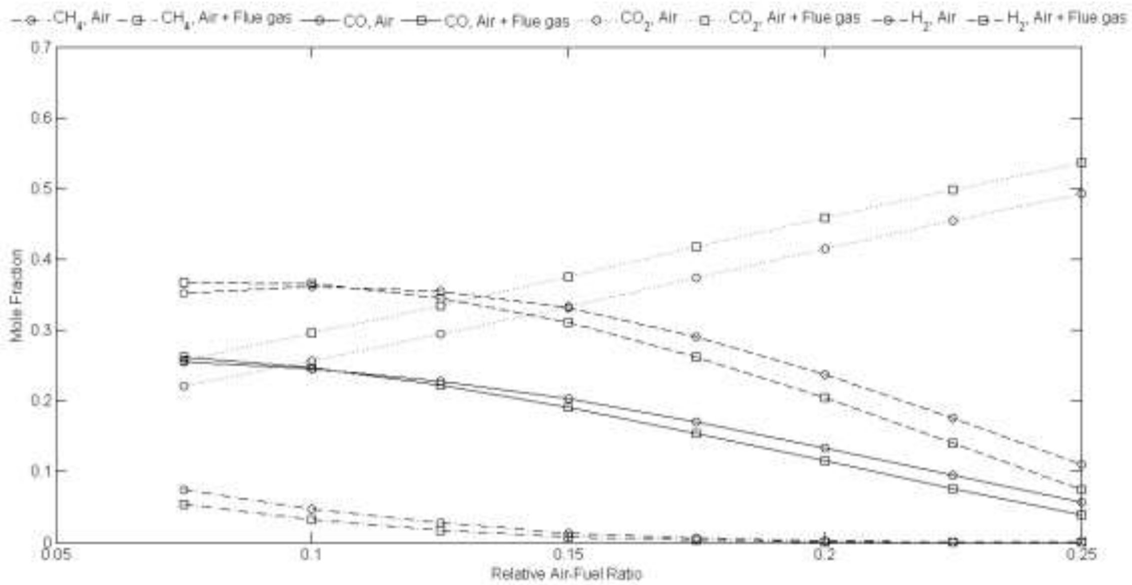


Figure 9: Variation in mole fraction of gases for gasifier pressure of 2 bar, flue gas-fuel ratio of 0.25, and steam-fuel ratio of 0.25.

Inferring from the above results, cold-gas efficiency and heating value of syngas produced have been calculated and tabulated in Table 2 and Table 3, respectively. The first column indicates the type of fuel (for example, Coal). Column "air" indicates the efficiency and heating value for gasification using air, while column "gas-fuel ratio" indicates the results for gasification using air with flue gas at different gas-fuel ratios mentioned in table 2. The optimum conditions are found to be as gasifier pressure of 2 bar, relative air-fuel ratio of 0.10, and steam-fuel ratio of 0.25. In the present work, coal is the primary input for the system, and as an outcome of the proposed system, syngas is produced. Thus, only the heating value of syngas produced is given in Table 3.

Table 2: Cold gas efficiency (%) at optimum conditions.

Fuel	Air	Flue Gas – Fuel Ratio			
		0.25	0.5	0.75	1.0
Coal	79.93	75.48	70.63	65.53	63.07

Table 3: Heating value (kJ/kg) at optimum conditions.

Fuel	Air	Gas – Fuel Ratio			
		0.25	0.5	0.75	1
Coal	26028.67	24578.62	22999.04	21338.68	20538.26

Cold gas efficiency is defined as the efficiency of potential energy of syngas produced with respect to the total energy input for production of syngas. The heating value is defined as the amount of heat released during the combustion of a unit mass of the gas. Table 4 presents the results for combustion of 1 kg-mol of filtered syngas at various gas-fuel ratios with gasifier pressure of 2 bar and steam-fuel ratios of 0.25 for coal gasification and co-gasification, and 0.2 for solid waste gasification. For full combustion system and partial oxidation system, the total fuel input is 1 kg-mol, while for integrated full combustion and partial oxidation systems, the total fuel input is 2 kg-mol, 1 kg-mol of coal in full combustion cycle, and 1 kg-mol of fuel in gasifier. The overall efficiencies for full combustion system and partial oxidation system have been considered as 37 % and 30 %, respectively.

For individual cycles of full combustion and partial oxidation, the amount of CO_2 released per kg-mol of fuel was found to be very high compared to that obtained for integrated cycle. The increment in steam-fuel ratio also affects the temperature of reactor bed. The increment in both relative air-fuel ratio and steam-fuel ratio decreases mole fraction of major components of syngas.

Table 4: Results for emissions and overall efficiency.

Fuel	Gas-Fuel Ratio	CO_2 (kg / kg-mol of fuel)	CO_2 (kg / kWh)	Overall Efficiency (%)
Full combustion system				
Coal	-	10.03	3.716	37.00
Partial oxidation system				
Coal	-	6.46	1.521	30.00
Integrated full combustion and partial oxidation system				
Coal	0.25	3.25	0.743	33.96
	0.50	3.28	0.769	34.08
	0.75	3.30	0.794	34.20

	1.00	3.31	0.807	34.27

The content of H_2, CO, and CH_3 in syngas influences the heating value of the syngas. The heating value of syngas is high at relatively lower air-fuel ratios. The increase in steam-fuel ratio in gasifier enhances the shift reaction in which carbon monoxide converts into carbon dioxide with the presence of steam and rise in both hydrogen and carbon dioxide contents being observed with the expense of carbon monoxide. It should be noted that there is no significant influence of gasifier pressure on gas composition. As per the obtained results, the proposed integrated full combustion and partial oxidation cycle presents itself as a potential solution. Although the mole fraction of components of syngas does not vary significantly with the introduction of exhaust flue gas, heating value and cold-gas efficiency indicate the decreasing quality of produced gas with increase in gas-fuel ratio. With the increase in gas-fuel ratio, gasifier temperature increases with the increase in carbon dioxide content, while carbon monoxide, hydrogen, and methane content of produced gas reduce. This can be accounted for with the fact that exhaust flue gas from power plants has high percentage of CO_2 that influences the mole fraction of other gases and gasifier temperature. Although the cold gas efficiency and heating value also reduce with introduction of flue gas, the carbon credit of proposed system was found to be nearly half of that from conventional coal based power plants. Also, the exhaust with zero sulphur content was obtained.

CONCLUSIONS

The research objective of the current article focuses on resolving the problem of sustainable power production using coal based thermal power plant by integrating gasification technologies to the system. Thus, the authors proposed and analysed an integrated full combustion and partial oxidation system, and MATLAB based simulations were done with varying gasifier pressure, air-fuel ratio, steam-fuel ratio, and gas-fuel ratio. The proposed cycle presents itself feasible and well suitable for its application in coal based thermal power plants, providing potential towards supplementary power generation and cleans exhaust. The important finding was that the system exhibits optimum performance of gasification system at gasifier pressure of 2 bar, air-fuel ratio of 0.1, steam-fuel ratio of 0.25, and flue gas-fuel ratio of 1.00. The cold-gas efficiency decreases steadily from 79.93 % for gasification process using air to 63.07 % with increasing gas-fuel ratio for gasification process through proposed integrated cycle, and the heating value of syngas decreases from 26028.67 kJ/kg to 20538.26 kJ/kg, respectively. But through the integrated circuit, a decrease in the amount of CO_2 released per kg-mol of fuel was observed to be nearly one-third of the amount of CO_2 released per kg-mol of fuel from coal based thermal power plants. Also, zero sulphur content was observed in conventional gasification cycle and proposed cycle, while 0.03 kg of SO_2 emission was observed from conventional coal based thermal power plants. The authors suggest that, in the future, any experimental analysis of coal thermal power plant using the above proposed method would ensure real time application for clean power production.

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