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(REVIEW ARTICLE)

Technology for trimming of greenhouse gas in thermal plant system

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Abstract

Industrial expansion depends largely on electric power generation for its operations. These industrial activities have contributed significantly to environmental degradation from frequent emission of large volume of greenhouse gases. Concentration of suspended greenhouse gases in the air of many cities exceed World Health Organization standards and its effect on human health can be devastating. Thus, utmost importance is to generate clean and efficient energy from power plant. The aim of this work is to foster a way of reducing emissions in Power Plants by integrating gasification technologies to the system. Emission data from thermal power plant was 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 was carried out using MATLAB. The analysis indicated supplementary power generation and cleaner exhaust. The progress of this work can greatly reduce greenhouse emission.

Keywords: Numerical simulation; Emissions, Gasification; Greenhouse gases: Power plant

1. Introduction

Emissions from fossil fuel combustion, especially thermal plant system, are major contributors to air pollution. Concentrations of suspended particles and greenhouse gases in the air of many cities exceed World Health Organization standards. Electricity from fossil fuelled power plants has been the key source of energy and power for most of the developing countries. The effects of this pollution on human health can be devastating and in the most seriously affected countries the economic costs are estimated to be a significant percentage of GDP. In the meantime, against a backdrop of increasingly severe global warming, early practical application of technology for reducing CO_2 emission is being demanded. Technical solutions include; switching from coal or fuel oil to natural gas in power generation, increased use of renewable energy sources, energy efficiency measures, coal washing, vehicle standards and transport fuel reformulation. However, these technologies are practically difficult to implement and sustained because they are broad projects that requires huge financial commitment.

Clean coal technologies are an especially important option for reducing hazardous fossil fuel emissions and, in developing countries where coal is readily available, are often a cost-effective option. 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

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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 NOx pollutants in pulverised coal was carried out (Huynh et al., 2019).

Furthermore, 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 using 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.

Numerous works have been carried out by the researchers to reduce the emission from thermal power plant using integrated gasification technologies. In the present work, data from a coal based thermal power plant integrated with circulating fluidised bed gasification system was analysed. 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 study focuses on analysing an integrated coal based thermal power plant with gasification cycle to determine the optimized condition for better cold gas efficiency along with complete reduction of greenhouse gases for cleaner emission using MATLAB. The conventional gasification system and the integrated cycle were analysed considering coal as fuel.

2. Methodology

Simulation of the gasification cycle with varying parameters was carried out to evaluate the efficiency of the Integrated coal-gasification combined cycle (IGCC) in reducing greenhouse emission from an existing coal gasification thermal plant. In this plant, oxygen gas (produced from air separator) carrying pulverized coal is fed into the furnace, where it is swirled around (see Fig. 1). The coal and oxygen are fed from the top and bottom burners, at which oxygen ratio is individually controlled. The amount of oxygen in the lower level is set so that the temperature in the furnace is higher than fluid point of ash, thereby enhancing slag melting. The amount of oxygen in the upper level is lowered so that the oxygen concentration in the entire gasification furnace is optimized. In this process, oxygen is properly distributed according to coal type, thereby assuring high-efficiency gasification. 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 like the above cycle.

2.1. Data Analysis

Cold gas efficiency (CGE) is a measure of the performance of converting process. It represents the energy preserved in the synthesis gas. 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. 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/kgmol. The MATLAB based simulations were done considering 1 kg-mol of fuel input. 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.

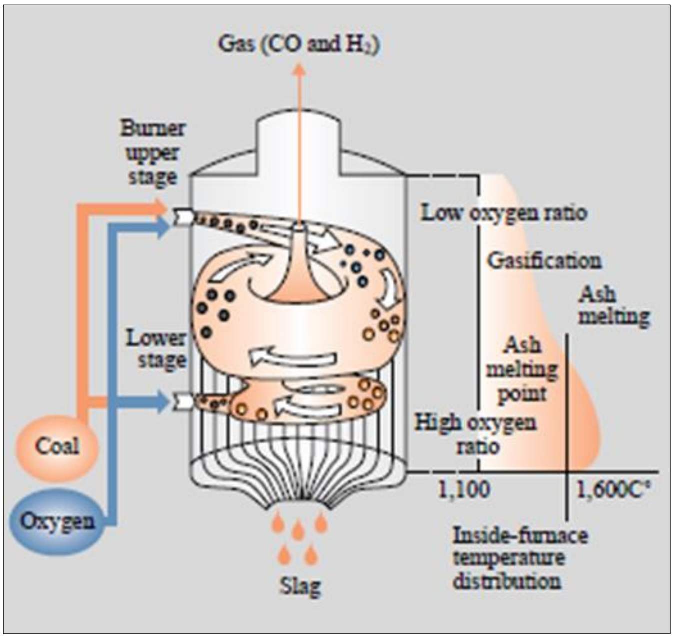

Figure 1 Concept of Coal Gasification. Grain dispersion in swirling flow is controlled, and appropriate oxygen delivery for all types of coal is assured

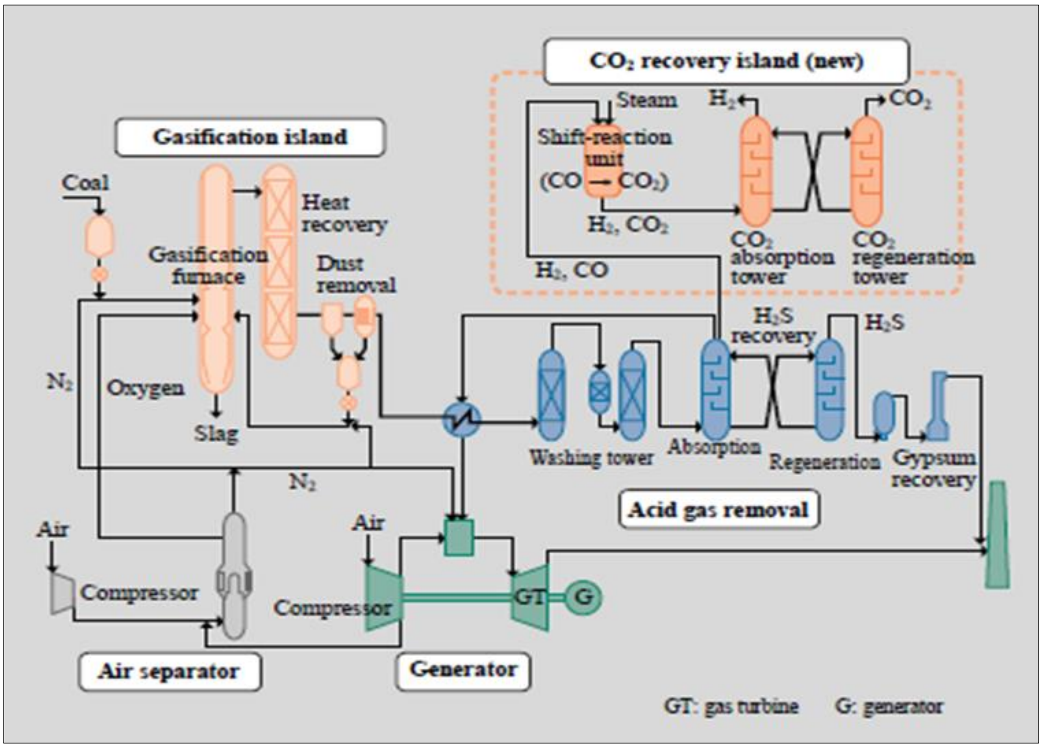

Figure 2 System Configuration

2.2. Numerical Simulation

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.

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

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

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 $Ca_1Ha_2Oa_3Na_4Sa_5$. 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. The improving accuracy of the gasification basic-testing results on a pressurized/normal pressure furnace are reflected in a gasification-furnace reaction simulation, identifying the issue of scalability, and confirming the reliability of commercial size plants (see Fig. 3).

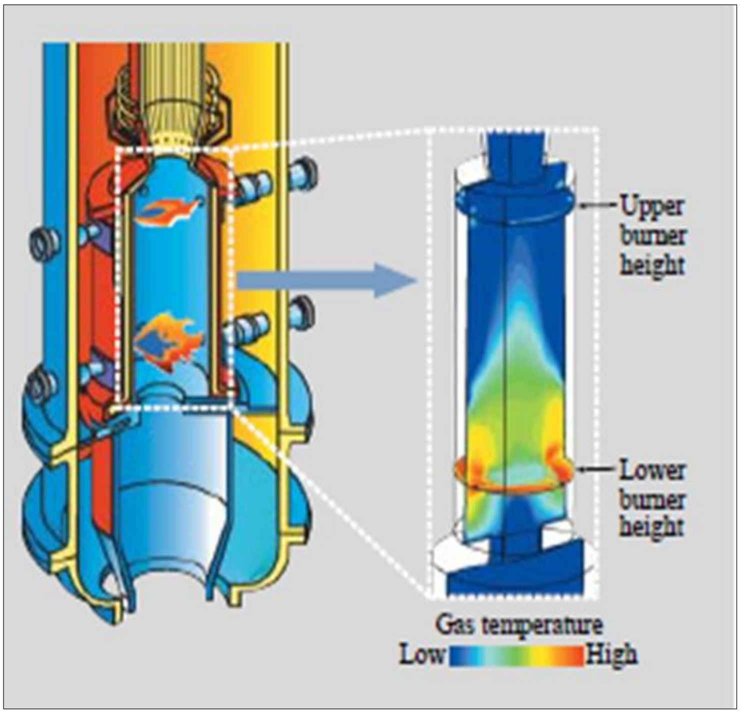

Figure 3 Numerical Analysis on Thermal-flow Dynamics of Coal gasification Furnace

3. Results

The result of the analysis indicates that 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. 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. The environmental emissions level with this technology are very low. The hot gas clean-up (HGCU) temperature can be lower with IGCC (500ºC) than with pressurized fluid-bed combustion since the gas will be ignited again at combustion. HGCU is a critical element in increasing plant efficiency.

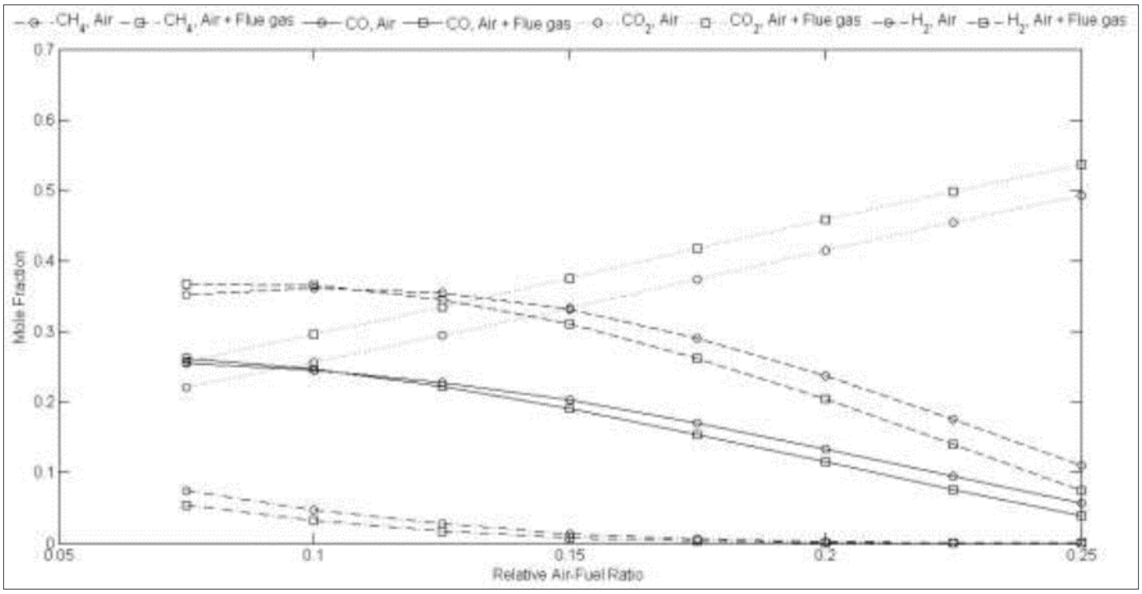

Figure 4 Variation in mole fraction of gases for gasifier pressure of 2 bar, flue gas-fuel ratio of 0.25, and steam-fuel ratio of 0.25

4. Conclusion

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 CO2 released per kg-mol of fuel was observed to be nearly one-third of the amount of CO2 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 0.03kg of SO2 emission was observed from conventional coal based thermal power plants. Further experimental analysis of coal thermal power plant using the above proposed method would ensure real time application for clean power production.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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