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Review of Performance of Coal Gasification Using Measured Property

Authors
Ashutosh Kumar Das[1], Dr (Prof.) Hitesh Kumar[2], Dr (Prof.) Naveen Agrawal[3]
[1]PG Scholar, Department of Mechanical Engineering
Technocrats Institute of Technology, Bhopal (M.P)
[2]HOD, Technocrats Institute of Technology, (Advance) Bhopal (M.P)
[3]HOD, Technocrats Institute of Technology, Bhopal (M.P)
Email: *ashu.das411@gmail.com*

Abstract
This paper addresses the question how coal gasification may be used more efficiently and economically than it is being used today. coal already plays a large role in the energy supply, especially in developing countries, analysis is done on different parameter such as moister content, heating value, fusion temperature, O/C ratio, carbon capture, slurry feed & dry feed technology, literature review show that low rank coal contain high inherent moisture & it require predrying of coal & its cost more. Technical bottlenecks (e.g. CO_2 Emission) and non-technical bottlenecks (e.g. cost of transportation of coal) are still hampering large-scale implementation.
A detailed explanation is given why coal gasification is more efficient than biomass co-fire gasification. The gasification efficiency that can be achieved for different fuels, ranging from biomass to coal, is compared. These fuels are distinguished by their atomic O/C and H/C ratios as shown in a Van Krevelen diagram. The amount of oxygen to be added for complete gasification relative to the amount required for combustion is lower for biomass than for coal. Consequently, a lower gasification temperature is theoretically required. However, at practical gasification temperatures in the range of 1200 K to 1500 K, biomass becomes over-oxidized.
Furthermore, the chemical exergy of biomass is high relative to its heating value, but this work potential is not fully utilized in the process. Review shows that how fusion temperature of coal affect the design of furnace in heating plant or electricity generating plant, Costly redesign of furnace is necessary in order to adapt different type of coal. Again study show that on 100% removal of exhaust gas 90% CO_2 is removed. However potential work is not done on the technology of (UGC &CCS) Underground coal gasification with CO_2capture & storage it will considerably reduce the transportation cost of coal. Again on the basis of fuel feed supply system dry fuel feed system generates higher energy efficiency than slurry feed technology.
Key words: *Moister content, Heating value. Fusion temperature, O/C ratio, biomass co-firing, Carbon Capture, slurry feed & dry feed technology.*

INTRODUCTION

Gasification is a thermo chemical process that causes the interaction of the fuel with oxidant (steam & air) & converts all the organic mass or fossil fuel based carbonaceous material into fuel gas, i,e, carbon monoxide (CO) hydrogen(H_2) and car- bon dioxide.(CO_2) This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen (less than 30% of required oxygen) and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of non renewable energy if the gasified compounds were obtained from fossil fuel. Gasification of coal can provide a clean energy fuel i.e, generator gas, & will expand the range and scale of the use of low grade solid fuels. Gasification also simplifies the preparation of fuel, as there is no need for pulverization (gasification of lump fuel) and purification of the combustion gases from fly ash, which instead used for cleaning the generator gas.[1]

Gasification technology is applicable to any type of carbon-based feedstock, such as coal, heavy refinery residues, petroleum coke, biomass and municipal wastes. Most of the research work of coal gasification performance are carried on bituminous coal. However approximate 47% of global coal reserves consist of lignite & sub-bituminous coal.

Coal rank is important concept in all classification of coal. Rank of coal is degree or stage that the coal has reached during its coalification process .i.e, its degree of metamorphism or geochemical maturity.

Low rank coals present unique challenges as well as opportunities for coal gasification techniques, since they typically contain more volatile (on the dry or equal moisture base), more inherent moisture, more alkali metal content (Na,K,Ca) and higher oxygen content than high rank coals, but contain lower sulfur and cost less. Furthermore, low rank coals higher reactivity compared to high rank coals (bituminous coal)

Low rank coals characteristics of higher moisture content, greater tendency to combust spontaneously; higher degree of weathering and a more adverse dusting nature have restricted their widespread use. The high moisture content leads to high transportation and pretreatment costs and parasitic energy consumption, resulting in reduced thermal efficiency for power generation either through the traditional pulverized coal (PC) combination process via an integrated gasification combined cycle (IGCC) system.

High inherent moisture content in the low rank coals reduce the amount of water required for making coal slurry but not much because to make slurry transportable through pipes a certain required amount of water is needed to reduce the slurry viscosity. But, other than that, the recipe of making coal slurry isn't affected much by the inherent moisture.'' Considering that the inherently high moisture content in low rank coals does not reduce much the required amount of surface water needed for making coal slurry, pre-drying of coal is considered. [2][3]

Coal Gasification is the process of producing syngas –a mixture consisting primarily of methane (CH_4) carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and water vapor (H_2O)–from coal and water, air and/or oxygen

COAL GASIFICATION REACTION:

I. $Coal \xrightarrow{pyrolysis} char© + coal\ volatile(VM)$

II. $VM + H_2 \xrightarrow{hydrocracking} CH_4 - \Delta H$

III. $VM + H_2O \xrightarrow{gasification} CO + H_2 + \Delta H$

IV. $C + 2H_2 \xrightarrow{hydrogaationsific} CH_4 - \Delta H$

V. $C + H_2O \xrightarrow{gasification} CO + H_2 + \Delta H$

VI. $C + CO_2 \xrightarrow{gasification} 2CO + \Delta H$

VII. $CO + H_2O \xrightarrow{shift\ conversion} CO_2 + H_2 - \Delta H$

VIII. $C + O_2 \xrightarrow{combustion} CO_2 - \Delta H$

Coal volatile include include all gases, tar & light light gaseous hydrocarbon. Pyrolysis reaction occur under all condition of gasification. The tar undergoes hydrocacking & gasification reactions producing CH4,H2, & CO. The char undergo hydro gasification & gasification reaction producing CH_4,H_2, & CO. The shift conversion reaction takes place under all conditions of gasification. Sulpher, nitrogen & oxygen present in coal are converted to H_2S,NH_3, and organic compounds containing sulpher, nitrogen, & H_2O respectively. the extent of coal conversion depends on thermodynamics & kinetics of these reactions.

The gasification V, VI are endothermic(+ ΔH *value*,require a continued input of energy from the surrounding to proceed)with an enthalpy of about 120-160 $kJmole^{-1}$. They are favoured at high temperature above 1000K. the shift conversion and hydro gasification reaction are moderately exothermic(-ΔH value, release heat from combustion reaction and is used to drive the gasification reaction, whch results in the generation of synthesis gas.) with an enthalpy of about 32-88

KJ mole^{-1}.they are favoured at low temperature below 1000K. The combustion reaction VIII is strong exothermic reaction with an enthalpy ΔH of about 376 KJ/mole-^{1}.

Temperature & pressure within the gasifier can be adjusted to favour production of syngas with an increased CH_4 content or a maximum concentration of H_2& CO. methane producing reaction are product favoured at lower temperature and higher pressure as predicted by Le-chatelier Principal. Conversly, formation of H_2 & CO is favourd at higher temperature & lower pressure. In addition to temperature & pressure the ratio of oxygen to steam fed to the gasifier can be adjusted to alter the syngas composition. If steam is dominant oxidizing agent, increased levels of H_2 & CH_4 will be present in the product gas. high oxygen to steam feed ratio results in increased formation of CO & CO_2.[4] [5]

GASIFIER FUEL CHARACTERISTICS

Coal is composed of complex mixture of organic and inorganic compounds. Organic compounds in coal are composed of the elements carbon, hydrogen, oxygen, nitrogen, sulfur & trace amounts of variety of other elements. Although only a few elements compose the organic compounds found in coal, these compounds are extremely complex and as a result they are not well understood. However research is being conducted into understanding organic structure in coal. Organic compounds in coal produce heat when coal is burned. They also may be converted to synthetic fuels or may be used to produce organic chemicals. The mineral content of coal determine what kind of ash will be produced when it is burned. The fusion temperature (melting point) of ash dictates the design of furnace and boiler. In general, if the fusion temperature is relatively low, then the molten ash is collected at the bottom of the furnace as bottom ash requiring one design. However if fusion temperature is relatively high, then the part of the ash that does not melt easily called “fly ash” is blown through the furnace or boiler with the flue gas and is collected in giant filter bags, or electrostatic precipitators, at the bottom of the flue stack, requiring a different design.

Coal that are relatively rich in iron- bearing materials (such as pyrite or siderite) have low fusion temperatures, whereas coals relatively rich in aluminum-bearing minerals (such as kaolinite or illite) tend to have high fusion temperatures. If electricity generating or heating plant is designed to burn one type of coal, then it must continue to be supplied with similar coal or undergo an extensive and costly redesign in order to adapt to a different type of coal. Similarly, furnaces designed to use coal that produce high amount of heat will suffer severe losses in efficiency if they must accept coal that burns with substantially less heat.[6]

FROM COAL TO BIOMASS GASIFICATION: COMPARISON OF THERMODYNAMIC EFFICIENCY

The effect of fuel composition on the thermodynamic efficiency of gasifiers and gasification systems is studied. A chemical equilibrium model is used to describe the gasifier. It is shown that the equilibrium model presents the highest gasification efficiency that can be possibly attained for a given fuel. Gasification of fuels with varying composition of organic matter, in terms of O/C and H/C ratio as illustrated in a Van Krevelen diagram, is compared. It was found that energy losses in gasifying wood (O/C ratio around 0.6) are larger than those for coal (O/C ratio around 0.2). At a gasification temperature of 927°C, a fuel with O/C ratio below 0.4 is recommended, which corresponds to a lower heating value above 23 MJ/kg. For gasification at 1227°C, a fuel with O/C ratio below 0.3 and lower heating value above 26 MJ/kg is preferred. It could thus be attractive to modify the properties of highly oxygenated biofuels prior to gasification, e.g. by separation of wood into its components and gasification of the lignin component, thermal pre-treatment, and/or mixing with coal in order to enhance the heating value of the gasifier fuel.[7]

THERMODYNAMICS OF BIOMAS CO-FIRING GASIFIER,FIRST & SECOND LAW ANALYSIS

The evaluation of gasification efficiency is based on energy analysis (formerly known in the USA as availability analysis). The exergetic efficiency is based on the first as well as the second law of thermodynamics, which is useful because it considers not only the decrease in energy of combustion of the product gas compared to the solid fuel (due to partial oxidation) but also increases in entropy (as a solid fuel is decomposed into many smaller molecules).

The first law of thermodynamics based analysis provides the performance of a thermal system based on conservation of energy However, first law analysis does not clarify where and why there are performance degradations ,which are mainly due to irreversibility generated in system or process. whereas second law analysis determine the magnitude & direction of irreversible proceses in a system and thereby provides an indicator that points the direction in which engineer should concentrate their efforts to improve the performance of the thermal systems. second law analysis is based on the concept of exergy(availability) it is the maximum amount of theoretical useful work obtainable in bringing the system of interest into the state of the environment.(Satyendra et al .;2014)The exergy losses for the co-firig option is more than that of baseline coal. from the exergy data for the plant shows the stack gas loss 97.6 GJ/hr. Boiler radiation losses 3.4 GJ/hr. Unburnt coal losses 5.5 GJ/hr.unaccouted for boiler heat losses 16.4 GJ/hr for coal only & that of 15% co-firing are 112.1 GJ/hr, 3.4 GJ/hr, 4.4 GJ/hr& 16.6 GJ/hr respectively.

Total exergy is the summation of physical exergy & chemical exergy. The exergy for the base coal line & co-firing at all state are tabulated in table-1.

Table-1. Total Exergy value on the state points.

state Point	Total exergy (GJ/hr)	
	Baseline coal only	15% Co-firing
1	1041.13	895.688
2	….	172.345
3	0.44	0.45

Some pros & cons of co-firing biomass in a coal fuel based power plant.

Pros

Through emission products like fly ash, bottom ash etc, the available energy losses comprehensively reduced by co-firing biomass.

Cons

Since total irreversibility losses including exergy losses corresponding to unaccounted boiler heat losses is more in case of bomass co-firing. Hence biomass co-firing is not acceptable option for prolong use.

Co-firing option in coal-fuel based power plant can be considerd as a short-term stop-gap measure to reduce environmental pollution.

It may continue till CO_2 sequestration option are available for the coal base thermal plant.[8]

EFFICIENCY ANALYSIS OF COAL FIRED POWER PLANT WITH CARBON CAPTURE

From the lower heating value of the fuel on a wet basis. It is possible to calculate the coal flow rate to provide the necessary heat for the cycle operation. From the coal flow rate and coal composition it is possible to determine the exhaust gas flow rate and composition, which is essential for the calculation of the capture system & its performance. From the proximate analysis of coal it is possible to calculate the wet LHV, which is neccesery to determine the steam generator efficiency

$$LHVwet = HHVwet - 23.944.(9.H\%wet + W.F\%)$$

$$\eta sg = \frac{Q1}{Qsg} = \frac{Q1}{\dot{m}coal.\dot{L}HVwet}$$

The use of different coal changes the exhaust gas composition & carbon dioxide flow rate by as much as 9% & 12% respectively.

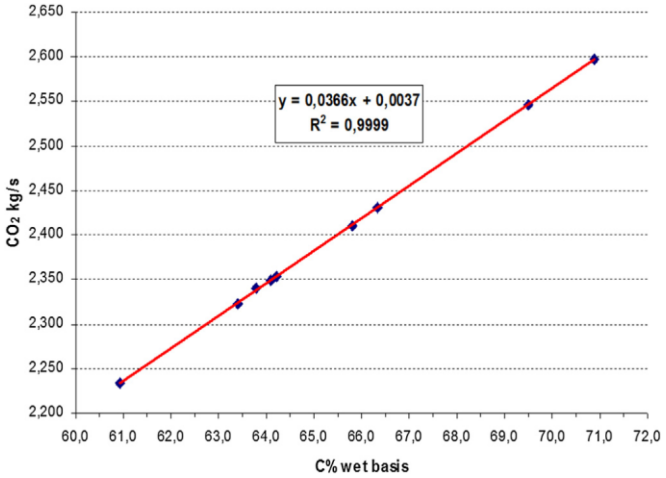

Fig:-1 shows how calculated CO_2 flow rate in the exhaust gas is correlated to the carbon content in coal on a wet basis.

This is an important parameter for the design of carbon capture system. It also provides the limits of operation of the carbon chemical absorption & stripping process.

Following are the expression for the plant efficiency with the capture system was given:

$$\eta with\ capture = \frac{W - Qreb.\eta reg}{Q1} = \eta without\ capture - \frac{Qreb.\eta reg}{Q1}$$

$$Qreb = Qspec.\dot{m}co2rem.$$

Where ,

$Qreb = reboiler\ heat\ demand$

$\eta reg = efficiency\ of\ steam\ cycle\ after\ steam\ extraction$

$Q1 = heat\ supplied\ to\ the\ steam\ cycle$[9]

TECHNOLOGIES COMPARISON WITH DIFFERENT APPLICATION

Coal Gasification technologies used in entrained flow gasifier with dry coal & slurry coal feed system are modeled & simulated. Since mot of the revised literature did not go deep in to model detail. (rolando et al.) presented comprehensive & complete model SNG process under thermochemical equilibrium developed in Aspen Plus software tools. Kunz & sliethaff developed a model with Aspen Plus to simulate a generic entrained flow gasifier. The aim was to analyze the effect of fuel feed system i,e dry feed & slurry feed on gasification process.at pressure 30 bar. They found higher energy efficiency for dry feed gasification (83%) when compared with slurry feed (72%) seifkar et al., studied the effect of coal supply & reactor cooling system on the entrained flow gasifier process. They three system ; first one dry coal feed with partial cooling with water , second, one dry coal feed with partial coling with water, and the last one is coal slurry feed system without refrigeration.

Musterd et al, presented a model with Aspen Plus to characterize an IGCC(Integrated Gasification Combined Cycle Plant) with an without CO_2 capture. They carried two technologies (dry feed & slurry feed) with five types of coal in IGCC plant energy behavior. They found that the thermal efficiency and power of the IGCC plant diminishes with the coal rank for the slurry feed technology, while the dry feed technology was not affected. Yu et all; studid the effect of gasification technology on the water gas shift reaction unit used for fischer-Tropsch processes.with an Aspen Plus model & showed that the dry feed technology presented higher energy efficiency and lesser H2/CO ratio with regards to the slurry feed technology.Armin and Silaen and Wang conducted numerical simulation of the gasification process in entrained flow gas reactor. They highlightd that syngas heating value (HHVsyngas) is higher with the dry system technology. Moreover, the carbon conversion efficiency and HHVsyngas incrase when oxygen is used as gasifying agent because the nitrogen inert effects of the air are avoided. With Aspen Plus analyze the thermochemical process or to study how the input parameters effect the IGCCs (Integrated gasification combined cycle plant) process. According to literature cited, the effect of coal gasfication technology on the SNG production using Aspen Plus model has not been presented Therefore, in the current study, two typical technologies used in entrained flow gasifier with dry coal & slurry coal feed systems are modeld and simulated. Empashis is put on interactions between the fuel supply technology and energy output parameters of coal SNG process, including carbon conversion efficiency, cold gas efficiency, process and global energy efficiencies, SNG heating value, whole index, and power. Since most of the revised literature did not go deep into model details, this study present an additional contribution, a comprehensive and complex model of coal to SNG process under thermochemical equilibrium developed in Aspen Plus.[10]

CONCLUSION

Based on the consequence presented in this dissertion, the following inferences can be drawn:

- Since, high moisture content coal (or low rank coal) require predrying of coal, it is not economically desirable.
- The equilibrium constant of reaction VIII show that the reaction has no significant thermodynamic limitation at temperature upto 2500K.Under practical condition of coal gasification, the combustion reaction proceed to completion while the gasificaion reaction & shift reaction approach pseudo equilibrium.
- Coal must be choosen on the basis of furnace designed in order to increase the efficiency,coal with low fusion temperature burn with substantially less heat.
- O/C ratio of wood are 0.6 & that of coal are 0.2, at 1200K Temp. O/C below 0.4 is recommended.
- Total irreversibility losses is more in case of biomass co-firing, hence it is not acceptable option for prolong use.
- Biomass co-firing system are not environment friendly till CO_2 capture system is available.
- In all different solvent configuration, 90% of CO_2 is removed on 100% of the exhaust gas flow rate.
- In all gasifier application higher energy efficiency is achieved for dry feed fuel system.

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