

HYDROGEN GAS PRODUCTION USING COAL GASIFICATION PROCESS: A PROSPECTIVE ENERGY SOURCES

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Abstract- Fossil fuel consumption is increasing day by day which have limited resources and as a consequences introduction to alternative sources of fuel and renewable energy sources is a major concern now a day. Energy from hydrogen is a potential source of energy as it is independent of weather unlike sources of solar energy. This paper presents hydrogen gas production from coal gasification process and this paper also represents that hydrogen can be served as an alternative solution of energy crisis due to its higher energy density and shows a coal gasification model which is developed to produce H₂ fuel and the process is simulated using ASPEN HYSYS, however maximum H₂ production rate was found 83.32 KGmole/hr for bituminous coal. This paper also illustrates the simulation of coal which is partially oxidized to produce syngas and then a water gas shift reaction where steam reacts with syngas to give the desired output of hydrogen. This process of hydrogen production is associated with the removal of sour gasses; absorber and distillation columns which are used to separate the impurities by another liquid solvent. For simulation in this system, different coal compositions are used to find the optimum feed rate, air flow rate, steam flow rate and solvent circulation rate for higher amount of hydrogen production. Moreover hydrogen, having a higher heating value of about 150 MJ/Kg, can be an environment friendly source of energy with zero emissivity.

Keywords: Hydrogen production, HYSYS, gasification, coal, zero emissivity.

1. INTRODUCTION

Due to limited sources of fossil fuel, the world is now at the stage to find alternative sources of energy. Coal gasification is the process of producing additional energy to make up the shortage in liquid and gaseous fuels. Now the world economy depends on energy provided mainly by oil and natural gas, however in the twenty-first century world petroleum and natural gas production will begin to decline because of increasing world population and aspirations for an improvement in the quality of life. The present energy crisis in Bangladesh is due to over dependence on gas which fulfills more than 70 percent of the country's energy needs [1]. The crisis is increased rapidly and so to find an alternative source of energy is essential. Bangladesh has an abundant reserve of coal of about 300 million metric tons [1] and the geological and social constraints of an over-populated fertile agricultural land area remain an obstacle to large scale coal mining and this has to be addressed rationally. In absence of other immediate energy options, gas exploration and partial coal exploitation program a\can be a potential solution of a developing country like Bangladesh. The invention of coal in Barapukuria and Khalaspir, Bangladesh, has opened the main source of fuel in our country [1]. The proper utilization of these resources requires a better understanding of the

formation, structure, composition and calorific value and method of analysis of the material and among these coal fields, coal has been mining only from Barapukuria coal field which is not so enough in quantity to meet the demand of coal as a fuel in our country since there is no petroleum resource in our country. The socio-economic condition of our country as well as the environmental degradation due to deforestation can be improved by proper and effective utilization of coal. The energy crisis in our country also can be decreased by making proper use of coal and so proper chemical and geochemical investigations on Bangladeshi and imported coal are so necessary for the improvement of our country. In order to meet the increasing demand, a huge amount of coal has to be brought into the production of energy. Coal is used as a primary fuel in the world to meet the demand of energy. However, coal is a very complex and heterogeneous material, but it is the most plentiful resource and will continue to be the principle fuel used for the electricity generation. On the other hand, as a matter of fact, coal has a hazardous nature when it is combusted in open air, sulphur and nitrogen contamination in the coal have a negative impact on the environment. For these reason, coal gasification is necessary. However as its name suggests, coal gasification converts coal into a gas form similar to

natural gas and gasification may occur in a separate processing facility or a coal mine. Moreover, these gases can be stored or burned for the production of electricity, fuel or chemicals. Gasification usually involves the use of oxygen and steam and this process offers several advantages and disadvantages with regard to efficiency, cost, environment and other factors. Coal is an abundantly available energy source and coal gasification is a primary way to produce liquid fuels for transportation and gaseous fuels for heating and chemical production. Moreover, some technologies for producing liquid fuels and gaseous fuels have been commercialized for quite some years and some are still under development [2]. In many cases these technologies are available; obstacles for commercial application have been the high cost and another reason for coal gasification is necessity to develop advanced power generation system. The world electric utility industry has greatly dependent on the relative abundance of coal. As, a consequences, more use of coal is still vital to future electrical power generation and the expansion use of coal must be required to carry out in an environmentally acceptable and economically competitive manner. For conventional pulverized coal fired power plants, it is difficult to meet these requirements. As an advanced power generation system, integrated coal gasification combined cycle (IGCC) offers an attractive approach to produce electrical power at high efficiency and has shown the greatest potential for meeting stringent emission control requirements [3]. Therefore coal gasification is a very important clean coal technology from the viewpoint of sustainable development. In this case, it requires using coal gasification technology and its applicable technologies.

This paper presents coal gasification process in order to produce hydrogen gas and major advantages of gasification include its abilities to produce different forms of energy and create useful byproducts [4]. People can use the energy immediately in the form of electricity or store it as a fuel for future and portable consumption. The U.S. Department of Energy indicates that byproducts of gasification include sulfur and ammonia, both of which have important industrial applications [5] and this improves the supply of such commodities and helps make gasification more economical for its operators. Gasification generates electricity more efficiently than simply burning coal, which reduces the amount of coal mining necessary to generate same amount of power or fuel. However, power plants that burn coal-derived gases also use their exhaust and heat to produce steam, according to the Department of Energy [5] and this steam turns a turbine to generate additional electricity, yielding efficiency rates at least 17 percent greater than those of conventional coal-fired plants [6]. One of the major disadvantages of coal gasification is the installation cost and maintains the necessary facilities. The Pacific Northwest National Laboratory indicates that gasifier refractories typically last about one year to 450 days at most, costing roughly one million dollars to replace [7]. They also take approximately 21 to 42 days to install, during which the gasification facility cannot operate. This raises the cost of energy and chemicals produced by

such plants, making it more difficult for them to compete with equivalent products generated using conventional methods. Moreover, despite certain environmental advantages, coal gasification still produces more pollution than many energy sources and cannot eliminate the environmental harm of coal mining.

Figure 1 shows coal gasification process and this paper presents hydrogen production from coal gasification process.

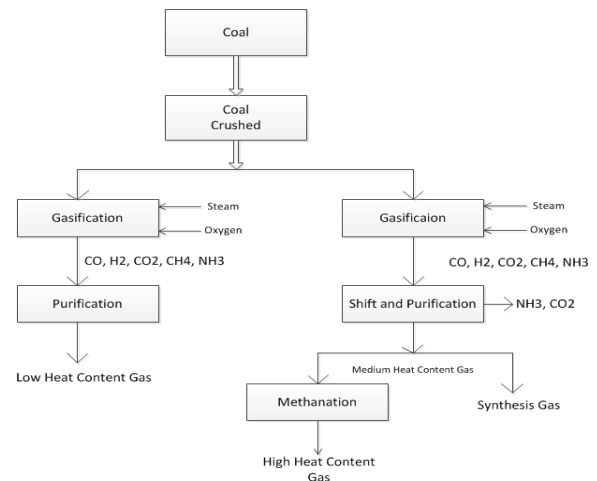


Fig. 1: Coal Gasification Process [2]

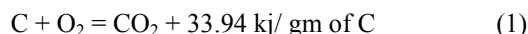
2. Methodology

Combustion is a chemical reaction of fuel and oxygen, when combustible elements of fuel combine with O_2 , heat energy produces and during combustion combustible elements like carbon, sulfur, hydrogen etc. combine with oxygen and produce respective oxides. However, source of oxygen in fuel combustion is air and by volume there is 21% of Oxygen presents in air and by weight it is 23.2%. Moreover though there is 79% (by volume) nitrogen in air but it plays no role in combustion and Nitrogen carries heat produced during combustion to steam boiler stack. However, according to combustion theory amount of air required for combustion is that amount which supplies sufficient O_2 to completely oxidize combustible elements of fuel and this quantity of air is normally known as stoichiometric air requirement, this amount of air depends upon the nature of fuel. However, Stoichiometric air requirements for different fuels are obtained by analysis of fuel and they are shown in Table 1.

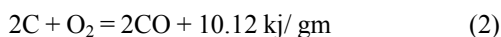
Table: 1 Stoichiometric air requirements for different coal composition

Fuel	stoichiometric air mass / unit mass of fuel
Bituminous Coal	11.18
Anthracite Coal	10.7
Coke	9.8
Lignite	7.5
Peat	5.7
Residual Fuel Oil	13.85
Distillate Fuel Oil(Gas Oil)	14.48

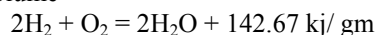
Combustion is not necessarily favorable for maximum degree of oxidation, and it can be temperature-dependent.



For sufficient air, it is said that mass wise there is 23.2 % O_2 presents and hence in air the amount of air required to provide 2.67 gm of O_2 is, $(100 \div 23.2) \times 2.67 = 11.5$ gm. As per ideal combustion theory, after combustion of one gm carbon (C), product of combustion contains only 3.67 gm of CO_2 and $(11.5 - 2.67)$ of N_2 . Incomplete combustion of coal will occur when there is not enough oxygen to allow the fuel to react completely to produce carbon dioxide and water. It also happens when the combustion is quenched by a heat sink, such as a solid surface or flame trap. Same as complete combustion, water is produced by incomplete combustion. However, carbon and carbon monoxide are the products instead of carbon dioxide. In incomplete combustion of coal, some of the hydrogen remains unreacted. A more complete set of equations for the combustion of a hydrocarbon in the air, therefore, requires an additional calculation for the distribution of oxygen between the carbon and hydrogen in the fuel. The amount of air required for complete combustion to take place is known as theoretical air.



After combustion of one gm carbon (C), product of combustion contains only 2.33 gm of CO and $(5.75 - 1.33) = 4.42$ gm of N_2 . From equation (1) and (2) it is clear that due to insufficient air combustion, the heat lose during 1 gm of coal combustion is, $(33.94 - 10.12) = 23.82$ kg. During the combustion of coal, minor constituents are also oxidized. Sulfur is converted to sulfur dioxide and sulfur trioxide, and nitrogen compounds are converted to nitrogen oxides. The incomplete combustion of coal and the combustion of these minor constituents results in a number of environmental problems. $S + O_2 = SO_2 + 9.141 \text{ kJ/ gm}$, so, air required for 1 gm sulfur combustion, is $(100 \div 23.2) \times 1 = 4.31$ gm, so, combustion product, after completing 1 gm of sulfur combustion, contains 2 gm of SO_2 and N_2 of $(4.31 - 1) = 3.31$ gm. Hydrogen combustion is the process by which hydrogen reacts with an oxidizing agent (a compound that supports or causes combustion of other materials) and burns. Hydrogen combustion is exothermic combustion, which means it releases heat and energy. Hydrogen gas is highly flammable and will burn in air at a very wide range of concentrations between 4% and 75% by volume



From combustion theory of C, S and H_2 it is found that 2.67 gm oxygen is required for 1 gm carbon combustion, which implies 2.67 C gm oxygen is required for C gm carbon, 1 gm oxygen is required for 1 gm sulfur combustion, which implies S gm oxygen is required for S gm sulfur and 8 gm oxygen is required for 1 gm

hydrogen combustion, which implies 8H gm oxygen is required for H gm hydrogen. Hence 1 gm of coal (fuel) which contains C gm carbon, S gm sulfur and H gm hydrogen requires $(2.67 C + S + 8 H)$ gm of oxygen for efficient combustion. Some amount of oxygen may be contained in the fuel itself in form of different compounds and it takes part in combustion also. If O is the original weight of the oxygen presents in 1 gm of fuel, net requirement of oxygen for sufficient coal combustion is $(2.67 C + S + 8 H - O)$ gm for that the amount of air required is $(100 \div 23.2) \times (2.67 C + S + 8 H - O)$. Gasification simulation is done on ASPEN HYSYS. Setting up the simulation environment is an important factor to get the perfect simulation data. Mass flow rate, molar flow rate, temperature, pressure etc. are to be defined before entering simulation environment. Several graphs are obtained from various components flow rate, composition and compositions. Production of hydrogen from coal gasification involves a number of chemical reactions and several treatment stages of impurities. Coal from the ore is pre-treated to remove the sulphur contamination. The pre-treated coal is burned in a conversion reactor where carbon presented in the coal reacts with the oxygen presented in the air and produce mainly carbon mono-oxide due to incomplete combustion. For incomplete combustion, air flow rate is controlled so as the rate of oxygen reacted with the carbon is limited and some of the carbon reacts with oxygen to produce carbon di oxide. The combustion mixer from the conversion reactor mainly consists of nitrogen, hydrogen, carbon mono oxide and carbon di oxide. Generally nitrogen oxides (NOX) are not produced because the combustion temperature is not high enough to produce nitrogen oxides. If oxygen is separated from the air in a reactor commonly known as cryogenic reactor, then the combustion mixer will only contain carbon mono oxide and hydrogen which is known as synthetic gas (syngas). In order to enrich the percentage of hydrogen in the syngas, the product of combustion is then allowed to react with steam in another conversion reactor where carbon mono oxide is converted to carbon di oxide by a chemical reaction known as water gas shift reaction. The product of combustion from the reactor is now composed of nitrogen, carbon di oxide and hydrogen. The products of combustion are now at the stage of purification. In this process simulation, a column absorber with a liquid solvent is used and for the removal of carbon di oxide, MEA (mono ethanol amine) is used. The flow rate of MEA is dependent on the percentage of carbon di oxide in the gaseous mixer. The absorbed CO_2 is sent for purification in a distillation column known as stripper or stripper. In the distillation column, CO_2 is separated from the liquid MEA, where it is passed through a condenser. Some of the MEA is still presented in the separated CO_2 , it is needed to separate again which is done by a simple separator and then CO_2 is sent to storage. The MEA stream from the stripper is passed through a re-boiler to recycling process. The gas mixer which is being separated during CO_2 removal, in now consists of nitrogen and hydrogen and a trace amount of MEA. The mixer is passed through a condenser and then to a

separator, where additional MEA is separated from the mixer. The separated mixed is now composed of only N_2 and H_2 . In order to separate H_2 from N_2 , the mixer is passed through another condensed where it is further condensed to the condensation temperature of N_2 . Liquid N_2 is then separated in another separator. The rest of the mixer is H_2 and both H_2 and N_2 are then sent to storage.

3. Results and discussion

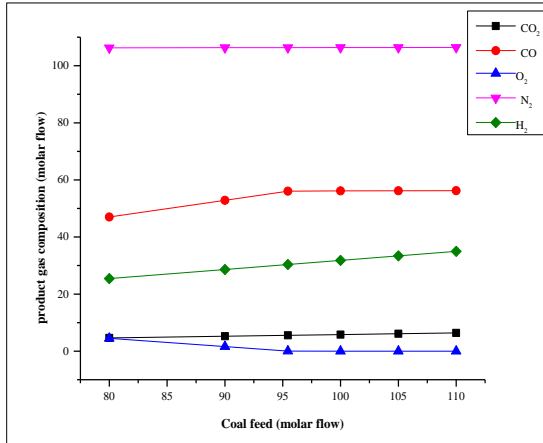


Fig.2: Product gas composition with respect to coal feed (molar flow) from conversion reactor 1

Figure 2 shows product gas composition (molar flow) with respect to coal feed rate (molar flow) for the combustion in the conversion reactor-1 and from Figure 2, it is seen that combustion products (H_2 , CO & O_2) increases with increase of coal feed rate except the amount of N_2 and CO_2 , as the amount of this component remains constant throughout the process. However, production rate of hydrogen increases and rate of production of CO is increased up to the point of feed rate is 96 and then it remains almost constant.

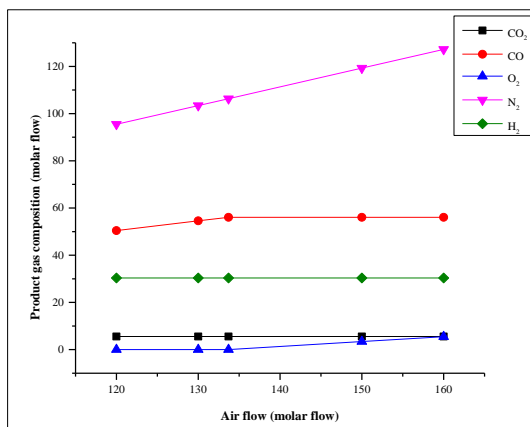


Fig.3: Product gas composition with respect to air flow rate (molar flow) from conversion reactor 1

Figure 3 represents the product gas composition (molar flow) with respect to air flow rate (mass flow) for combustion in the conversion reactor-1 and from Figure 3 it is also illustrated that combustion product (N_2 , CO & O_2) increases with an increase in air flow except the

amount of H_2 and CO_2 , as the amount of this component remains constant throughout the process.

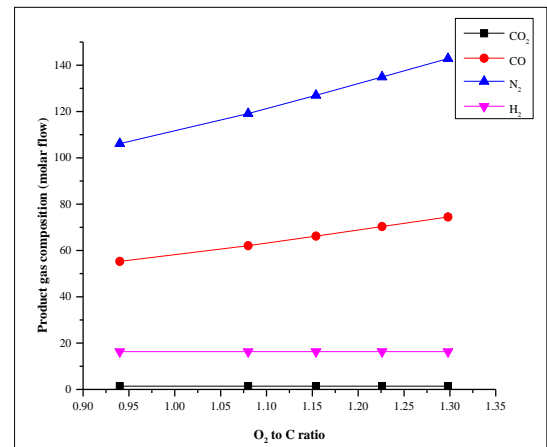


Fig.4: Product gas composition with respect to oxygen to carbon ratio from conversion reactor1 for anthracite

Figure 4 is drawn on the basis of anthracite coal sample containing 92% carbon and Figure 4 shows relation between the product gas molar flow rate and the ratio of oxygen to Carbon flow ratio. Moreover, it is seen from Figure 4 that amount of CO_2 is almost same throughout the reactor, but the flow rate of CO is increased as the C/O ratio increased and the amount of H_2 production is constant but the N_2 flow rate is varied.

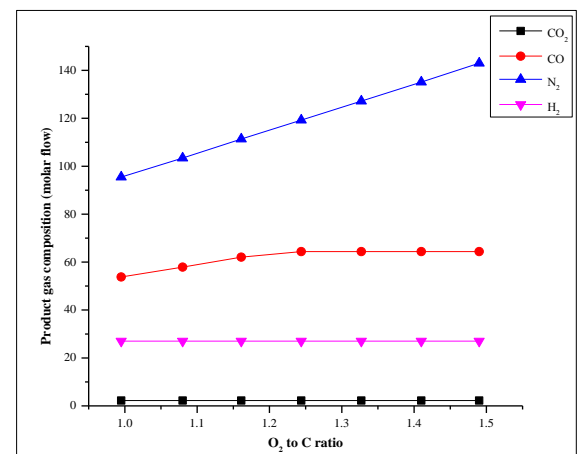


Fig.5: Product gas composition with respect to oxygen to carbon ratio from conversion reactor 1 for bituminous coal

Figure 5 is drawn on the basis of bituminous coal sample containing 80% carbon. Figure 5 presents relation between product gas molar flow rate and ratio of oxygen to carbon and the amount of CO_2 and H_2 are almost constant throughout the reactor, though the H_2 molar flow rate is much higher than anthracite coal, though the flow rate of CO and N_2 are increased as C/O ratio increased.

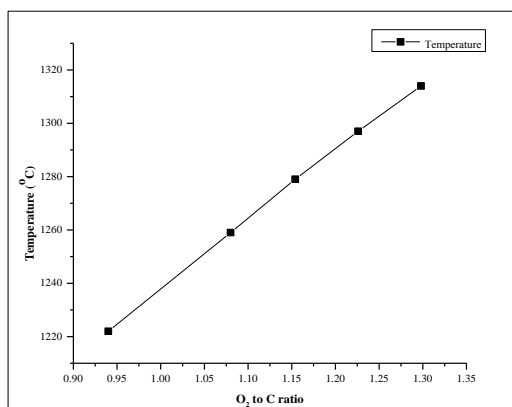


Fig. 6: Product gas temperature with respect to oxygen to carbon ratio from conversion reactor for bituminous coal

Figure 6 shows relation between temperatures of combustion product leaving the conversion reactor at O/C ratio of 1.00 is about 1235°C, the temperature is increased up to the O/C ratio of 1.17 and then the temperature is decreased due to the excess air inlet.

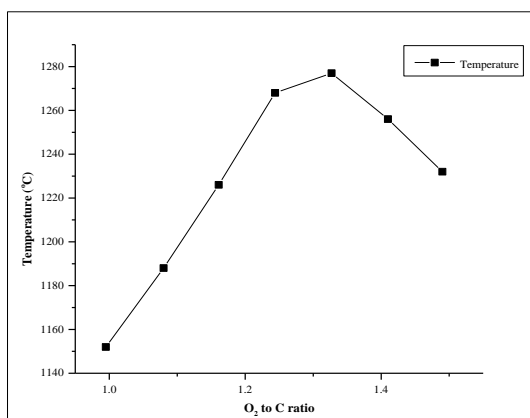


Fig. 7: Product gas temperature with respect to oxygen to carbon ratio from conversion reactor for bituminous coal

Figure 7 is illustrated for anthracite coal and it is seen from Figure 7 that temperature of combustion product leaving conversion reactor at C/O ratio of 1.00 is about 1240 °C unlike bituminous coal the temperature is increased almost linearly as the C/O ratio increased, because of the much higher carbon containing in anthracite coal.

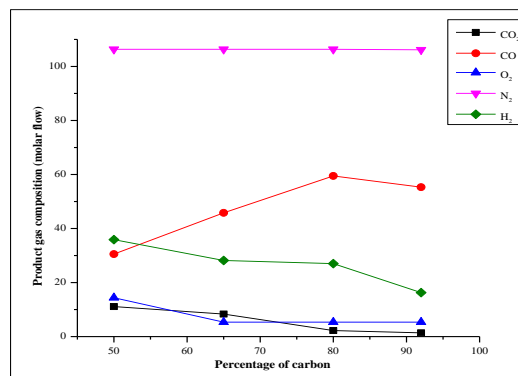


Fig. 8: Product gas composition with respect to carbon percentage for different types of coal

Figure 8 shows graph for four different types of coal (peat coal, brown coal, bituminous coal and anthracite coal) by keeping air flow rate and coal flow rate constant and CO₂ in the product gas for all kind of coal is almost same because it is independent of carbon percentage and amount of CO flow is increased as the carbon percentage increases up to 80%. On the other hand flow rate of H₂ decreases as H₂ percentage decreases in the coal.

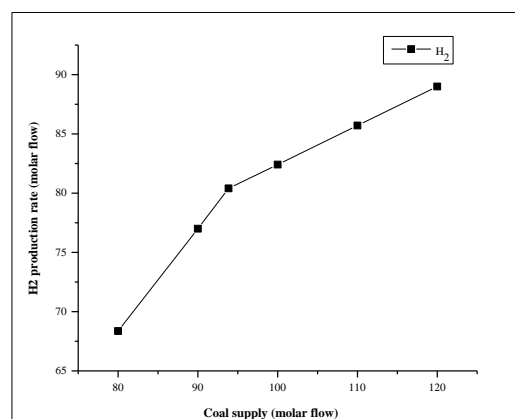


Fig. 9: H₂ production rate with respect to coal supply for bituminous coal

Figure 9 shows, H₂ production rate with respect to coal supply for bituminous coal, it also represents that flow rate of hydrogen increases as the coal supply increases.

4. Conclusion

A gasification model has been developed to analyze various types of coal combustion and coal gasification process has been simulated using ASPEN HYSYS software where coal feed rate, air flow rate, steam flow rate and solvent circulation rate were taken as the parameters. Moreover, varying these parameters, maximum H₂ production rate was found 83.32 KGmole/hr for bituminous coal when air flow rate, steam flow rate and solvent circulation rate were 133.7 KGmole/hr, 80 KGmole/hr and 40000 KGmole/hr respectively. Moreover as the absorber pressure was just a little above the atmospheric pressure, mono ethanol

amine (MEA) was used as CO₂ absorbing agent and percentage of CO₂ capturing was almost 100 when the liquid solvent circulation was above 40000 KGmole/hr.

5. REFERENCES

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