

STUDY ON PERFORMANCE OF PARTIAL COMBUSTION UNIT AT DIRECT
REDUCTION PLANT BY USING CFD

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ABSTRACT

Partial Combustion (PC) system is one of the very important systems in Direct Reduction Plant (DRP) which allows increasing the production rate, quality of Direct Reduced Iron (DRI), and diminishing the natural gas consumption. This system consists of one transfer line with two oxygen lances placed in horizontal position in the middle of transfer line. The transfer line is situated in between the gas heater and reactor. The objectives of this study are to validate the temperature profile of simulated result with current installation in real plant and to define more accurate temperature reading of Partial Combustion system. Besides, the other objective of this study is to propose new position of oxygen lances installed. To modify an existing system, it actually requires high cost. Hence, in this study a simulation was performed in order to solve the problem exists. Computational Fluid Dynamic (CFD) is a tool used in this simulation which consists of GAMBIT and FLUENT. Volume meshing in GAMBIT is an important part to be considered before doing simulation in FLUENT as a solver. Parametric study was proposed to give more accurate temperature reading. New model of transfer line with considering refractory is believed can give better result for the same purpose. In real plant, the transfer line was covered by the two layers of refractory brick. For further modification, new position of oxygen lances also introduced to increase the temperature of reactor inlet. Increasing of temperature at reactor inlet can increase the production rate and will increase the tubes life in heater. For this purpose, the modified of oxygen lances position give better performance than existing position. From this study, the temperature profile of Partial Combustion system can be validated thus can give better performance for this system.

ABSTRAK

System Separa Pembakaran (Partial Combustion System) merupakan satu sistem yang sangat penting dalam Loji Direct Reduction (Direct Reduction Plant) yang membolehkan peningkatan kadar pengeluaran, kualiti Direct Reduced Iron (DRI), dan mengurangkan penggunaan gas asli. Sistem ini terdiri daripada satu pemindahan selaras dengan dua tombak oksigen yang diletakkan di dalam kedudukan mendatar di tengah – tengah ‘transfer line’. ‘Transfer line’ terletak di antara pemanas gas dan reaktor. Objektif kajian ini adalah untuk mengesahkan profil suhu hasil simulasi dengan pemasangan semasa di dalam loji sebenar dan menentukan bacaan suhu lebih tepat sistem Pembakaran Separa. Selain itu, objektif lain kajian ini adalah untuk mencadangkan kedudukan baru tombak – tombak oksigen dipasang. Untuk mengubahsuai sistem yang sedia ada, ia sebenarnya memerlukan kos yang tinggi. Oleh itu, dalam kajian ini, simulasi telah dijalankan untuk menyelesaikan masalah yang wujud. Computational Fluid Dynamic (CFD) adalah alat bantuan pengkomputeran yang digunakan dalam simulasi ini yang mana terdiri daripada Gambit dan Fluent. Jumlah jaringan bersirat dalam Gambit adalah satu bahagian penting yang perlu dipertimbangkan sebelum melakukan simulasi dalam Fluent. Kajian berdasarkan parameter adalah dicadangkan untuk memberikan bacaan suhu yang lebih tepat. Model baru transfer line dengan mengambil kira refraktori dipercayai boleh memberikan keputusan yang lebih baik untuk tujuan yang sama. Dalam loji sebenar, transfer line telah dilindungi oleh dua lapisan bata refraktori. Bagi pengubahsuaian lanjut, kedudukan baru lance oksigen juga diperkenalkan untuk meningkatkan suhu masuk bagi reaktor. Meningkatkan suhu di bahagian masuk reaktor boleh meningkatkan kadar pengeluaran dan akan meningkatkan hayat tiub pemanas. Bagi tujuan ini, kedudukan lance oksigen yang diubah suai memberikan prestasi yang lebih baik daripada kedudukan yang sedia ada. Dari kajian ini, profil suhu sistem Pembakaran Separa boleh disahkan dengan itu dapat memberikan prestasi yang lebih baik untuk sistem ini.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Steel has become one of the most important materials and highly demanded from heavy industries nowadays. In Malaysia, Perwaja Steel Sdn. Bhd. is the only iron and steel making company that provides the materials all over the country. The plant that used is Direct Reduction Plant. In Direct Reduction Plant, Partial Combustion Unit is important to increase the temperature of reducing gases for purpose of removing the oxides inside the ore. This unit located between the heater and reactor which contains one transfer line and two oxygen lances where the oxygen is injected in the transfer line. Besides that, Partial Combustion Unit is important to increase the temperature of reducing gases entering the reactor. The temperature inlet of reducing gases is about 900 – 930°C. This plant consists in the removal of oxygen from iron ores at temperature under the melting point of the solid material, for the production of a high content of metallic iron and a certain level of carbon mainly as iron carbide (Fe_3C). Since 1984, Perwaja Steel Sdn. Bhd. has been operating an iron and steel mill based on the direct reduction – electric steelmaking process route in the Malaysian federal state of Terengganu. The partial combustion of the natural gas generates the hydrogen and carbon monoxide reducing gases and also provides the additional energy required for natural gas reforming and carburization of the metallic iron. Because of partial combustion, the reducing gas temperature at the furnace inlet is above 1000°C. But due to the endothermic behavior of the combined chemical reactions taking place inside the shaft furnace, the resulting temperature at the reduction zone is below the potential for material cluster formation (Gerardo G. L. and Eduardo N., 2008).

1.2 DIRECT REDUCTION PLANT

Direct Reduction (DR) plant is an iron making process which utilizes natural gas to reduce iron ore to produce Direct Reduced Iron (DRI). Tenova HYL is one of the suppliers that supplies direct reduction plants worldwide in a wide variety of configurations for each particular client requirement. DR plants can be designed to produce cold discharge DRI, hot discharge DRI for direct feeding to an adjacent electric furnace meltshop, or for production of HBI for commercial trade.

The raw material is commonly iron ore pellets or lump iron ore. Then, this material will reduce to metallic iron by means of reduction gas. The reducing gas is produced from a mixture of natural gas which is usually methane and recycled gas from the reduction furnace. The mixture flows through catalyst tubes where it is chemically converted into a gas containing hydrogen and carbon monoxide. The desired reducing gas temperature is typically in the range of 900°C. Once in contact with the solid material inside the reactor, further reforming and cracking are carried out due to the catalytic effect of metallic iron.

1.3 PARTIAL COMBUSTION SYSTEM

This study is focus on Partial Combustion (PC) system in DR plant. PC unit consists of a transfer line included two oxygen lances inside the transfer line. This system will allow an important increase in the reducing gas temperature, as well as in – situ reforming, decreasing the reformed gas consumption by about 25%, combined with increased reactor productivity.

1.4 DIRECT REDUCED IRON

Direct Reduced Iron (DRI) is a main product of DR plant. It is mined iron ore produced in the form of small pellets, lumps or in the fine form. It undergone a process of chemical reduction to remove the oxide from the iron ore by introducing a reducing agent to the iron ore and a series of chemical reaction occur under high temperature in the presence of catalyst.

1.5 PROBLEM STATEMENT

The temperature profile evaluation from the previous study of this Partial Combustion system shows the better results regarding to the increment of temperature at the inlet to the reactor. It can be improve in order to get more accurate value of temperature at the same thermocouple position by using existing data from real plant. By performing Computational Fluid Dynamic (CFD) simulation, the performance of this system can be improved for further optimization. It will be easier to propose the modification for the real plant. For better result, new geometry of transfer line which is considering refractory lining is proposed due to existing plant nature. Besides, the new position of oxygen lances installed also investigated by performing a simulation on Partial Combustion system by using CFD regarding the temperature drop happened in transfer line.

1.6 OBJECTIVES

The objectives of this study are:

- (i) To validate the temperature profile of current Partial Combustion unit in plant with simulation result.
- (ii) To obtained more accurate value of temperature at the thermocouple point.
- (iii) To propose new position of oxygen lances in transfer line.

1.7 SCOPE OF STUDY

To achieve the objectives of this study, there are some scopes in this study such as:

- (i) Performing simulation on Partial Combustion unit.
- (ii) Considering the refractory lining in modeling the transfer line.
- (iii) Exploring new position of oxygen lances in transfer line.

CHAPTER 2

LITERATURE REVIEW

2.1 DIRECT REDUCTION PROCESS

There are many technologies in iron making and steelmaking industry such as Tenova, Midrex, HYL, Corex. In Perwaja Steel Sdn. Bhd (PSSB), they have been operating an iron and still mill based on the direct reduction – electric steelmaking process since 1984 (Morales R. G., Prenzel M., 2002). Based on the industrial experience of the last decade, HYL have developed and engineered Partial Combustion System for the existing or new plants based whether on reformer or ZR process (Perwaja Steel).

For steel making, the iron changing are mainly hot metal and scrap. They used moving bed reactors in the process. This reactor will increase the productivity of iron. Blast furnace (BF) is the classic iron making process that extracts metallic iron from iron ore by carbon. Actually, general routes of iron making are Smelting Reduction (SR) and Direct Reduction (DR).

Smelting reduction processes include reduction of iron oxides and gasification of carbon-bearing materials (normally coal) in a liquid metal bath, at above the fusion temperature of pure iron (1535°C). The smelting reduction processes differs from the conventional blast furnace route in that non-coking coal can be directly used for are reduction and melting work, eliminating the need for coking plants, hence considerably reducing raw-material costs and environmental emissions. The use of lump are or pellets also dispenses with the need for sinter plants. Typical smelting reduction processes are Corex, Finex , and HIs melt. Corex developed by Siemens-VAI is an

industrially and commercially proven smelting-reduction process for the cost-efficient and environmentally friendly production of hot metal from iron ore and coal (Fruehan R. J.). But, this research is only focus on Direct Reduction process as belongs to Perwaja Steel.

A direct reduction process consists in the removal of oxygen from iron ores. For this purpose, reducing gases as Hydrogen (H_2) and Carbon Monoxide (CO) are used at certain temperature and pressure. The product obtained is a solid with a high content of metallic iron and some carbon that is known as direct reduced iron (DRI) (Perwaja Steel). DRI is actually produced from direct reduction of iron ore by or reducing gas from Natural Gas (NG) or coal. As Direct Reduction Plants are not built on the same, enormous scale as blast furnaces, their investment costs are lower, and they have been mainly constructed in developing countries where natural gas is relatively inexpensive. Recently, however, even in developed countries, such as the United States, Direct Reduction Plants are drawing more and more attention as a way to provide a stable supply source of pure iron, substituting steel scrap.

In one another process, the conversion of the iron oxides to metallic iron is a reduction process in which CO and H_2 are the reducing agents. The overall reaction of this process is:



CO is obtained within the furnace by blasting the coke with hot air from a ring fuyeres about two – thirds ($\frac{2}{3}$) of way down the furnace. The reaction of CO is:



Blast Furnace Hydrocarbon (oil, gas, tar, etc.) was added to blast to provide a source of H_2 . In modern direct reduction, H_2 and CO may be produced separately so that the reduction process can proceed at a lower temperature.

Direct Reduction is the removal of oxygen from iron ores at temperature under the melting point of the solid material, for production of a product with high content of metallic iron and a certain level of carbon mainly as iron carbide (Fe_3C) (Morales R. G., Prenzel M., 2002). Hot Briquetted Iron (HBI) is produced increasing the DRI density, by applying pressure at high temperature (700°C). HBI is more commonly used on a merchant basis for export and also can be produced when friable iron ores are to be produced. These ores cannot be used for the production of cold DRI due to high fines generation.

New direct reduction process needs such a long time and significant capital expenses. Besides that, this process must have the advantages that include lower energy consumption, lower investment costs, higher product value or higher flexibility for using cheaper raw materials and reducing gas. There was three main chemical factor used in order to characterized the DRI which are the metallization level (metallic iron), the content and form of carbon and the content and type of gangue (non – ferrous oxide). The typical metallization levels in modern DR process vary in a range from 92% - 95%, whereas the DRI carbon content can be controlled up 5% (HYL Process) mainly in the form of iron carbide (Fe_3C) (Morales R. G., Prenzel M., 2002). The content of residual elements such as Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo) and Tin (Sn) is normally very low (traces) in DRI.

In industries, Midrex and HYL operate DR as gas – based process which is operate under a moving bed reactor (shaft furnace) concept for iron ore reduction. It use raw material DR grade – pellets ad lump ores. This raw material was proven extensively their economic results and plant reliability reaching plant availability higher than 90%. The process steps also completely developed and highly flexible (Morales R. G., Prenzel M., 2002).

2.2 HYL DIRECT REDUCTION PLANT

Figure 2.1 shows the development of HYL process. The original process is development from using fixed bed reactor to moving bed reactor which is continuous process. This process was firstly starting in Hylsa Monterrey, Mexico in May 1980. After several years, another development are implemented which is in 1986, CO₂ removal system was incorporated in the reducing circuit. Through the years, the partial combustion technique was applied in HYL industrial plant in 1995. The injection of oxygen at the transfer line between the reducing gas heater and the reactor inlet applied in this technique. After that, in 1988, the self – reforming system was developed. The reformed gases make – up is decreased to zero (Morales R. G., Prenzel M., 2002).

The general diagram for HYL process is shown in Figure 2.2. It is designed for conversion of iron ore (pellet/lump) into metallic iron, by the use of reducing gases in solid – gas moving bed reactor. Oxygen was removed from the iron ore by chemical reactions based on H₂ and CO for the production of highly metalized DRI. The reducing gases are generated by self reforming in the reduction reactor. The equation for the self – reforming of Natural Gas are:



NG is fed as make –up to the reducing gas circuit and oxygen inject at the inlet of the reactor. Partial combustion of NG with oxygen generates reducing gases in – situ (H₂ and CO) and increasing the operating temperature which is required for reforming and iron ore reduction. Further reforming and cracking are carried out due to the catalytic effect of metallic iron once in contact with the solid material inside the reactor. Other alternatives sources of reducing gases are reformed gas, coal gas and others which have same basic process scheme (Morales R. G., Prenzel M., 2002).

There are many applications in industries that use HYL process. First HYL moving bed plant outside Hylsa was built by a Consortium Formed by Ferrostaal AG and MAN – GHH of Germany, for the Government owned Mexican Steelmaker, Sicartsa. It has a nominal production capacity of 2.0 Million ton/year of DRI. It's operating with four moving bed reduction reactors and two reformers. One reformer serves two reactors; each reactor is directly connected to one reducing gas heater. Main equipment and auxiliary systems serving the two modules are Iron ore and DRI handling/storage systems, Inert gas generation unit, Water treatment plant, Cooling water systems (process and equipment), Instrument air system, Electrical equipment and Control system. In this plant, CO₂ absorption unit was not incorporated in the reducing gas circuit. Energy integration in the process scheme with CO₂ removal is optimized generating steam for the CO₂ desorption unit, by recovering energy from the reformer combustion gases. Without a CO₂ removal unit, the specific energy recovery scheme was based on an integrated reformer – gas heater arrangement in Figure 2.3, where a fraction of the recycled reducing gas stream is preheated in the reformer convection section, recovering sensible energy from the reformer combustion gases. Final heating is carried out in the reducing gas heaters. The combined efficiency of this reformer – heater arrangement is over 91% (Morales R. G., Prenzel M., 2002).

Second plant that operates in August 1990 is P.T. Karakatau Steel (PTKS) which based on HYL moving bed process. One of the four HYL fixed plants was decommissioned. Only the corresponding reformer and general services were used for further operation with the new HYL moving bed reactors. With the existing reformed gas capacity, which previously was only enough for the production of 500 000 ton/year of DRI, two HYL moving bed reduction units are currently producing over 1.35 Million ton/year of DRI. Actually, the moving bed reduction units achieved considerably better chemical utilization of the reducing gas than the fixed bed reactors that previously used. The CO₂ removal system incorporated to assures that the reducing gas constituents are fully recycled for optimum plant productivity. DRI produced in the HYL moving bed plant has higher metallization, higher carbon, and uniform quality. This plant which has two reduction reactors, two gas heaters, three process gas screw compressors for the reducing gas and cooling gas, and the material handling equipment for the iron ore pellets, lump ore and DRI. The moving bed proven that can give the higher productivity

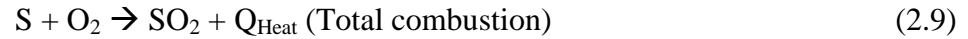
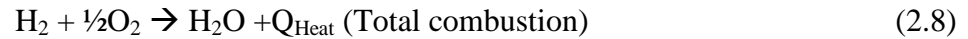
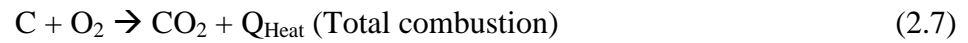
because of increasing capacity over 2.8 Million ton/year starting from year 1993. Figure 2.4 will shows the conversion of PTKS DRI Plant which used HYL fixed – bed reactors before to HYL moving bed reactors.

In September 1990, a Consortium consisting of Ferrostaal AG, MAN – GHH, and Hylsa S.A. received an order to convert the plant for increasing the plant capacity from 600 000 to 1 200 000 ton/year of DRI, using the existing reformer and part of the general services and infrastructure. First step in the modernization involved systematically inspecting the idle plant. Based on these activities, the repair and conversion of the plant components, such as reformer, CO₂ removal unit, boiler feed water treatment system, material handling systems for iron ore pellets and lump ore, were prepared and carried out. The existing shaft furnace was scrapped and replaced by two HYL moving reactors in a new reactor tower. Main new equipment incorporated consisted of two gas heaters, an additional CO₂ scrubber, and a compressor facility comprising two –stage turbo – compressors for the reducing gas and two single – stage turbo – compressors for the cooling gas, all of them supplied by MAN – GHH. Other new systems incorporated included the material handling, storage and screening systems for the DRI, as well as a control and instrumentation system, for which the control room was enlarged and redesigned. Figure 2.5 will shows the process schematic for DR Plant Partial Combustion in Perwaja Steel Sdn. Bhd.

2.3 PARTIAL COMBUSTION FUNDAMENTAL CONCEPT

From Webster's dictionary, combustion is defined as rapid oxidation generating heat, or both heat and light; also slow oxidation accompanied by relatively little heat and no light. Besides that, combustion also can be defined as a chemical reaction between a combustible material or a fuel and oxygen releasing heat. Oxygen is come from the air, where its dry basis composition is 21% oxygen and 79% nitrogen. In fuel, it have hydrocarbon which is part of carbon and hydrogen. Sometimes, sulfur also exists in fuel. Therefore, the combustion can occur in different grades.

The basic of combustion reaction are:



The consumption of oxygen in these reactions may increase the temperature. The types of the combustion reaction depend on the amount of oxygen supplied to the combustion process which are:

2.3.1 Perfect Combustion

It called perfect combustion when the amount of oxygen supplied is the stoichiometrically required to burn a fuel in such a way that either fuel or oxygen are left. The reaction is:



Based on the reaction above, a quantity of oxygen is supplied just enough to burn the whole quantity of methane in such a way that oxygen is left.

2.3.2 Complete Combustion

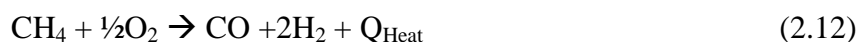
It occurs when amount of oxygen is bigger than the stoichiometrically required in order to have the fuel completely burned off. The reaction is:



Some equipment applied this process such as gas process heaters and boilers which are designed to operate with some excess oxygen.

2.3.3 Incomplete Combustion

Incomplete combustion occurs when there is not enough oxygen supplied. It will cause an excess of fuel in the products of the combustion. The reaction for this process is:



The oxygen supplied is not enough in this combustion process; therefore methane is partially burned, leaving unburned carbon monoxide which is also combustible. Actually, this type of combustion is not desirable in thermal equipment unless it used to increase the temperature of gas mixture to a certain level, also controlling the amount of oxygen injected to such mixture to obtain a reducing atmosphere as desired.

2.4 PARTIAL COMBUSTION UNIT IN DIRECT REDUCTION PLANT

The Partial Combustion Unit in Direct Reduction Plant has many benefits as applied in Monterrey plant which has successfully implemented in 1994. The benefits of introducing this unit are; the production can be increase by 23.87%, decrease of 6% in the natural gas consumption, possibility to increase the DRI carbon and increase the life of the tubes (Perwaja Steel).

The main components of the process gas at the reactor inlet are Hydrogen (H₂), Carbon Monoxide (CO), Carbon Dioxide (CO₂), and Methane (CH₄). The temperature of process gas may increase at the reactor inlet because the Oxygen (O₂) is injected into the reactor transfer line. This oxygen will react with H₂, CO and CH₄.

The reactions that take place in PC unit are:



In this unit, the process gas leaves the process gas heater to a temperature of 933°C, which is the process gas sent to the reactor through of a transfer line. The transfer line is a collector of hot process gas where homogenize the temperature of the gas from the risers, in this section is where is carried out the partial combustion through an injection of oxygen controlled (Perwaja Steel).

The partial combustion system equipment consists in one oxygen skid, two oxygen lances and a transfer line.

2.4.1 Oxygen Skid

The function of this oxygen skid is to control the oxygen flow rate to be injected into the reactor transfer line. This skid is connected to oxygen lances which are installed in the transfer line. There is a nitrogen supply pipe line is used to purge the oxygen pipe line from oxygen skid to reactor transfer line in order to avoid mixture of process gas and oxygen inside the oxygen pipeline.

2.4.2 Oxygen Lances

The function for this oxygen lances is to direct the oxygen flow in order to avoid damage the transfer line refractory. The oxygen injected must be at a subsonic velocity to assure a good combustion near the nozzle. This oxygen lances are placed in horizontal position at the middle of the transfer line. This oxygen lance is formed by a stainless steel pipe.

2.4.3 Transfer Line

The transfer line is normally made from carbon steel tube which has 1760 mm in external diameter and 15 mm of thickness. This transfer line is covered with two layers of refractory brick which has five expansion joints to compensate the refractory expansion up to 10 mm each. The refractory brick used in this transfer line is KX – 99. This type of brick is a trademark used for Fire Brick and owned by A.P Green Refractories Co., A.P Green Fire Brick Company.

2.5 REDUCTION PROCESS

The direct reduction process is commercially used for the production of sponge iron by reducing gases from steam and the dry reforming of natural gas. In the moving bed reactor, the reducing gas mixture flows upward and counter-current to the downward flow of solids and reduces the hematite pellets.

The reduction reactions take place in the reactor reduction zone. The conversion of the reduction reactions depends mainly of the reducing gases composition and temperature. It is very important due last to maintain the lowest possible amount of oxidizing gases like water (H_2O) and Carbon Dioxide (CO_2) in reducing gases at the reactor inlet.

The reactor inlet temperature is an important issue in the plant production rate as high is possible is the better but there is a practical limitation in reactor inlet temperature; this limitation is the iron ore sticking tendency. The reducing gas temperature at process gas heater outlet is restricted to the equipment design in this case the design of the process gas heater did not allow increasing the process gas heater outlet temperature. The use of the partial combustion system will allow the temperature increment at reactor inlet without affecting the process gas heater equipment design.

The overall reaction scheme can be simplified to:



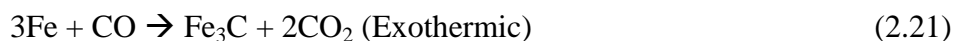
In the past three decades, the subject of direct reduction of iron oxides has been studied by presenting some mathematical models.

Some of the reactor models include one reacting gas. Most of the models have used pure H₂ (Turkdogan E. T. et al., McKewan W. M., Usui T. et al.), pure CO (Tien R. H., Turkdogan E. T., 1972) or a mixture of H₂ and CO as reducing gas (Kam E. K. T. et al., Negri E. D. et al.). Whereas reducing gas at a practical direct reduction reactor is a mixture of H₂, CO, H₂O, CO₂ and CH₄. Recently, the moving bed direct reduction reactor has been modeled by unreacted shrinking core model for two industrial plants (Parisi D. R., Laborde M. A., 2004).

Reduction process is occurred in the reactor when the process gases that passed through the partial oxidation entered the reactor with higher temperature. The hot reducing gases were fed into the reactor at the lower level for the counter-current contact with the iron ore. This is due to optimizing the resident time between the contacts of the gases and solid and thus resulted in optimize reduction rate process. The exhaust reducing gas left the reactor from the top side of the reactor at about 400°C and then passed through the top heat recuperator where its energy was recovered to produce steam for the heating and utilities purposes (Danieli, Tenova et al.). The water that produced during the reduction process was condensed and removed from the gas stream and most of the dust carried with the gas also separated. Currently, most of the DR plant operates at high temperature which is 920°C-950°C. Therefore, this research is carried out to lower the operating temperature which is possible hence resulted in higher cost effective.

In optimizing the rate of DRI production, the hot reducing gases is needed since carburization process is varied with the temperature of the reducing gases.

Below are the list of carburization process occurred in the reactor:



Referring to the carburization process through CH_4 , if higher amount of NG fed into the reactor, the temperature of the reducing gas became lower due to the endothermic nature of the reaction (Raul, 1995). These lower reducing gases affected the low level of metallization process and gave the lower productivity of DRI. Therefore, the additional energy is provided by the Partial Oxidation of NG and thus improved the carburizing quality gases which are required for the carburization of the metallic iron. Reaction 2.22 is part of the in situ reforming process. The high carbon DRI produced has a very high metallization and controlled carbon content which is between 0.8% - 5%.

2.6 ADVANTAGES OF HOT AND HIGH CARBON DRI

There are more advantages of hot and high carbon DRI. In high content of carbon, it can improve the stability of DRI itself. It is because the carbon shell acts as the inhibitor. Besides that, it can be shipped without cost of briquetting. It also can reduce need for carbon additions to the Electric Arc Furnace (EAF). With high carbon DRI, it will increase yield and productivity, especially when hot charged via HYTEMP System.

The carbon itself is energy. And this energy is finally utilized at the EAF when the DRI is melted. From the combination of these reactions, the yields will more than 37kWh/tls per each 1% carbon in the DRI. The following reactions show how the carbon yields the energy:



The Figure 2.6 below shows the effect of DRI temperature and carbon on electricity consumption and power – on time. In this figure, when the temperature of DRI increases, the electricity consumption may also decrease. It is same goes to power – on time, when the temperature of DRI increases, the power – on time may decrease. From this figure, noted that the effect of hot and high carbon content of DRI are important and can give more advantages. So, that is why the temperature drop in transfer line must be investigated to assure the temperature at reactor inlet is high as possible.

The combined effects of high temperature and high carbon content of DRI have a positive influence on the productivity of the EAF, arising from the corresponding decrease of the electric energy required to melt the charge The sensible heat of the DRI results in a lower electric energy consumption in the furnace, increasing productivity and reducing related operating costs, such as electrodes, refractories and fluxes (Raul, 1995).

Another benefit is the high carbon content which is mostly as iron carbide plays a significant role in providing energy to the system in a clean and easy manner, without graphite additions to the bath (Raul, 1995).

Figure 2.7 shows the amount of oxygen consumption in the EAF using different charges of DRI at various carbon levels. While Figure 2.8 shows the decrease in the amount of electrical energy needed for melting in the EAF according to the carbon content in DRI. This figure is almost the same as the Figure 2.6. Energy consumption is decrease with respect to the increment of DRI temperature.

The Figure 2.9 shows the productivity increase of the EAF, in terms of the corresponding power on time which is the time that has required for melting and refining. It is depends on DRI temperature, DRI carbon and metallic charge composition.

As shown in Figure 2.10, it is important to note the efficient use of energy while producing a high – energy content DRI with 3.5%C and 700°C (Pablo E.D., 2007).

2.7 INTRODUCTION OF COMPUTATIONAL FLUID DYNAMIC

Computational Fluid Dynamics (CFD) is software that used in order to do the simulation. Recently, following the progress in computer technology, many researchers began to use commercial CFD programs in their investigations. It relies on the use of computers to solve the equations that describe the motion of fluids, include both liquids and gases. The main advantage of CFD code is that it uses the full Navier–Stokes equations and provides a solution to the flow problem, whereas finite difference codes are based on the Reynolds equation. The results obtained by the two approaches are therefore likely to differ. Moreover, the CFD packages are applicable in very complex geometries. Kuipers and van Swaaij (1998) provide a useful introduction to the development of CFD codes, and state that their initial development was driven by the aerodynamic community. They describe the expansion of CFD techniques in particular in the field of chemical reaction engineering. They recognize ‘the importance of CFD as a “workhorse” for the chemical engineering community’ (Kolaczowski et al.). At PO unit, this software is applied to investigate its performance. By modeling, simulation can be run to give more accurate results. The boundary conditions defined to knows the interaction of liquid and gas surface so that it can be simulate.

2.7.1 GAMBIT

GAMBIT is software that has a single interface for geometry creation and meshing that brings together all of Fluent’s preprocessing technologies in one environment.

2.7.2 FLUENT

FLUENT is a CFD software package to simulate fluid flow problems. It uses the finite – volume method to solve the governing equations for a fluid. Besides that, FLUENT is a general purpose CFD software ideally suited for incompressible and mildly compressible flows.

2.7.3 Fundamental of CFD

It should be clear that successful simulation of fluid flows can involve a wide range of issues from grid generation to turbulence modeling to the applicability of various simplified forms of the Navier – Stokes equation.

2.7.3.1 Turbulence Modeling

Deriving k - ε, it is assumed that the flows are fully turbulent and the effects of molecular viscosity are neglected. Therefore, it is only valid for fully turbulent flows such as this study.

2.7.3.2 Transport Equation

For turbulence kinetic energy, k and its dissipation rate ε, both are obtained from the following equations:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \right] + G_k + G_b - \rho \epsilon - Y_M + S_k \quad (2.25)$$

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \right] + C_{1\epsilon} \frac{\epsilon}{k} (G_k + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} + S_{k\epsilon} \quad (2.26)$$

Where G_k is the generation of turbulence kinetic energy due to the mean velocity gradients and was calculated as follows:

$$G_k = -\overline{\rho u_i' u_j'} \frac{\partial u_j}{\partial x_i} \quad (2.27)$$

From equation (2.29) and (2.30), G_b represents generation of turbulence kinetic energy due to buoyancy and is calculated as follows:

$$G_b = \beta g_i \frac{\mu_t \partial \tau}{\rho r_t \partial x_i} \quad (2.28)$$

where p_{rt} is the turbulent Prandtl Number for energy and g_i is the component of the gravitational vector in the i^{th} direction.

From equation (16), the thermal expansion coefficient, is defined as:

$$\beta = -\frac{1}{\rho} \left(\frac{\partial \rho}{\partial \tau} \right)_p \quad (2.29)$$

Y_M in equation (14) represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate and defined as:

$$Y_M = 2\rho\epsilon M_t^2 \quad (2.30)$$

where M_t is the Turbulent Mach number and defined as:

$$M_t = \sqrt{\frac{k}{a^2}} \text{ where } a (\equiv \sqrt{\gamma RT}) \text{ is the speed of sound}$$

2.7.3.3 Mass Transfer and Species Transport Equation

The local mass fraction of each species Y_i can be predicted through the solution of a convection-diffusion equation for the i^{th} species. This conservation equation takes the following general form:

$$\frac{\partial}{\partial t} (\rho Y_i) + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot \vec{J}_i + R_i + S_i \quad (2.31)$$

where R_i is the net rate of production by chemical reaction and is the net rate of creation by addition from the dispersed phase. An equation of this form will be solved for $N-1$ where N is the total number of fluid phase chemical species present in the system. Since the mass fraction of the species must sum to unity, the N^{th} mass fraction is determined as one minus the sum of the $N-1$ solved mass fraction.

2.7.3.4 The Eddy-Dissipation Modeling

In combustion, most of the fuels are burning quickly and the turbulent mixing will control the overall rate of reaction. For this premixed flames, the turbulence slowly convects/mixes cold reactants and produced hot products into the reaction zones where reaction occurs rapidly. In this transport phenomena, the net rate of production of species i due to reaction r , $R_{i,r}$ is given as follows:

$$R_{i,r} = v'_{i,r} M_{w,i} A \rho \frac{\epsilon}{k} \frac{\min}{R} \left(\frac{Y_R}{v_{R,r} M_{w,R}} \right) \quad (2.32)$$

$$R_{i,r} = v'_{i,r} M_{w,i} A \rho \frac{\epsilon}{k} \left(\frac{\sum_p Y_p}{\sum_j^N v_{R,r} M_{w,R}} \right) \quad (2.33)$$

where Y_p is the mass fraction of any products species, P , Y_R is the mass fraction of a particular reactant, R while A and B are empirical constants which equals to 4.0 and 0.5 respectively.

2.7.3.5 Convective Heat and Mass Transfer Equation

For this study, the heat transport is modelled using the concept of Reynolds's analogy to turbulent momentum transfer. The 'modelled' energy equation is thus given by the following:

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i} [u_i (\rho E + p)] = \frac{\partial}{\partial x_j} \left(k_{eff} \frac{\partial T}{\partial x_j} + u_i (\tau_{ij})_{eff} \right) + S_h \quad (2.34)$$

where E is the total energy, k_{eff} is the effective thermal conductivity and (2.34) is the deviatoric stress tensor which is being defined as:

$$(\tau_{ij})_{eff} = \mu_{eff} \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) - \frac{2}{3} \mu_{eff} \frac{\partial u_k}{\partial x_k} \delta_{ij} \quad (2.35)$$

2.7.3.6 The Energy Equation

Generally, FLUENT solves the energy equation as follows:

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla(k_{eff} \nabla T - \sum_j h_j \vec{J}_j + (\bar{\tau}_{eff} \cdot \vec{v})) + S_h \quad (2.36)$$

where \vec{J}_j is the diffusion flux of species j .

In equation (2.36), E is defined as:

$$E = h - \frac{p}{\rho} + \frac{v^2}{2} \quad (2.37)$$

Where sensible enthalpy for incompressible flows is defined as:

$$h = \sum_j Y_j h_j + \frac{p}{\rho} \quad (2.38)$$

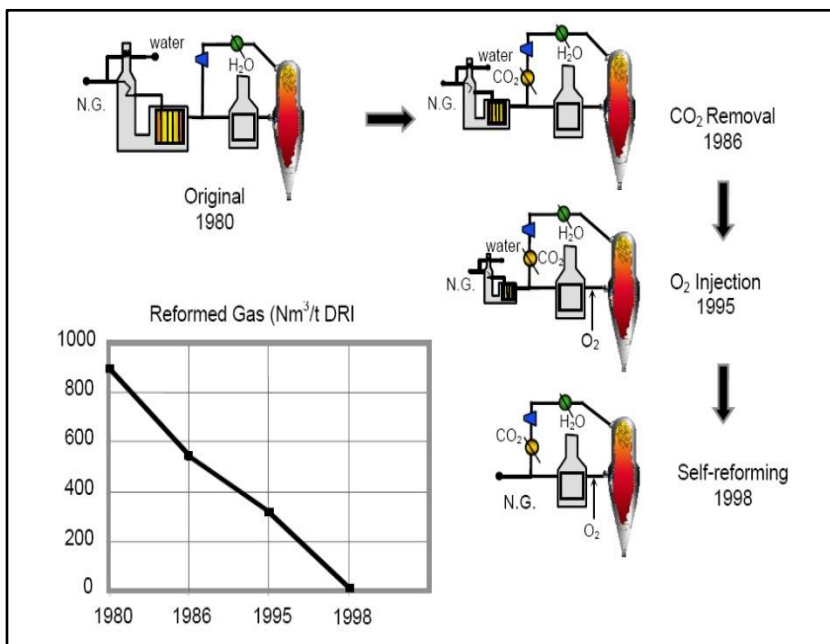


Figure 2.1: HYL Process Development

Source: Morales R. G., Prenzel M., 2002

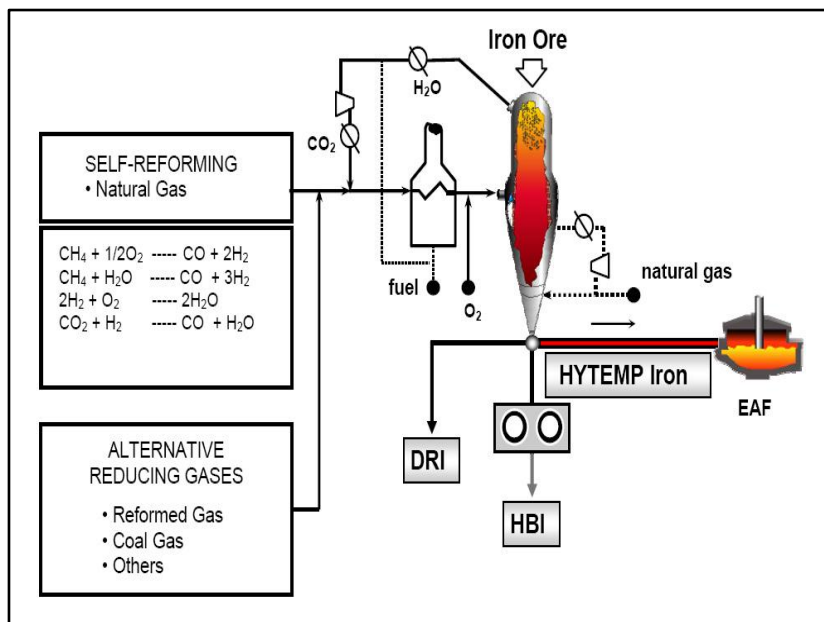


Figure 2.2: HYL Process Diagram

Source: Morales R. G., Prenzel M., 2002

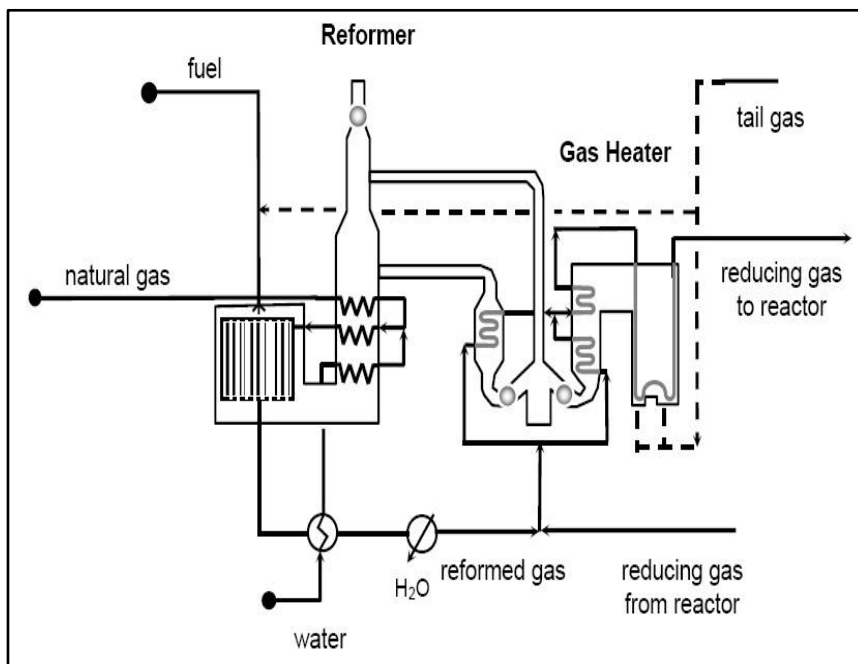


Figure 2.3: IMEXSA Plant Integrated Reformer – Heater Arrangement

Source: Morales R. G., Prenzel M., 2002

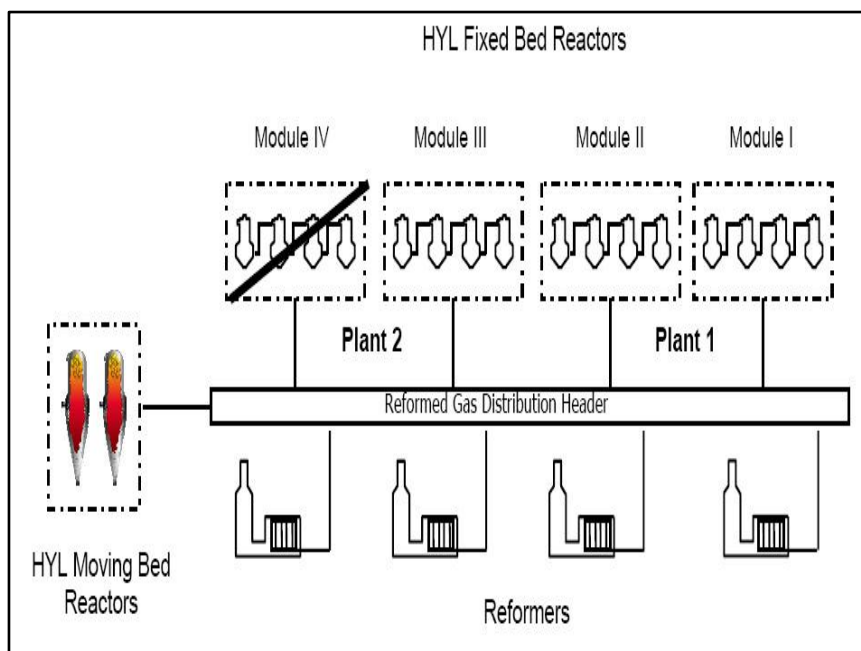


Figure 2.4: Conversion of PTKS DRI Plant

Source: Morales R. G., Prenzel M., 2002