STUDY THE EFFECT OF OXYGEN TO METHANE RATIO ON THE TEMPERATURE OF PARTIAL OXIDATION UNIT AT DIRECT REDUCTION PLANT BY USING CFD

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ABSTRACT

Direct Reduction Plant is a plant that can produce high quality of iron product. In this plant, the very important thing is the Partial Oxidation (PO) system that allows increasing the productive rate, the quality of Direct Reduced Iron (DRI), and can save the usage of natural gas consumption. Besides, there is a transfer line with two oxygen lances is situated between the gas heater and reactor. The main objective of this study is to consider the oxygen to methane ratio supplied form the oxygen lance on the temperature profile in the combustion chamber. High temperature in the transfer line is needed in order to get high quality of iron product. In order to get the result, the simulation was performed by using Computational Fluid Dynamic (CFD) software that contents Fluent and Gambit. Volume meshing in GAMBIT is very important part before doing simulation in FLUENT as a solver. For further modification, only one lance of oxygen is considered in this study. Besides, the steady state condition of the partial oxidation system also included in this report. From this study, the temperature profile of Partial Oxidation system can be determined thus can give better performance for this system.

MENGKAJI KESAN NISBAH OKSIGEN KEPADA METANA TERHADAP SUHU UNIT PEMBAKARAN SEPARA DI DALAM LOJI PENGURANGAN LANGSUNG MENGGUNAKAN CFD

ABSTRAK

Loji Pengurangan Langsung (Direct Reduction Plant) adalah plant yang boleh menghasilkan kualiti yang tinggi produk besi. Dalam tumbuhan ini, perkara yang sangat penting adalah Pembakaran Separa (PO) sistem yang membolehkan meningkatkan kadar produktif, kualiti Mengurangkan Langsung Besi (DRI), dan boleh menjimatkan penggunaan penggunaan gas asli. Selain itu, ada garis pemindahan dengan dua tombak-tombak oksigen terletak antara pemanas gas dan reaktor. Objektif utama kajian ini adalah untuk mempertimbangkan kepekatan oksigen yang dibekalkan membentuk tombak oksigen pada profil suhu dalam kebuk pembakaran. Suhu yang tinggi dalam barisan pemindahan diperlukan untuk mendapatkan kualiti yang tinggi produk besi. Dalam usaha untuk mendapatkan keputusan, simulasi telah dijalankan dengan menggunakan Dinamik Bendalir Komputeran (CFD) perisian bahawa kandungan fasih dan Gambit. Jilid bersirat dalam Gambit adalah bahagian yang sangat penting sebelum melakukan simulasi dalam FLUENT sebagai penyelesai. Bagi pengubahsuaian selanjutnya, hanya satu tombak oksigen dipertimbangkan dalam kajian ini. Selain itu, keadaan mantap sistem pembakaran separa juga dimasukkan dalam laporan ini. Daripada kajian ini, profil suhu sistem Sebahagian Pembakaran boleh disahkan itu boleh memberi prestasi yang lebih baik untuk sistem ini.

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LIST OF SYMBOLS

°C	Degree Celcius
°K	Degree Kelvin
L	Liter
m3	Meter cubic
%	Percentage
m/s	Meter per secomd
Pa	Pascal
US$	United State Dollar
k	Turbulence Kinetic Energy
Ɛ	Turbulence Dissipation

LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamic
DR	Direct Reduction
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
HBI	Hot Briquetted Iron
PCU	Partial Combustion Unit
R&D	Research & Development
RHF	Rotary Hearth Furnace
HPAC	Highly Preheated Air Combustion

CHAPTER I

INTRODUCTION

1.1 Overview of Direct Reduction Plant

The rapid development nowadays causes the high demand of steel from the heavy industries. Thus, there are many evolution on the steel making processing in order to produce the high quality steel as required, which is also environmental friendly and have low energy consumption and investment costs. The high product value is needed to ensure the steel produce has a high resistant. In Malaysia, Perwaja Steel Sdn. Bhd. is the leading manufacturer company of primary steel product. Direct Reduction (DR) reactor used by this company is HYL III, which is capable to producing up to 1.5 million metric tons of Direct Reduced Iron (DRI) per annum. The reducing agent used in processing the DRI is natural gas-based or coal-based direct reduction process. Oxygen is removed from the iron ore by chemical reactions based on Hydrogen, H_2 and Carbon Monoxide, CO for the production of DRI and Hot Briquetted Iron (HBI) (Raul & Matthias et al., 2002). This company is using the natural gases as a reducing agent. The natural gas will generated as self-reforming in the reduction reactor. Through the partial oxidation of natural gases and oxygen, reducing gases in-situ that is H_2 and CO will generate. Thus, the operating temperature will increase as required for the process of reduced iron ore.

1.2 Background of Study

Partial Oxidation (PO) unit takes place in between the reactor and heater. The PO unit consists of transfer line and two oxygen lances. The heated NG from the heater will be supplied to the transfer line. The oxygen will be injected in the transfer line through the oxygen lances for partial combustion and increasing the temperature of NG. In this unit, the partial oxidation of natural gases and oxygen will generate the in-situ gases. Besides that, through this unit, the operating temperature can be increased (temperature enter the reactor). The high temperature of reducing gases is important in order to remove the oxides inside the iron ore to produce the DRI and HBI. Because of these processes, the PO unit had become the more important part in this process.

Thus, many research had been carried out in propose of improving the PO unit. Several considerations should take into account such as the need to be optimized to achieve higher Partial Combustion ratio (Yun Li & Richard J. Fruehan et al.). In this research, the consideration is only about the heat lost from the transfer line to the surrounding. Thus, the material of the brick and the type of wall of the refractory boundary should be identifying. Besides that, the temperature of along transfer line also should be analyzed in order to ensure the NG enters the reactor at high temperature. The new material of the boundary refractory and designing should be analyzed for purpose of the unit optimization.

1.3 Problem Statement

In the PO unit, the high temperature is required in order to remove the oxide inside the iron ore by the oxidation reaction between the iron ore and the NG. It is important to ensure the temperature of the system is operating at high temperature but concentration of oxygen supply during the combustion might affect the temperature profile in the combustion chamber.

1.4 Objectives of Study

The objectives of the study are:

- To study the effect of oxygen to methane ratio on temperature profile in combustion chamber by using CFD.
- To study the effect of oxygen to methane ratio on the methane conversion in partial oxidation process.

1.5 Scope of Study

To achieve the objectives, scopes have been identified in this study. The scope of this study as listed below:

- Perform simulation on Partial Combustion unit by considering the different concentration of oxygen.
- Study the suitable oxygen concentration in order to get optimum temperature in combustion chamber by using CFD.

1.6 Rationale and Significance

The rationale of this study and the significance of the research are listed as below:

- To get the optimum high temperature profile in partial combustion reaction.
- Prevent the heat to be loss to the surrounding.
- Increase the effectiveness of the system by increasing the production of DRI.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

2.1 Direct Reduced Iron (DRI) Process

Direct-reduced iron (DRI), also called sponge iron is produced from direct reduction of iron ore (in the form of lumps, pellets or fines) by a reducing gas produced from natural gas or coal. The reducing gas is a mixture majority of hydrogen (H_2) and carbon monoxide (CO) which acts as reducing agent. This process of directly reducing the iron ore in solid form by reducing gases is called direct reduction. The significant of partial oxidation is to increase the temperature of reducing gas that entered the reactor. In order to get high temperature of DRI when leaving the reactor, the high amount of heat transfer is needed to achieve it. The main component of the gas supply is methane, so the other type of gases is negligible (M. Irwan Shah Md Zain et al., 2011).

The oxygen that injected to the reactor is burned partially. Then, the temperature is increases and the reductive reaction rate increases in the shaft furnace. If there is excessive oxygen, we do not have to install a new reforming furnace and the productivity will increases. In general, reduced iron ore is cooled before stored in being charged in the electric furnace. The hot reduced-iron from the bottom is conveyed to the top of the electric furnace and directly charged the hot reduced iron ore (Harada et al., 2005). One of the new commercial sources of reducing gas is coal. The mixture of coal and iron ore is introduced into the upper end of a huge inclined rotary kiln. Along the kiln, the air is introduced in various points then, producing partial combustion of the coal and producing carbon monoxide as the reductant (Hsieh, 1979).

Mostly, direct reduction processes are gas-based which is there are using gas to remove oxide inside the iron ore. The feed of iron ore may in the form of fluids bed or pellets in lump in the reduction furnace. The feedstock input size must suitable to the reduction furnace, so, it need to be screening or grinding to get the smaller size. CO_2 and H_2 is used to remove the oxide inside the iron ore and there are several processes to produce those gasses. Natural gas enters the furnace and gets heated at high temperature to remove the oxide inside the ore. Besides, coal also has been used too to remove the oxide. There are two different products of from this process, which is HBI (hot briquetted iron) – the product while it is still hot and DRI (direct reduction iron) after it is cooled down (Roy Whipp, 2000).

2.1.1 HYL Direct Reduction

The heat absorption will affect the reaction rate and production consumption and to achieve that, the HYL plants are used to increases the temperature reduction. By made the modifications, the temperature of the reducing gas stream will increase and enter to the reactor. This scheme is carried out by the injection of oxygen in the transfer line between the reducing gas heater and the reduction reactor. This method will increase the temperature of reducing gas in the transfer line. Under these conditions, the reactor productivity is increased and the reducing gas utilization is optimized (Block, 2001).

The HYL process is a designed for the direct reduction of iron ore (pellets or lumps) by using the reducing gas in a solid-gas moving bed reactor. The chemical based reaction on hydrogen (H_2) and carbon monoxide (CO_2) is the reaction in order to remove oxygen in the iron ore. This method can produce high-metalized Direct Reduced Iron (DRI) (Raul, 2000).

Energiron HYL (Alliance of Danieli & Co), offers reducing gas produced directly in the shaft reactor by means of in-situ reforming reactions. The reactor has reactor lining inside, and the diameter is approximately 6 meters for 2 million ton/year production. The reactor pressure is about 5-6 bars and the latest information, the gas pressure is about 2.5-6 bars. The operating temperature was 800-850 °C and the new is 950 °C. The addiction of water is above 100 °C to as high as 1085 °C in the in-situ reforming (Roy W et al., 2000).

2.1.2 Midrex Direct Reduction

The common method of Iron reduction is Midrex direct reduction process. This process consists of two main stages, which are reduction zone and cooling zone based on natural gas. Pores are left behind in the DRI after oxygen has been removed. If these pore filled with water, it can cause the iron to reoxidize at ambient oxygen, produce heat and can ignite a fire. This makes it difficult to transport the product by ship or to store it in the open air over an extended period. The energy consumption from this process is about 12 GJ for every ton hot metal. The product can support world iron demand at least 60 % of the world total DRI. Figure 2.1 below show the comparison between specifications of DRI and HBI.

	DRI	HBI
Fe total (%)	90~94	←
Fe metallic (%)	83~89	←
Metallization (%)	92~95	←
Carbon (%)	1.0~3.5	←
P* (%)	0.005~0.09	←
S* (%)	0.001~0.03	←
Gang* (%)	2.8~6.0	←
Mn, Cu, Ni, Mo, Sn Pb and Zn (%)	trace	←
Bulk density (t/m^3)	1.6~1.9	←
Apparent density (t/m^3)	3.4~3.6	5.0~5.5
Discharge temperature (℃)	40	80

* depends on components of iron ore

Figure 2.1: Specific of DRI and HBI.(Kobe Technology Review, 2010)

The lump ore, or pallets prepared for the direct reduction iron making, used as the raw material and entered at the top of the furnace. The iron ore is reduced and the discharged at the bottom of the furnace. The reaction occurring in the furnace is the well-known reduction reaction of iron, described as follows:

$$FeO_2 + 3CO \longrightarrow 2Fe + 3CO_2$$

$$Fe_2O_2 + 3H_2 \longrightarrow 2Fe + 3H_2O$$

The top gas containing CO2 and H2O are passing through the reformers that contains hundreds tubes filled with nickel catalyst. The mixture of top gas and natural gas is reformed to produce reductant gas consisting od carbon monoxide and hydrogen. The reaction that occurs in the reformer tubes is as follows:

$$CH_4 + CO_2 \longrightarrow 2CO + 2H_2$$

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$2CH_4 + O_2 \longrightarrow 2CO + 4H_2$$

$$CO + H_2O \longrightarrow CO_2 + H_2$$

$$CH_4 \longrightarrow C(S) + 2H_2$$

2.1.2.1 Oxygen Injection Into Reducing Gas

Injecting high purity oxygen into the hot reducing gas has further raised the reducing gas temperature to about 1000 °C. Although a portion of hydrogen and carbon monoxide is consumed by combustion with oxygen, raising the temperature of the reducing gas has improved shaft furnace productivity by 10 to 20 %.

2.1.2.2 Improved of Oxygen Injection Technology

The oxygen injection, described above, has evolved into an improved technology that made possible by the introduction of a partial combustion technique. As shown in Figure the oxidation employs a combustor in addition to the reformer. The combustor partially burns natural gas and oxygen to produce hydrogen and carbon monoxide, which are added to the reducing gas generated by the reformer.

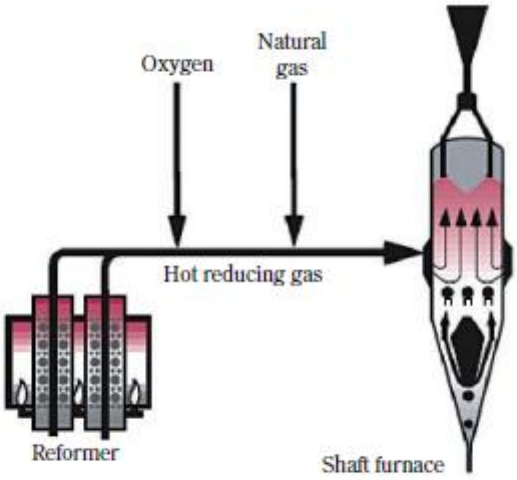

Figure 2.2: Hot Reducing Gas Line

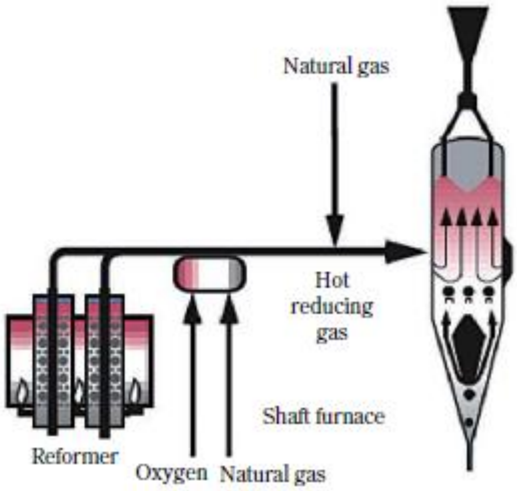

Figure 2.3: Hot Reducing Gas Line with Combustion Chamber

2.2 Partial Oxidation

The high amount of natural gas must be handling appropriately. Currently, synthesis gas is produced by catalytic steam reforming. The typical process, natural gas is partially reacted with steam to produce syngas at an H_2: CO ratio of 3:1. In order to prevent the carbon formation on the catalyst, excess steam is used. Potassium compounds or other bases (CaO and MgO) are typically used to accelerate carbon removal reactions. Over the years the steam reforming process has been optimized with the design of better burners for the furnaces, highly creep resistant materials for the reformer tubes, and new sulfur passivated catalysts which inhibit carbon formation (Bharadwaj et al.,1994).

In present invention, partial combustion process is in the external combustion chamber. The process is counter current process that has content the mixture of natural gas and process gas and react partially inside the chamber. The natural gas is converted by oxygen-enriched air produce heat and reducing gas at about 1000 °C – 1100 °C. The oxygen-enriched air consists of catalyst, usually nickel catalyst. After that, the reducing gas is injected to the reforming zone of the shaft furnace. The reducing gas will made contact with iron oxide material (hot DRI metalized iron), where as the direct reduction process is take place. Usually, the feed of iron in pellet form with has 63 %-68 % iron by weight. After the reaction, the direct reduced iron has about 85 %-90 % iron by weight (Dam G. et al.,1991).

The partial oxidation using oxygen is the preferred one for the production of syn-gases if the feedstock is heavier than the natural gas. By using gas-heater reformer, it will give a massive efficiency of synthesis gas generation due to the calorific value of the raw syn-gas and the hydrogen content of the fuel gas. However, it will cost by having this overall power generation process, much of this gains will lost by need to add large amount of steam to the gas turbine with the result that the power generated is more expensive (IEA Greenhouse Gas R&D Programme, 2000).

Nouri et al., said that 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. At pellet scale, the main assumption is about the unreacted shrinking core model of the previous model have used. Through this model, it shows the experimental data very well but the reacted and unreacted zones in pallet are nor separated by a sharp boundary. Mostly, the industry nowadays use two main gas to remove oxide in the iron ore by using pure H2 and CO, but some of the reactor may use only one reducing gas. Apparently, moving bed reactor has been modeled by unreacted shrinking core model for two industrial plants. The grain model with product layer resistance has been developed to simulate the direct reduction reactor. This reactor included intergrain diffusion of the porous hematite pellets as well as the product layer.

To produce virgin iron units for EAFs', the gas-based reduction process is the mostly plant that has been used. By using the moving bed of iron oxide pellets and lump ore, the reducing gas is move in by counter current flow. Danarex™ High Kinetic Reduction is the new direct reduction process to produce DRI called SPM

Supermetallic. This process gives the highest levels of plant efficiency and good quality product. This kind of gas-based process will convert iron oxide pellet, lump ore or pellet/lump ore mixtures into a highly metalized and fully passivated product. Besides, the content of carbon in the form of Fe_3C is controlled. Under melting process, the carbon content is fully recoverable to make a source of other chemical purpose. This process consist of dual chamber reactor where the moving bed is move downward and the hot reducing gas is moving upward, it is called counter current direction. The mix of reducing gases which is carbon monoxide, hydrogen, methane, carbon dioxide and steam will react with the oxygen inside the iron ore in order to remove the oxygen and good quality of DRI will produced (Danieli et al., 2006).

2.3 Overview market for Direct Reduced Iron.

Direct reduction iron making is a method to produce iron without using a blast furnace. Direct reduction iron making consist of two ways based process that is gas-based and coal-based process. The production of direct reduced iron has increase steadily since 1970 to 2008. Kobe Steel is the first company that delivered their direct reduced iron to Qatar Steel Company and currently, about 58 % of the direct reduced iron in the world is made by MIDREX process.

Direct reduced iron plant is much less capital compared to blast furnace and does not required coke. Nowadays, the country that has their owned development of natural gas is economic to have direct reduction plant. After the process, there is no oxygen inside the iron ore, and it will leave the pores. These pores, if filled with water it will cause the iron to re-oxidize, generate heat and can ignite fire. This will make difficulty to transport them, and ironworks must consume it in-house. To solve this problem, Kobe Steel has converted the direct reduced iron into hot briquette iron (HBI) to prevent re-oxidation. With this technology, several countries have begun to export their HBI product to others, such as Venezuela. The table below shows the increasing of demand for crude oil steel.

Table 2.1: Crude Oil Steel Demand (Midrex Technologies, Inc.)

Year	Total	Year	Total	Year	Total	Year	Total
1970	0.79	‘80	7.14	‘90	17.68	‘00	43.78
‘71	0.95	‘81	7.92	‘91	19.32	‘01	40.32
‘72	1.39	‘82	7.28	‘92	20.51	‘02	45.08
‘73	1.90	‘83	7.90	‘93	23.65	‘03	49.45
‘74	2.72	‘84	9.34	‘94	27.37	‘04	54.60
‘75	2.81	‘85	11.17	‘95	30.67	‘05	56.99
‘76	3.02	‘86	12.53	‘96	33.30	‘06	59.79
‘77	3.52	‘87	13.52	‘97	36.19	‘07	67.22
‘78	5.00	‘88	14.09	‘98	36.96	‘08	68.45
‘79	6.64	89	15.63	‘99	38.60		

The demands for the direct reduced iron are still increase although in 1998, the world financial crisis was triggered. Many plants has been built in year 2005 to 2008 included top three regions producing reduced iron ore, there are, Asia/Oceania, Middle East/North Africa and Latin America (Sawada et al.,2010).

Crude steel production becomes more popular and the demand is increases annually. High and rapid growing demand in these several years causes cost increases of, such as iron ore and cokes including those for transportation, combined with the increment of energy costs. Further, environmental impacts become one of the important concerns to the iron and steel industry. Although the market situation has drastically changed, the missions of the iron and steel industry are unchanged. This product is continuously process and the industry needs to supply steel products to social due to massive development in some countries. In order to catch up the highly cost, some of company has install of mini/small-blast furnaces including construction of integrated iron and steel complex is also planned such as in Thailand, Malaysia and Vietnam. Iron steel company need to find the new technology to overcome this situation and. There are some process can handle this problem such as Rotary hearth furnace (RHF) based technologies, tmk3 and FASTMELT (Seki et al., 2006).

2.3.1 Mini/Small-Blast Furnace

This solution is to face the increase of cost and scarcity in raw materials, namely, scrap and pig iron, they are trying to secure stable raw materials sources. In order to overcome the facing difficulties, several mini-mills selected “hot metal” discharge into the electric arc furnace (EAF) as a solution. The installation cost of a mini/small-blast furnace is negligible compared to an integrated iron and steel complex, and, as it is neither necessary nor possible to develop the complex, it seems natural and simple for a single private mini-mill to select this facility as a solution.