ISSN 2229-5518

TECHNICAL DEVELOPMENTS IN THE MIDDREX PROCESS

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Abstract— This paper presents an overview of the history of the technical developments in MIDREX process, as well as the latest developments in this field. The conventional way of iron and steel making consumes high fuel and even causes emission of carbon dioxide. They face problems in utilizing old scraps. MIDREX process is the new emerging technique to produce iron and steel, which demands less fuel, accepts scrap and is environment friendly. The production of direct reduced iron has been continuously increasing by this method due to advanced technologies. Technical development in this process has lead to fulfillment of market needs.

Index Terms— Alternative methods of iron making, CO_2 emissions, DRI, Ironmaking, MIDREX, Shaft Furnace, Steelmaking

1. INTRODUCTION

In 1966, Donald Beggs of the Surface Combustion Corporation looked upon the idea for the MIDREX direct reduction process. He proposed the concept of combining stoichiometric natural gas reforming with shaft furnace direct reduction of iron ore. This process came in use for the first time by the Midland-Ross Co., which later became MIDREX Technologies, Inc. The plants were built in Toledo, Ohio in 1967 and in Portland, Oregon, in 1969. Since 1969, DRI production through MIDREX process has crossed 500 million tons. The capacity of first commercial plant was 150,000 tons per year. Later, Kobe Steel constructed a plant with a production capacity of 400,000 tons/year. Earlier the technology of this process wasn't self-sufficient. But MIDREX Technologies and Kobe Steel made contributions in the technical improvement of the process. Design of the plant developed to increase its capacity.

The maximum production capacity of a MIDREX unit in 1984 was 600,000 tons per year. MIDREX shaft furnaces with 5.0 m, 5.5 m, and 6.5 m shaft diameters having annual production capacities of 800,000 tons, 1 million tons and 1.6 million tons of DRI respectively constitutes different development stages. Later with the improvements made, the capacity has increased to a level of 1.8 million tons per year in 2007, which is comparable to that of a fairly good size blast furnace. Super Megamod module having a capacity of 2.2 million tons of DRI per year has a shaft furnace with an internal diameter of 7.5 m and capability to produce more than 275 tons per hour. Today the Super Megamod module can have a capacity of even 2.7 million tons per year.

The productivity gains of the MIDREX process is due to (i) larger capacity shaft furnaces due to scale-up of the process equipment, (ii) continual refinement of the process which includes increased heat recovery, (iii) improved catalysts, (iv) hot briquetting, and (v) incorporation of new technologies such as double bustle, in-situ reforming, oxide coating, thin wall refractory, oxygen injection etc.

Over the past few decades, MIDREX process has been able to meet the needs of the Direct Reduced Iron in terms of production and process flexibility to meet the constantly evolving nature of steelmakers and ore-based metallic providers.

2. MIDREX PROCESS

2.1 HISTORY

In the old plants of MIDREX process, large shaft furnace were not enough large to meet the need of the market. To increase the productivity, the shaft furnace size has to be increased. As a result, the shaft diameter was increased to 5.5m and then to 6.5m (MEGAMOD shaft furnace). This has increased the production capacity from the previous maximum of less than 400 thousand tonnes/year, first to 800 thousand tonnes/year, and then to 1.5 million tonnes/year 1). The temperature of the reducing gas was also raised by coating the raw material with lime hydrate which has a melting point higher than that of DRI. This has raised the reducing gas temperature to about 900℃ and improved shaft furnace productivity by more than 10%. Further development efforts led to increase in the reducing gas temperatures at the cost of the reducing gas quality. The higher reducing gas temperature along with the loss of the reducing gas quality provided a clear production advantage. The introduction of O2 injection resulted into combustion of a portion of the reducing gas $CO+H_2$ by O_2 and helped in the achievement of this effect successfully. The O_2 injection practice has resulted in increase in the reducing gas temperatures to more than 1000 deg C and further increase in the burden temperature upto 70°C. Although a portion of H_2+CO is consumed by combustion with O_2, raising the temperature of the reducing gas improves the productivity of the shaft furnace by 10 % to 20 %. Typical consumption of oxygen for this improvement is in the range of 12 N cum/ton to 15 N cum/ton. The overall productivity increase over the productivity of the first MIDREX unit of 1969 due to use of lump ore, iron oxide coating and O_2 injection is around 37 %.

The O_2 injection has evolved into an improved technology, called OXY+, which was made possible by the introduction of a partial combustion technique. The OXY+ employs a combustor in addition to the reformer. The combustor partially burns fuel gas with O_2 to produce H_2+CO, which are added to the reducing gas generated by the reformer. The OXY+ system generates a reducing gas by reacting O_2 and fuel gas at a stoichiometric ratio of around 0.5. This system gives stable combustion and eliminates the soot generation. It also protects the material of construction from corrosion at extreme temperatures. The optimum productivity is achieved by maximizing the reducing temperature of the burden and the quality of the reducing gas entering the shaft furnace. These two factors are the keys to optimizing the production of the shaft furnace and its related gas generating equipment.

MIDREX double bustle design to distribute the reducing gas to the shaft furnace consists of two rings of ports around the circumference of the shaft furnace. Double bustle allows better distribution of the reducing gas when compared with a single bustle. Double bustle also allows higher flows of the reducing gas to the furnace without local fluidization of the DRI. These advantages help in increasing the shaft furnace productivity. The MIDREX shaft furnace is the most flexible and versatile reduction vessel for DRI producers.

2.2 PROCESS

MIDREX process is simple to operate and involves three major unit operations namely (i) iron ore reduction, (ii) gas preheating, and (iii) natural gas reforming. The heart of the MIDREX process is its shaft furnace. It is a cylindrical, refractory-lined vessel and is a key component of the direct reduction process. It is flexible as well as a versatile reactor. It can use natural gas, a syngas from coal, coke oven gas, or exhaust gas from Corex process as the reducing gas.

The shaft furnace is designed on the principle of counter flowing gas and solids to maximize reduction efficiency. The furnace assures uniform solids flow by effectively distributing the furnace burden and avoiding material bridging and gas channeling. Control is exercised with respect to the flow of gases between the various furnace zones. Shaft furnace also prevents the reducing gas from coming into contact with air. It prohibits gas flows from fluidizing the furnace burden. A uniform temperature profile is maintained across the cross-section of the furnace. The stoppage of furnace burden flow is avoided. The furnace design eliminates the need for water-cooled discharge cone.

Operation of the shaft furnace is simple and straight-forward. Iron burden material is introduced at the top of the furnace through a proportioning hopper and descends downward by gravity flow. In the furnace it is contacted by upward flowing high temperature reducing gas, heated and converted to DRI. The reducing gas, which is primarily hydrogen (H_2) and carbon mono oxide (CO), reacts with the iron oxide (Fe_2O_3) to reduce i.e. to remove the oxygen (O_2) content and carburize the material prior to discharge. For the production of CDRI, the reduced iron is cooled and carburized by the counter-flowing cooling gas at the lower portion of the shaft furnace. The DRI can also be discharged hot either as HDRI or fed to a briquetting machine to produce HBI. Hence, the product of the furnace can be discharged as CDRI, HDRI, HBI or any combination simultaneously.

The exhaust gas (top gas) emitted from the top of the shaft furnace is cleaned and cooled by a wet scrubber (top gas scrubber) and recirculated for reuse. The top gas containing CO_2 and H_2O is pressurized by a compressor, mixed with natural gas, preheated and fed into a reformer furnace. MIDREX process uses a solid catalyst for the gas phase reaction. Alumina or magnesia is the carrier material which gives the catalyst its shape and strength. The active ingredient of the catalyst, which increases the speed of the reaction, is normally nickel. Cobalt has also been used in some cases. Sulphur and halogens are the most common reforming catalyst poisons.

The MIDREX reformer furnace is provided with several hundreds of reformer tubes filled with nickel catalyst. Passing through these tubes, the mixture of top gas and natural gas is reformed to produce reductant gas consisting of CO and H2. The MIDREX reformer differs from steam reformer in many ways. It (i) reforms both carbon dioxide and water vapour, (ii) operates at an oxidant/carbon (MIDREX stoichiometric) ratio of around 1.4, (iii) operates with sulphur present in the reformer feed gas, (iv) operates at low pressure, and (v) requires a unique catalyst design.

The thermal efficiency of the MIDREX reformer is greatly enhanced by the heat recovery system. Sensible heat is recovered from the reformer flue gas to preheat the feed gas mixture and the burner combustion air. In addition, depending on the economics, the fuel gas can also be preheated.

2.3 RECENT TECHNOLOGICAL TRENDS

Year	Total World Production of DRI (in Million tons)
2013	75.0
2014	74.6
2015	72.6

Based upon data collected by MIDREX Technologies, the production of direct reduced iron has been 72.57 million tons in 2015. This was nearly two million tons lower than 2014, a decline of 2.7%. The slowdown was commensurate with the rest of the steel industry, which fell by 2.5% worldwide. 74.6 million tons and 75.0 million tons of DRI products were produced in 2014 and 2013. Production fell slightly from 2013 due to natural gas shortages and curtailments in India, and operational disruptions in other DRI producing regions, as well general downturns in steel market conditions. DRI growth was evident in a number of nations including the USA and Bahrain. Plants based on MIDREX® Direct Reduction Technology accounted for 47.12 million tons, which once again led all technologies with 63.2 percent of the market total.

	2013	2014	2015
MIDREX	**63.5%**	**63.2%**	**63.1%**
HYL	**15.1%**	**16.2%**	**16.0%**
Other gas	**0.2%**	**0.0%**	**0.7%**
Coal Based	**21.3%**	**20.6%**	**20.2%**

Production by plants employing MIDREX® Direct Reduction Technology was 45.75 million tons, or 63% of the world total. This was the 37th consecutive year that production by MIDREX® Plants exceeded half of the world's total DRI output. Approximately 25 million tons of new DR capacity is under construction. In Iran alone, eight new MIDREX® Plants are in progress. Of the remaining, non-Iranian capacity being built, MIDREX Plants account for 8.8 million tons. Although growth suffered from two setbacks over the past few years the financial crisis in 2008-2009 and the steel industry slowdown in 2015 when viewed over the longer term, direct reduction has enjoyed excellent growth averaging 4.3% per year since 2001. Major factors driving growth continue to be the need for iron metallics in many parts of the world where scrap steel is scarce relative to the demand from EAF steelmakers and the ability of DRI to provide low residual iron for manufacture of high quality steels.

Energy Source	CO_2 Emissions	
	(t/TJ)	(lbs/MMBtu)
Natural gas (CH4)	49	115
Bituminous metallurgical coal	90	212
Bituminous steam coal	94	220

In the DR/EAF route, carbon emissions can be further reduced by hot charging the DRI to the EAF. Traditionally, almost all MIDREX® Plants with an adjacent melt shop have cooled the DRI and stored it for later charging to the EAF. Now, MIDREX has developed three methods for discharging the DRI at elevated temperature, transporting it hot to the melt shop, and charging it to the EAF at 600-700º C. These methods lower the electricity required per ton of steel produced, which also reduces CO_2 emissions from the power

ISSN 2229-5518

plant. The electricity savings occur because less energy is required in the EAF to heat the DRI to melting temperature. The rule-of-thumb is that electricity consumption can be reduced about 20 kWh/t liquid steel for each 100º C increase in DRI charging temperature. Thus, the savings when charging at over 600º C are 120 kWh/t or more. With the use of hot charging, the DR/EAF route becomes even more attractive.

3. CONCLUSION

The increasing emphasis on the environment creates a need for innovative solutions to reduce carbon emissions from iron and steelmaking facilities. One good approach is to use natural gas as a reluctant and fuel source, since it results in far less CO_2 emissions than coal. A proven method is natural gas-based direct reduction, such as the MIDREX® Process, paired with an electric arc furnace. Use of 80 percent hot charged DRI in the EAF results in 47 percent lower carbon emissions per ton of steel produced than the blast furnace/BOF route. Many regions with abundant natural gas have seen major growth in DRI production and there is over 14 million tons of new MIDREX Plant capacity recently started up or under construction in the Middle East, Latin America, Asia, and Russia. Several approaches hold the possibility of reducing carbon emission even further.

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