JESTECH, 15(2), 71-76, (2012)

JESTECH

ULTRA–LOW CARBON DIOXIDE (CO_2) STEELMAKING

Mehmet YANMAZ*, and Durmuş KAYA**
*KARDEMİR A.S, Karabuk, Turkey
**Karabuk University, Karabuk, Turkey

Abstract

Steel production is one of the most energy-intensive and, therefore, CO_2 emitting industry. This production is responsible for an estimated 5.2% of total global greenhouse gas emissions and 21% of total EU industrial emissions. Approximately 80-90% of these emissions are connected to the blast furnace converter process. The size of the CO_2 emission per tonne of hot metal is connected to the required amount of reduction agents and the carbon intensity of the applied agents. Current consumption of reducing agents for the blast furnace–converter route in the EU-15 amounts to 490–470 kg/tonne hot metal (HM) and comprise of coke, pulverized coal and a small amount of fuel oil. Among the types of reducing agents applied in practice are natural gas, biomass and secondary fuels, e.g. waste plastics. In the steel industry, there are three potential technological directions for realizing a significant reduction in CO_2 emissions, in a wide manner; design a new process which is essentially more energy efficient and/or carbon-neutral, low carbon reducing agents and fuels, CO_2 capture and storage. As the largest R&D program, called ULCOS (Ultra Low CO_2 Steelmaking) has been running in the EU since 2004.

In this paper, it has been made an intensive review about new technologies in ULCOS for steel production to reduce CO_2 emissions. As new technologies; blast furnace top gas recycling (TGR), smelting reduction process, direct reduction of iron-ore with natural gas, hydrogen-based steelmaking, iron-ore electrolysis and biomass based steel production are examined.

Keywords: Iron-Steel Industry, Carbon Dioxide Reduction, Greenhouse Gas Emission

1. Introduction

The iron and steel sector is one of the highest industrial CO_2 emitters. All over the world, between 4 and 7% of the anthropogenic CO_2 emissions originate from this industry. CO_2 reductions in the iron and steel industry are vital if governmental climate protection aims are to be accomplished [1]. To meet Kyoto requirements, the steel industry is including the challenge of sustainable development by developing its rivalry and economic success while reducing its environmental impacts. Merging environmental considerations into the traditional product design process, for vigorous eco-efficiency, is now one of the main primacies for steelmakers [2]. There is no simple process, available off-the-shelf, that can achieve this. Deep paradigm shifts in the way steel is produced have to be imagined and the corresponding cutting edge technology designed and improved by powerful R&D programs. The biggest R&D program, called ULCOS (Ultra Low CO_2 Steelmaking), has been implementing in the EU since 2004 to progress in this way [3]

ULCOS stands for Ultra–Low Carbon dioxide (CO_2) Steelmaking. It is a consortium of 48 European companies and organizations from 15 European countries that have started a cooperative research & development initiative to ensure drastic reduction in Carbon dioxide (CO_2) emissions from steel production. The consortium comprise of all major EU steel companies, of energy and engineering partners, universities and research institutes and is supported by the European Commission. The main purpose of the ULCOS programme is to reduce the Carbon dioxide (CO_2) emissions of today's best routes by at least 50 percent [4]. The steel industry is looking for some serious solutions to solve the threat of global warming in today. The

Corresponded Author; dkaya@karabuk.edu.tr

consortium's expertise ranges from steelmaking to biomass production and geological Carbon dioxide (CO_2) storage and it includes process science as well as engineering, economics of energy and foresight studies in relation to climate change. The budget is 75 million Euros over a 6 year period, which means that approximately 80 man-years are dedicated to the programme every year and involves double this number of individuals. The partners in the ULCOS consortium foot the bill for 60 percent of the total cost. The European commission financially contributes the remaining 40 percent through its 6th Framework and the RFCS (Research Fund Coal Steel) programmes. Both are arranged and ready to promote industrial research and technological development within Europe.

The development of cutting edge technologies into mature industrial applications associates a level of risk and entails at least one additional scale up step. This demonstration stage will take the ULCOS programme into phase II. ULCOS II will examine some of the technologies investigated under ULCOS I as to their potential and feasibility under large scale, industrial production conditions. This will employ considerable additional R&D investment by the ULCOS consortium, the European Commission and other funding partners. Both the ULCOS Consortium main members and the European Commission have decided to further move forward during the last meeting of the European Steel Technology Platform (ESTEP) and to start ULCOS II to adopt that work as soon as ULCOS I is finished in 2010. ULCOS II is planned to run from 2010 to 2015. The results of ULCOS II can potentially be submitted into production plants some 15 to 20 years from now. ULCOS has selected four process concepts that could lead to a reduction of Carbon dioxide (CO_2) emissions by more than half compared to present best practice. The four cutting edge technologies described are: Top Gas Recycling Blast Furnace with CO_2 Capture and Storage (CCS), HIsarna with CCS, ULCORED with CCS, Electrolysis. For the Top Gas Recycling Blast Furnace, HIsarna and ULCORED, the aim of a 50% reduction of Carbon dioxide (CO_2) emissions can only be accomplished if each of these technologies is combined with Carbon Capture and Storage technology. Electrolysis entails the availability of Carbon dioxide (CO_2)-free electricity in a large amount. Another option that might reduce the amount of Carbon dioxide (CO_2) emissions in producing steel is the use of Carbon from Sustainable Biomass.

2. New technologies for steel production to reduce CO_2 emissions under ULCOS Options

2.1. Blast furnace top gas recycling (TGRBF)

The Steel Industry products steel from iron ore basically with coal, using an exclusive chemical reactor that ranks among the true technological accomplishments of the 20th century, the Blast Furnace (BF). The first part of the ULCOS program, backed by the RFCS, appraises how to leverage on the sophistication of the modern Blast Furnace to cut CO_2 emissions [5].

The Top Gas Recycling Blast Furnace (TGRBF) is a steelmaking version of the integrated cycle technologies of the energy industry and of the "pre-combustion capture" concepts that CO_2 engineering has begun to make accustomed [5]. The concept depends on the removal of the CO_2 held in the top gas of the blast furnace so that the useful components – $CO+H_2$ can be recycled back into the furnace and reused as reducing agents. This would reduce the quantity of coke needed in the furnace. Besides, oxygen (O_2) injection into the furnace instead of preheated air, removes unwanted nitrogen (N_2) from the gas, promoting CO_2 Capture and Storage (CCS) [6].

There are four versions of the Top Gas Recycling Blast Furnace approaches were suggested. The common characters of the different TGRBF processes are the use of the oxygen instead of pre-heated air, the CO_2 removal and the re-injection of the recycled CO-rich top gas into the BF. The main differences between different versions are the recycled gas temperature for injection and injecting position on BF. The recycled top gas can be injected into conventional tuyere only, e.g. version 3, or shaft/stack tuyere only or both, e.g. version 4. Recycled gas temperature can vary too, from room temperature to a temperature of about 1250°C. Figure 1 demonstrates the a view of the TGRBF process with CO_2 removal unit – VPSA plant [7].

Figure 1. ULCOS blast furnace at LKAB's EBF plant

2.2. Process of Smelting Reduction [7]

Smelting reduction (SR) processes is about reduction of iron ore without the need for coke and mostly agglomerated ore. The motivations behind the development of SR processes are the decrease of capital and operation costs and the less environmental influence, both of which can be accomplished by discarding coke ovens and ore agglomeration.

The principle of SR can be described as that iron oxide is reduced in the liquid state by carbon or carbon monoxide. Liquid state reactions are much faster than solid state reactions. In that the reduction in a blast furnace is a solid state reaction, the reduction time can be decreased. In principle, an SR process can comprise of a single reactor in which unprepared iron ore and coal react to form a product similar to steel; namely, decarburization of the iron takes place in the same reactor. Practically, SR processes consist of at least two reactors, and the product seems pig iron, which has to be refined in a separate reactor for steel to be achieved.

Diagrammatic representations of SR processes are showed in Figure 2. In SR processes, iron ore is pre-reduced in the solid state in a pre-reduction shaft by a reducing gas generated in a smelting reduction vessel. Melting and final reduction usually occur also in this smelting reduction vessel. In most SR processes, the reaction site is the slag floating on the bath of liquid iron. Coal reacts with oxygen or iron ore in the liquid state to form a gas that comprises mainly of carbon monoxide. The gas causes the slag to foam. Foaming slag is important for developing reaction kinetics and heat transfer but should be hold under a critical value to assure normal operation. The gas can be moderately post-combusted above the slag to adjust the chemical composition. The degree of post-combustion should be controlled to guarantee that the composition and the temperature of the reducing gas match the needs of the pre-reduction. The heat generated by post-combustion should be come back to the bath.

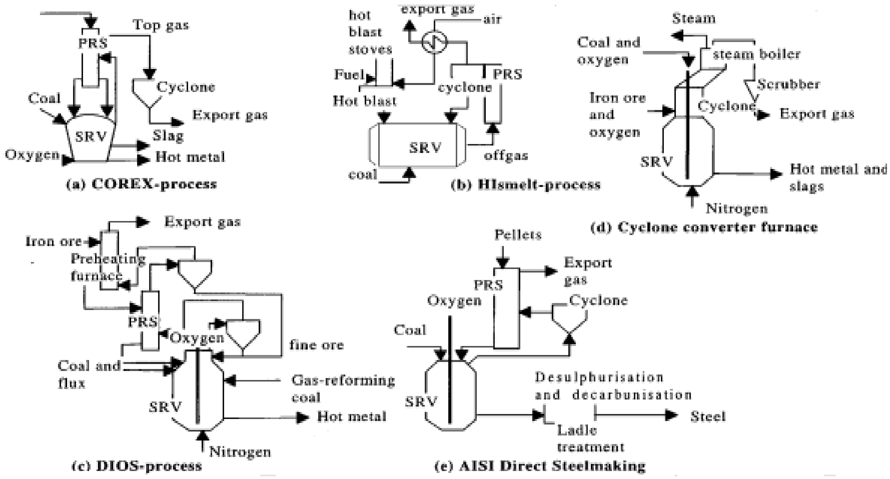

Figure 2. The representations of smelting reduction processes (Not on the same scale). PRS: Pre-reduction shaft; SRV: smelting reduction vessel.

2.3. Direct reduction of iron-ore

Direct-reduced iron (DRI) is called sponge iron [8], manufactured from direct reduction of iron ore. It is mostly in the form of lumps, pellets or fines. This manufacturing is occured by a reducing gas produced from natural gas or coal. The reducing gas is a mixture that mainly of hydrogen (H_2) and carbon monoxide (CO) which acts as reducing agent. The process of directly reducing the iron ore in solid form by reducing gases is called direct reduction [8].

DRI can be described as a solid state product of direct reduction processes which is produced either in the form of lump or pellet. Availability of vast amount of non-coking coal, scarcity of coking coal deposits and industrial importance of DRI led to many endeavors for the development of many direct reduction processes [8].

In the ULCOS project development is under a method for reduce natural gas consumption needed to produce DRI. This is moderately obtained by replacing the traditional technology, reforming, by partial oxidation of the natural gas. This will largely reduce capital expenditure, as well [4].

In the new layout there will be a single source of Carbon dioxide (CO_2). This Carbon dioxide (CO_2) will be clean enough for geological storage [4]. In the next ULCOS phase the fractional oxidation will be more investigated and a pilot plant for the new concept will be commissioned [4].

2.4. Hydrogen-based steel making

Hydrogen steelmaking will rely heavily on the availability of green hydrogen, while the use of charcoal, far way from developing countries, would entail the set up of complex logistics, including heavy infrastructure across several continents [3]. The discussions have been made until now on the main sources of CO2, which admits to cut emissions for the whole steel mill by more than 50%. It is possible to cut emissions more, by treating the other stacks of the steel mill: the cost of reduction would of course be much higher. With this reasoning, though, zero emissions could be achieved [3].

2.5. Iron-ore electrolysis

In the metal industry, electrolysis is largely used to produce aluminum, copper or zinc. Electrolysis is in effect using electrons to reduce metal cations into the zero valence-element. Although not used in the Steel Industry, electrolysis could in principle be performed in different ways to produce steel [9]:

• Aqueous solutions of Fe^{3+} ions obtained by leaching iron ores or scrap by HCl can be electrolyzed directly into a foil, 10 to 150 μm in thickness. A pilot plant based on this concept was experimented at CRM under the name of Electro-oil process, with an output of 4.5 t/h and a drawing speed of 31 m/min for the 0.15 mm thickness [8]. The solution was either reload with scrap or with sulphide ore [9].

• A soda solution that iron ore pulp was dissipated was also experimented upon at IRSID [9]. Electrolysis was accepted to dissociate water into OH^- ions and free hydrogen, which would then reduce Fe_2O_3 and regenerate water. The iron deposit had to be melted, cast, rolled and finished [10].

• Iron ore can also be melted into liquid salts (e.g. $Na_2CO_3+B_2O_3$) at high temperature and the electrolysis carried out in the salt. Depending on the temperature, solid iron can deposit on the cathode, or liquid iron can flow down to the bottom of the cell, thus mimicking aluminum production. These routes have been studied at MIT [10].

The energy essentials for the first process was 6 400 kWh/t or 23 GJ/t (electrolysis + annealing), while the second one used up 3800 kWh/t or 13.7 GJ/t., for the electrolysis and 1300 kWh/t or 4.7 GJ/t for the consequent production. Electrolysis, which leads directly to final products, is to be compared to a whole conventional mill, which has an energy consumption of 15 to 20 GJ/tls, a same order of magnitude. The technology might be charming in terms of CO emissions, if the carbon content of electricity is adequately low. Electrolysis, yet, needs to be better understood, before its importance for the future can be appraised [9].

2.6. Biomass and steel production

Biomass is general term of biologically produced material that readily burns or can be converted into char. Biomass materials include wood and wood wastes, agricultural crops and their waste products. Biomass and char have been used as fuels and as reductants in metallurgical processes since ancient times. The use of biomass wood char in iron making has been largely reviewed by Gupta, while Burgess and Dell Amico et al [5] have also described applications of biomass wood char in iron making in detail. [5].

Woodchar or biomass char is taken into account as a renewable because the carbon cycle via wood (biomass) is very short (5-10 years) compared to fossil coal (approximately 100 million years). However, the challenge is to be able to improve and manage the wood source on a sustainable basis and to improve charcoal production technology that produces charcoal at a importantly lower cost [6] and with lower environmental effects than current production methods [5].

SP7, lead by Corus and associating the expertise of institutes and laboratories working on biomass (CIRAD, BTG, ECN, CSM), has researched the different opportunities in relation to committed crops plantations or of agricultural residues, produced in tropical countries especially where the light efficiency is highest or in Europe, and of conversion into a solid (charcoal, ArcelorMittal- CPM, Kassel University), a liquid (bio-oil, BTG) or a gas (biogas or syngas, CSM).

CIRAD has developed a scientific case for stating definitely what carbon neutrality means and how it can be achieved. Some more work is required in this topic during phase 2 to close the case. Bio-oil is likely better made for the transportation sector, as it will be expensive relative to other kinds of biomass. Biogas might be achieved from agricultural residues and used for example as alternate to natural gas in direct reduction processes, but its accessibility in quantity and quality is a question that needs to be solved in phase 2.

The most open and applied solution for producing biomass for the Steel Industry is to make charcoal from sustainable plantations of eucalyptus trees grown in tropical countries for example in Brazil or Congo, and modify there to be transported to Europe. PCI can be altered fully by charcoal in large BFs is about 40% of the carbon input, while Smelting Reduction can accommodate more like up to 100%. Plantation technology is developed and has advanced to a notable level of excellence in Brazil. Progress has to be occured on the alteration process, by scheming constant, high productivity furnaces, possibly working under pressure, to alter Missouri kilns. Small BFs running with 100% charcoal operate in Brazil for example in Acesita and the dare for ULCOS is to bring a version of this technology to Europe.

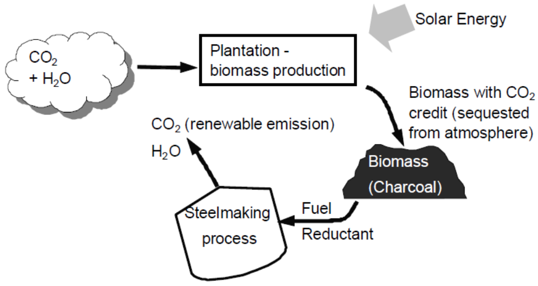

Figure 3. Schematic explanation of biomass carbon cycle.

3. Conclusion

The ULCOS program has been running in line with the plan: it has transferred from phase 1 to phase 2 during its second year and produced a considerable amount of knowledge and of scientific and technological conclusions.

Different routes of steelmaking have been examined in phase 2 is 5, a 14-fold reduce relative to phase 1. They all are likely to succeed for reducing CO_2 emissions and for economic applicability in a post-Kyoto, carbon restricted world. Their number is connected to the spectrum of energy which the Steel Industry is likely to use that remains open and might advence as to its order of merit in a far future. CCS is a requirement and biomass is a wise option to keep open.

The ULCOS program has also improved a considerably long list of technologies that may be used in the shorter term, with less aspiration on CO_2 alleviation. Phase 2 of the program, presently under way has actively been moving onward. It has already proved that the Top Gas Recycling Blast Furnace concept does deliver on its promises, after 6 weeks of experimental trials on the LKAB experimental Blast Furnace. A small pilot ISARNA furnace is being designed and built for tests in Völkingen in 2009/2010. A new Direct Reduction process is under elaborated design. Electrolysis is happening with an alkaline water solution experiment and a high-temperature, molten slag one at a larger laboratory extent. ULCOS I has kept on its promises until today and can therefore be contemplated as a success, opening the way to the advancement of a series of carbon-lean iron and steelmaking technologies for the Steel Industry to use in a post-Kyoto, carbon restricted world.

References

1. Marlene Arens, Energy efficiency and CO_2 emissions reduction in the steel industry, EFONET WORKSHOP 4.3, Berlin, February 19th 2010.

2. Ana-Maria Iosif, Jean-Pierre Birat, Olivier Mirgaux, Denis Ablitzer, Reduction of CO_2 Emissions in the Steel Industry Based on LCA Methodology, Source from www.ulcos .org
3. Jean-Pierre BIRAT, Steel and CO2 – the ULCOS Program, CCS and Mineral Carbonation using Steelmaking Slag ArcelorMittal, Maizières-lès-Metz, France
4. www.ulcos.org
5. SCANMET III, 3rd International Conference on ProcessDevelopment in Iron and Steelmaking 8–11 June 2008, Luleå, Sweden.
6. Guangqing Zuo and Alexandra Hirsch, The Trial of the Top Gas Recycling Blast Furnace at LKAB's EBF and Scale-up, Proceedings of the 4th Ulcos seminar, 1-2 October 2008
7. J. Beer, E. Worrell and K. Blok, Future Technologies for Energy-Efficient Iron and Steel Making, Annu. Rev. Energy Environ. 1998. 23:123–205
8. What is direct reduced iron (DRI)? definition and meaning". Businessdictionary.com. Retrieved 2011-07-11.
9. J-P.Birat, J-P.Vizioz,Y. Pressigny, M. Schneider, M. Jeanneau, CO_2 Emissions and the Steel Industry's available Responses to the Greenhouse Effect, IRSID - RE 99 .001, 1999.
10. IEA Energy Technology Perspectives 2008; total greenhouse gas emissions from human activities in 2004 were 49 billion tonnes (IPCC Working Group III, Climate Change 2007).