



USE OF CHEMICAL ENERGY IN SUBMERGED ARC FURNACE TO PRODUCE FERROCHROME: PROSPECTS AND LIMITATIONS

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ABSTRACT

High carbon ferrochrome production process is energy intensive, consumes approximately 3300-3400 kWh per ton of metal produced. This amounts to ~ 34% of the total ferrochrome production cost. The power costs in India are almost 4 times greater than the leading ferrochrome producing countries like South Africa. Hence there is a need to look for alternative sources of energy. In ferrochrome making process large volumes of high concentration CO gas (~ 85%V) is developed at ~400-500°C, which if combusted within furnace represents high potential for significant electrical energy savings. In a typical heat in the state-of-the-art submerged arc furnace, about 34 kmol of CO gas is generated per ton of ferrochrome metal, which, if post combusted to CO₂, represents 7620 MJ of energy. Post combustion of the evolving CO (and H₂) gas to CO₂ can be achieved by providing additional oxygen before the generated CO gas leaves the furnace. In this paper, a concept of post combustion in submerged arc furnace as potential source of significant electrical energy saving in ferrochrome making process has been explored. The prospects and limitations of the same are discussed. The value of this paper lies in its attempt to explore the postcombustion application to submerged arc furnace with an objective of significant reduction in electrical energy consumption in ferrochrome production process.

1. INTRODUCTION

In ferrochrome production processes, carbon monoxide is generated by releasing energy when oxygen is reacted with carbon during reduction reactions of chromite. This CO gas can be further oxidized to CO₂ if mixed with oxygen before leaving the furnace. By this oxidation process, it releases about 3 times the energy released by oxidation of carbon to CO. The potential use of this energy and the corresponding increase in productivity is the economic driving force behind postcombustion (PC) technologies. Vast literature is available on approaches that have been tried in the past for use of combustion energy of CO gas in steelmaking with electric arc furnace⁽¹⁻⁶⁾. However no such literature is available in public domain for postcombustion in submerged arc furnace (SAF) especially related to ferrochrome production process. For achieving maximum benefits from postcombustion technologies, the major challenge lies in transferring the generated heat efficiently to the solid charge in SAF. Also it is essential to assure that the gas does not leave the furnace at high-temperature. The heat transferred to the furnace wall must also be minimized in order to save the refractory from damage and associated heat losses.

1.1. Ferrochrome Production Process

High carbon ferrochrome (HCFerCr) is produced by carbothermic reduction of chromite. In this process, electric power is generally used to supply the energy required for carrying out the smelting and reduction reactions. The reactions involved are



Coke is used as reductant. Quartzite, bauxite, olivine, dolomite, limestone and calcite are used as slag additives. The charge is dosed into the smelting furnace as cold, preheated or prereduced. The raw materials are in the form of lumpy ore, upgraded lumpy ore, ore fines and concentrates. Factors which affect energy consumption in this process include the quality of raw materials and their pre-treatment before smelting, the utilization of reaction energies and heat contents from the processes.

1.2 Closed Submerged Arc Furnace

The closed type submerged arc furnace includes three-phase A.C. operations with three Soderberg electrodes and energy generation by electric resistance heating. A schematic of typical closed submerged arc furnace is shown in Fig. 1. Material balance over submerged arc furnace for ferrochrome production are shown in Fig. 2, on the basis of production of one ton of metal and the corresponding slag of the composition as shown. The totally closed electric furnace is covered by a water-cooled refractory or metal roof. The smelting charge flows continuously from the tubes to the hearth. Chromite is reduced both in solid and liquid state. Smelted products go on to the bottom of the furnace. The formed ferrochrome and slag are tapped intermittently. In

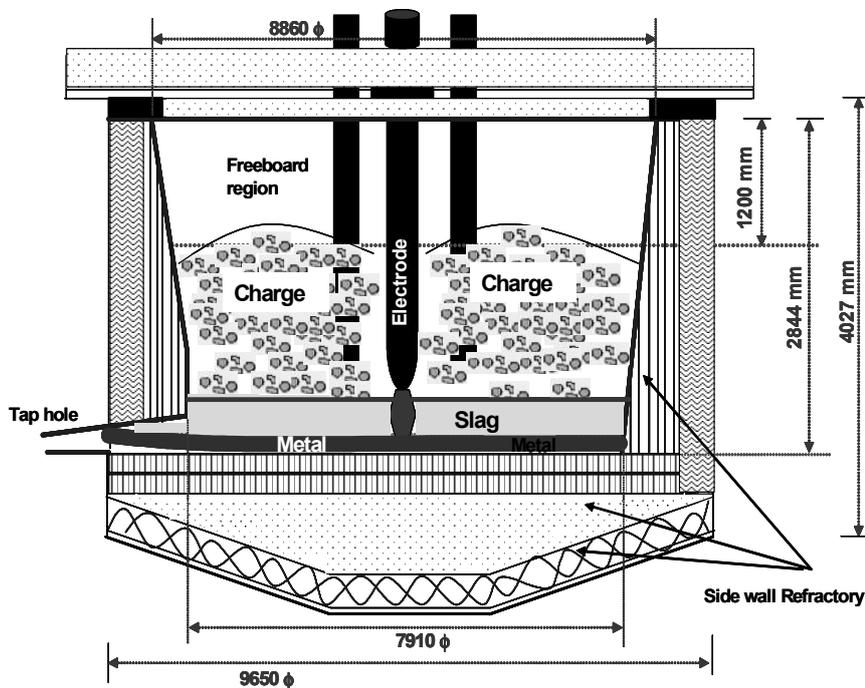


Figure 1: Schematic diagram of closed submerged arc furnace

this process, CO-rich off gas are produced during the smelting-reduction reactions. It can be seen from Fig. 2 that, theoretically ~ 34 kmol of CO rich off gas is generated per ton of ferrochrome metal produced.

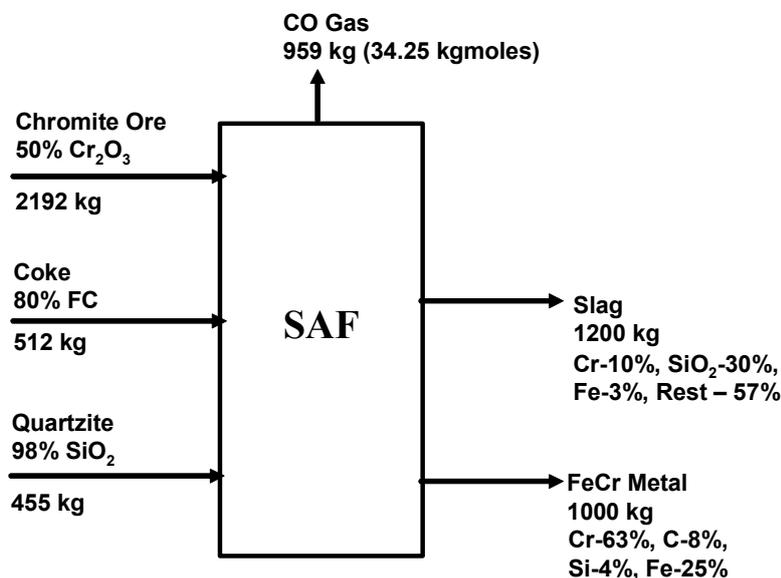


Figure 2: Material balance over submerged arc furnace

1.3 Carbon Monoxide Gas in Submerged Arc Furnace

The reduction reactions in submerged arc furnace generate about 650-750 Nm³ of carbon monoxide rich off gas per ton of FeCr metal with reaction energy of ~ 7550 -8300 MJ (2100-2300 kWh) by assumption of good furnace sealing. The combustible gas produced during smelt reduction reactions consist of high concentrations of CO. The typical composition of CO rich-off gas is given in Table 1. The CO gases formed are sucked out from the closed furnace through two take offs to wetting scrubbers. The CO gas is transferred by means of pipelines in the plant area as easily as any fuel gas. The CO gas is used in coke drying, sintering, preheating and heating of ladles. In case of integrated works, CO gas is also used in the stainless steel production.

Table 1: Composition of submerged arc furnace off gas

Gas	Composition (Vol. %)
CO	85-90
CO ₂	2-5
H ₂	5-7
N ₂	2-5
H ₂ O	1-2

1.4 Shankey Diagram over Submerged Arc Furnace

In order to minimize the electrical energy consumption in SAF process, it is essential to know the distribution of supplied heat in the furnace. Hence, the Shankey diagram over the submerged arc furnace for a typical ore is shown in Fig. 3. The shankey diagram is the heat flow diagram over a process equipment or unit. It shows how the supplied heat is being utilized in the system. It can be seen that in submerged arc furnace operation almost 40% (~ 1200 kWh) of the input energy is utilized towards heating of the charge. This indicates that there is a significant opportunity to substitute this heat by alternative energy available such as the chemical

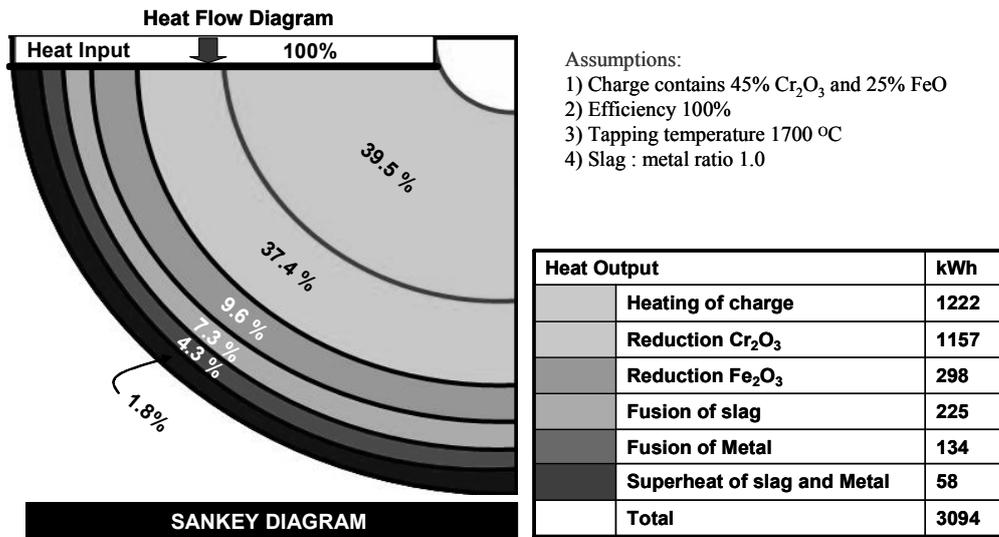


Figure 3: Energy balances over submerged arc furnace process

energy of CO rich off gas. The energy balance calculations are shown based on the 100% efficiency of the furnace assuming there are no heat losses.

2. DESCRIPTION OF POSTCOMBUSTION

2.1 Reactions

In post combustion, chemical energy available in furnace off gas is used for heating the charge in furnace. It consists of burning the CO and H₂ gas evolving from charge by providing the oxygen for combustion. Potential sources for CO and H₂ generation in ferrochrome production process include the carbothermic reduction of chromite, iron oxides and silicates as given in reaction [1-4]. H₂ originates from the reduction of moisture in charge according to reaction [5-6].



In Table 2, the postcombustion reactions of CO gas are given along with their standard heats of reaction. It can be seen that the postcombustion of CO to CO₂ can produce twice as much energy as the combustion of C to CO.

Table 2: Standard Heats of Reaction for the oxidation of Carbon and Hydrogen

Reaction	ΔH^0 (kJ/mole)
$C + \frac{1}{2} O_2 \rightarrow CO$	-110.53
$CO + \frac{1}{2} O_2 \rightarrow CO_2$	-282.99
$C + O_2 \rightarrow CO_2$	-393.52
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	-241.83

2.2. Hypothesis of Postcombustion

The most significant opportunity for energy savings in submerged arc furnace smelting can be found in utilization of chemical energy of CO gas for heating of the charge by combusting the gases in furnace freeboard. Post combustion to some extent occurs in almost every SAF operation even if there is no post-combustion system installed on the furnace. Air drawn into the furnace due to minor leaks provides the oxidant for burning a portion of the CO and H₂ generated during ferrochrome making. CO will be the predominant gas in the freeboard during the SAF operation. Temperature of this gas is generally close to 400-600 °C and has high calorific value (~ 2492 kWh). If this CO rich off gas is burned in the freeboard it is possible to recover heat within the furnace. It can be expected that 30-40% of the theoretical heat content of the CO could be transferred to the charge surface through efficient postcombustion of CO in furnace freeboard. This can result in potential electrical energy savings per ton of ferrochrome metal produced. In Table 3, the theoretical potential energy savings per ton of metal which can result based on the above hypothesis at different combustion rates at realistic heat transfer efficiencies of 40% are shown. It can be seen that at combustion rate of 50%, around 500 kWh of electrical power can be substituted by combustion energy of the CO rich off-gas per ton of ferrochrome metal produced.

Table 3: Theoretical postcombustion heat generation at different combustion rates

Combustion rate (%)	Heat generated (J)	Heat generated (kWh)	Heat utilized for charge heating (kWh)
100	-8.99×10^{09}	2492	997
50	-4.50×10^{09}	1246	498
20	-1.80×10^{09}	498	199

3. CHALLENGES IN POSTCOMBUSTION PROCESS

3.1 Effect on Refractory

While carrying out postcombustion in furnace freeboard, it is expected that the sidewall refractory and roof may be exposed to high temperatures due to post combustion heat since radiation is the dominant heat-transfer mechanism at high temperatures. This could lead to the rapid erosion of the refractory material. The furnace interior especially the carbon electrodes and its steel casing are also likely to experience damage due to the postcombustion heat. In order to overcome this, the combustion of CO gas inside submerged arc furnace freeboard must be carried out selectively which can be achieved by proper injection of the combustion oxygen. This includes the optimization of the various oxygen injection parameters like injector height, angle and velocity of inlet oxygen.

3.2 Effect on Coke

The primary purpose of the coke in ferrochrome production process is as reductant. Due to postcombustion in the furnace freeboard the surface temperatures of the charge are expected to be higher. It is anticipated that at high temperatures some amount of the coke present may be gasified thus will not serve the purpose as reductant. This will lead to coke deficit ferrochrome making process. Thus demands for excess coke requirements than current level. However this situation may be circumvented by controlling the temperatures and oxygen injection parameters as discussed above. Also, in cold charge condition, the actual surface temperatures with postcombustion may not exceed 1000°C and below these temperatures the coke gasification may be insignificant.

4. FUTURE STUDIES

In postcombustion studies, since high temperature are involved, it is difficult, to do a physical study on the characteristics of flow and combustion heat transfer inside ferrochrome making submerged arc furnace but

with the availability of increasing development of commercial codes for computational fluid dynamics (CFD), a number of numerical studies have been carried out on post combustion in steelmaking processes⁽⁶⁾. Studies on the similar lines may be helpful for postcombustion problem in submerged arc furnace applications.

5. SUMMARY AND CONCLUSIONS

Ferrochrome making process being energy intensive with high electrical energy costs in the region, demands the search for alternative energy sources. Postcombustion in ferrochrome making submerged arc furnace could be a potential source for electrical energy savings. Postcombustion approach in submerged arc furnace freeboard is associated with process challenges which include the refractory and electrode damage due to postcombustion heat. For successful commercialization of postcombustion technology in submerged arc furnace these challenges needs to be overcome with proper strategy for oxygen injection to the furnace freeboard. Further computational and experimental efforts will be required to explore the postcombustion feasibility in submerged arc furnace with objective of minimizing the electrical energy consumption in ferrochrome production process.

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