

Lecture No. 2-4

Oxy-Fuel Burner Technology for Cupola Melting

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SUMMARY

Cupolas are a major contributor to the iron production in Europe and in the U.S.A.. Over 60% of the produced iron passes through the runner of a cupola. Since the invention in 1794 by John Wilkinson, this melting unit and melting process has been continuously improved. The improvements aim at better environmental sustainability, to increase the efficiency and to make the operation more flexible. The idea to use alternative forms of energy (natural gas or oil) is not new; in the 70's there have been several published cases. This was probably inspired by the good success of alternative fuels in the blast furnace operation. In this paper the differences to the projects of the seventies will be described and some literature will be quoted. Operating results from cupolas in the USA and Germany will be presented and discussed. Experiences and conclusions from the project "Ecological and economical optimisation of the cupola melting process with the use of oxy - fuel burners with optional solids injection (Kupolopt)" as part of the BMBF funded program "Integrated environmental protection in the foundry industry" are presented. This project, with a duration of three years has the objectives of maximising melt rates, reducing emissions and recycle foundry residuals and residuals from other industries.

KEYWORDS

Oxy-Fuel Burner

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INTRODUCTION

The recycling of metals has a substantial meaning for protecting the environment and global resources. Ferrous metal is an ideal recycling material. It can be used over and over again without losing quality. The reuse of ferrous metal scrap instead of smelting it from iron ore reduces the required energy by 90% and the CO₂ emissions by more than 80%. Modern cupola melting shops are mainly ferrous metal scrap melting units. They are charged with steel and iron scrap as well as foundry returns. Despite the important role of the cupola to conserve our global resources and to protect the environment, it has come under scrutiny. These days, cupola operators fear high cost of their operation associated with disposal of foundry residuals, and foundry coke, and with the burn off of metallic alloying agents. A cupola that with some help can become more competitive would be advantageous to operate. The idea is to provide process support in form of high-density energy in the tuyere, a location where it helps to enhance the overall cupola process in terms of operating flexibility and consistency of product quality, and at the same time allows to continuously inject solids. These solids should have the characteristics of supporting the cupola process when being recycled in this environment. This way the cupola fulfills a double role. In addition to its efficient and productive operation, it recycles components like iron, iron oxide and combustibles right away. The result in the end is saving space for disposal and ore resources on our earth.

REVIEW OF NATURAL GAS USE IN CUPOLAS

The cupola was invented as a coke fired and brick laid rectangular shaft furnace. Tuyeres in the lower section provided combustion air to burn the coke. A spout at the bottom allowed the iron to exit the furnace for further processing. The development and optimisation of the melting furnaces allowed to use hot blast and oxygen in a way for the coke rates of today and lead to satisfactory results of the iron products.

Around 1930 Morawe describes the oxygen use in cupolas [1]. In the following decades more knowledge of how to apply oxygen most efficiently is published. The use of alternative fuels (natural gas and oil) for a cupola is described in the literature of the 60's and 70's. This work is very useful to understand the specifics and issues that are involved when using natural gas or oil in a cupola. It was early understood that water vapour from the combustion of natural gas is likely to dissociate to hydrogen, hence consuming heat and cooling the center of the furnace was feared. Higher hydrogen concentrations in the top gas would add to a delicate situation. Most of the publications of the 70's deal with this situation and describe engineered solutions to overcome these issues. During that time the burners are designed in a way to ensure that only fully combusted gases get to meet charge material in the shaft furnace. The objective is to pre heat the coke and scrap in order to reduce coke rate and to melt more efficiently. Dahlmann describes in [2] a vortex chamber tunnel burner (see Figure 1), which main objective is to burn out the gases before they enter the furnace shaft.

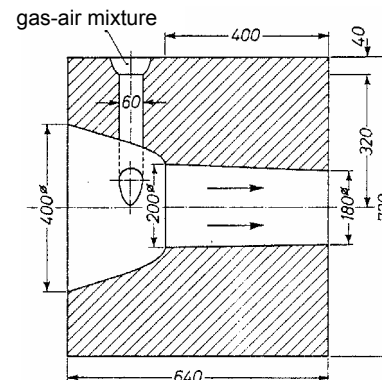


Figure <1> Vortex Chamber [2].



Stone describes in 1965 [3] an air fuel burner with a tunnel to complete the combustion before it enters the cupola (Figure 2). In his paper he emphasizes the importance of the burner position in a cupola shaft. Stone suggests to install the burner 0.25 to 0.4 m above the tuyere level.

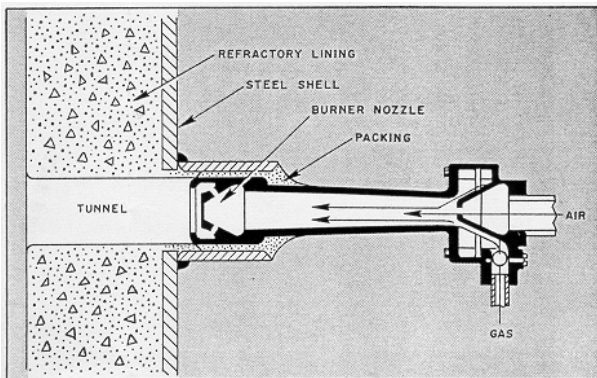


Figure <2> Air – Natural Gas Burner [3].

Later the literature suggests to stay about 0.8 m above tuyere level [2]. Then the combustion gases like CO₂ and H₂O do not have to pass the glowing coke bed and hence, when fired care-

fully they will not get dissipated. Figure 3 shows a typical burner arrangement. This good preparatory work can be regarded as a foundation to start with for oxy-fuel burner use and future work. It contains very valuable concerns and information of how, where and why to introduce alternative fuels in the cupola.

The APCOS technology (Air Products Cupola Oxy-Fuel System) uses compact designed oxy – fuel burners that are installed inside the body of a hot blast tuyere. Here natural gas and oxygen are injected into the glowing and hot coke bed (Figure 4).

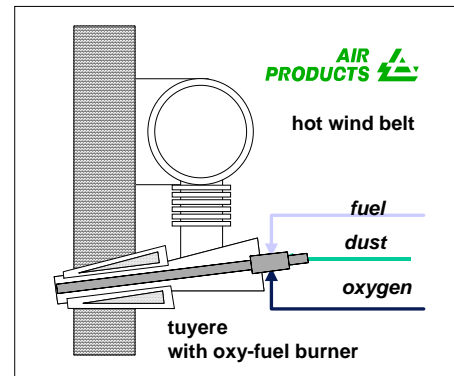


Figure <4> APCOS Burner Installed in Cupola Tuyere.

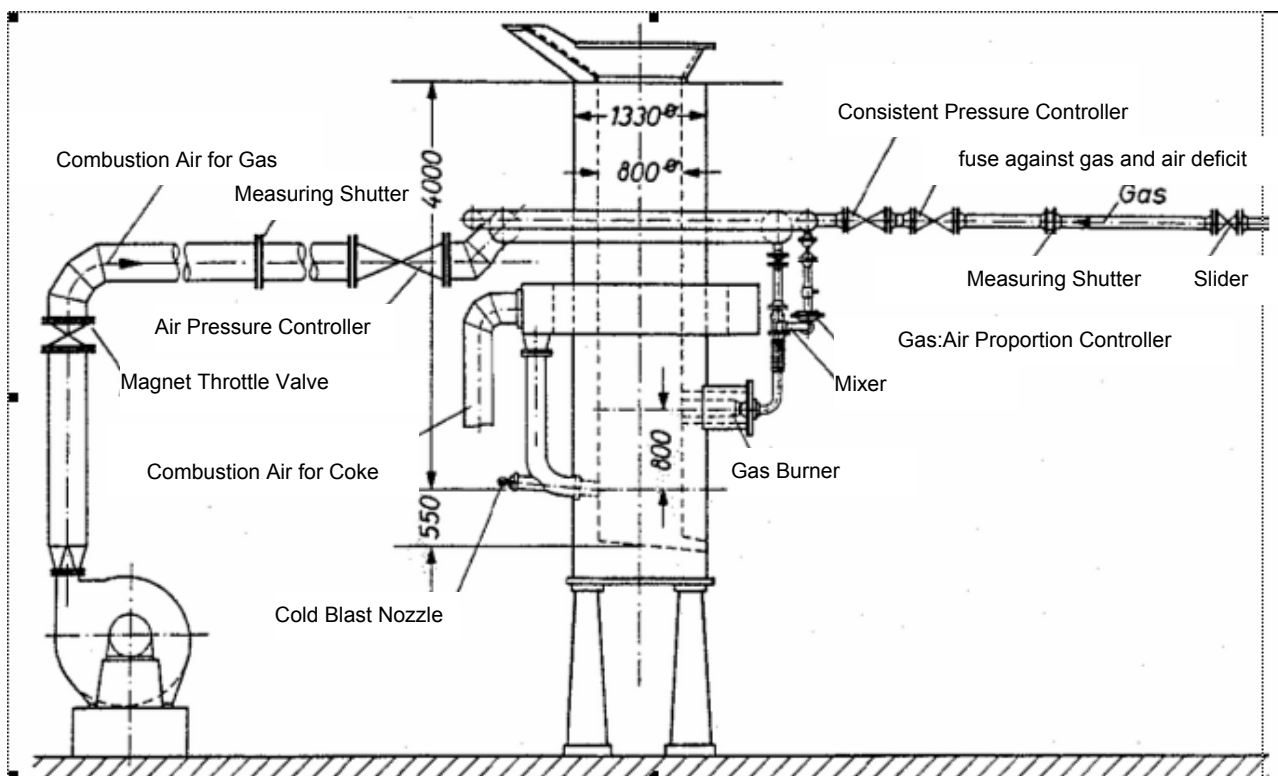


Figure <3> Cold Blast Cupola with Air – Natural Gas Burners [2].

BMBF FUNDED RESEARCH PROJECT - KUPOLOPT

In 2001 the consortium of the following six companies and institutions are awarded BMBF project funding:

- Fritz Winter Eisengiesserei GmbH & Co. KG, Stadtallendorf
- Ruhrgas AG, Essen
- Air Products GmbH, Hattingen
- Küttner GmbH & Co. KG, Essen
- Fraunhofer Institut UMSICHT, Oberhausen and

- IEHK Institut für Eisenhüttenkunde (Institute for Ferrous Metallurgy), RWTH Aachen

The project has a time frame of three years and is divided into four work phases. There the baseline operation is documented and analysed and compared with oxy-fuel burner use. Later solids are injected. These solids can range from alloying agents (SiC, FeSi) to powder like charge materials (coke) over solid foundry residues containing combustibles and iron or iron ox-



ides. Even the injection of non foundry generated materials is planned.

Fritz Winter Eisengiesserei GmbH & Co. KG operates two hot blast cupola furnaces in Stadtallendorf. The cupola used for this project is a modern hot blast cupola furnace (24 t/h) of Küttner design, which mainly produces grey iron. The charge consists mainly of steel scrap (70%) and in house foundry returns (30%). Fritz Winter Eisengiesserei GmbH & Co. KG produces high quality iron castings for the automotive industry.

OXY-FUEL BURNER OPERATION

Six oxy-fuel burners are installed in cupola No. 2 at Fritz Winter Eisengiesserei GmbH & Co. KG. Each burner has a firing capacity of 1,000 kW (total 6,000 kW). The burners are in use since 2002 and results regarding melt rates, energy and combustion efficiency are now available. The melt rate can be increased by more than 20%. This is based not only on short term monitoring and observation but also on long-term results. The increase in melting rate is limited to operating conditions at Fritz Winter Eisengiesserei GmbH & Co. KG, as the automated charging system operates at its capacity limit. Figure 5 shows relative melt rate scenarios for a variation of total oxygen flow rate through the cupola furnace. The total oxygen is the sum of oxygen introduced via hot blast air, oxygen lancing and oxy-fuel burner operation.

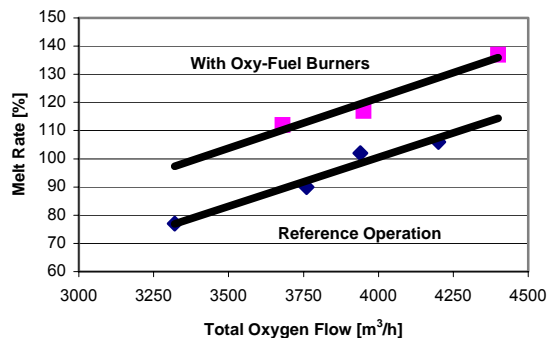


Figure <5> Melt Rate Results with Oxy-Fuel Burner use, results from the project at Fritz Winter Eisengiesserei GmbH & Co. KG.

It is believed that the melt rate increases due to several factors including the packing of the cupola charge in the furnace shaft and the altered way of how the coke (carbon) is oxidized and gasified. First about 6% less coke and about 10 % less silicon (Si) containing alloying briquettes is charged. This gives room for more iron and steel mass per furnace volume. Hence, the melt rate has to increase. Less coke and less silicon briquettes lead to reduced ash and slag of about 8% ($\approx 6 \text{ kg}_{\text{slag}}/\text{t}_{\text{Fe}}$). The energy to melt and vitrify this 8% of slag is available to heat and melt the metal. However, the energy that is provided from the oxidation of silicon needs to be replaced by oxy-fuel energy.

Table <1> Results of Oxy-Fuel Burner Operation at Fritz Winter Eisengiesserei GmbH & Co. KG

Effect	Result
Melt Rate Increase	21 %
Coke Reduction	5 %
Silicon yield improvement	10 %
Reduction in slag generation	8 %
Reduction in SO ₂ emissions	7 %
Increase in CO ₂ emissions	2.5 %
Reduction of Manganese losses	12 %

The use of hydrocarbon fuels shifts the equilibria of various gas to gas and gas to solid systems. This is described in [4]. When the temperature increases and at the same time the availability of hydrogen molecules rises due to additional natural gas, this will then have an impact on the water gas shift reaction with the presence of coke. Finally this will result in an increase of CO and H₂ in the raw top gas of the cupola operation. For hot blast cupolas the chemical energy contained in the top gas is partially recovered in the post combustion chamber followed by a recuperative heat exchanger to pre heat the blast air. Figure 6 details the changes in the top gas composition over total burner firing rate for two different burner settings.

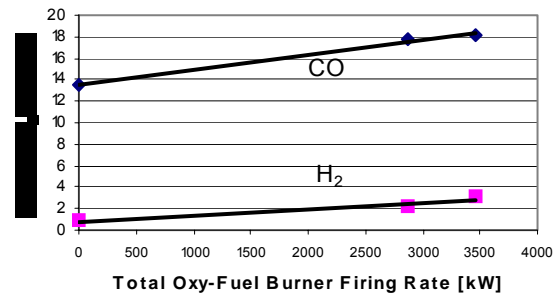


Figure <6> Change of Top Gas Composition when using Oxy-Fuel Burners, results from the project at Fritz Winter Eisengiesserei GmbH & Co. KG.

Combustion efficiency of coke (carbon) combustion is described by the following:

$$\eta_c = \frac{CO_2}{CO_2 + CO} * 100\% \quad (1)$$

For hydrogen this is:

$$\eta_H = \frac{H_2O}{H_2O + H_2} * 100\% \quad (2)$$

And for the mix of carbon and hydrogen fuel it is:

$$\eta_{c,H} = \frac{CO_2 + H_2O}{CO_2 + CO + H_2O + H_2} * 100\% \quad (3)$$

For most cupola operations coke is the main fuel. Coke contains about 90 to 93 % of carbon and very little hydrogen. The hydrogen measured in the top gas of a coke-fired cupola is mainly generated by the dissociation of water vapour contained in the blast air. When a hydrocarbon fuel is added to the coke (carbon fuel) then equation (3) describes combustion efficiency better than equation (1). Figure 7 shows the changes to the combustion efficiency over the total burner firing rates. The lower curve describes the behaviour of coke (carbon) combustion when adding natural gas and oxygen through the tuyeres. The upper curve describes the combustion efficiency of hydrocarbon combustion for these scenarios.



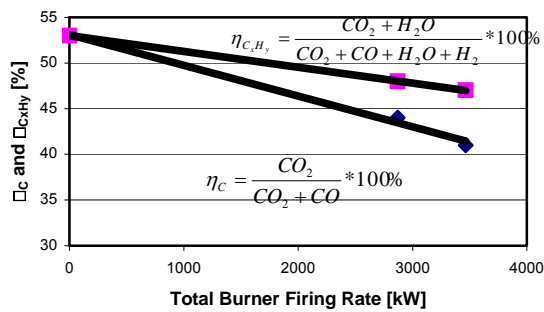


Figure <7> Effect on Combustion Efficiencies when using Oxy-Fuel Burners, results from the project at Fritz Winter Eisengießerei GmbH & Co. KG.

It can be seen that without natural gas firing the combustion efficiency reaches a maximum of 53% (on the left side of Figure 7). The more natural gas is used the larger the decrease in the combustion efficiency. However, the cupola is operated at lower blast rates (about - 10%) and hence produces less top gas per produced tonne of iron (about -7%). Despite the fact that the combustion efficiency drops the net effect on the overall heat balance is almost neutral. Mainly leaving the in Table 1 described benefits.

Table 2 compares two heat balances to better demonstrate where and how the introduced energy is divided. The right data column gives the heat balance for the baseline operation and the right column is for oxy – fuel burner assisted operation. At the below shown natural gas usage (about 60 kWh/t_{Fe}) the coke energy is reduced 5% of the overall heat balance and the silicon energy reduces 1.7 % of the overall heat balance. The total heat turnover per tonne of iron is about 1,100 kWh (≈ 3,960 MJ/t_{Fe}).

Table <2> Heat Balances for baseline operation and oxy – fuel burner assisted operation

HEAT BALANCE (At about 1,100 kWh per tonne of iron)	Baseline Operation	
	Operation	APCOS
HEAT INPUT	[%]	[%]
Foundry Coke	79.7	74.6
Silicon burn up	10.6	8.9
Hot Blast	7.2	7.1
Natural Gas	0	5.3
Other	2.5	4.1
HEAT OUTPUT	[%]	[%]
Runner Iron	35.9	33
Top Gas	39.5	42.4
Water Cooling	15.7	12.9
Slag	4.1	3.1
Other	4.8	8.6

EXPERIENCES FROM THE USA

Air Products converted the hot blast cupola No. 2 from Wheland Foundry to oxy – fuel burner assisted operation in 1999. The considered furnace is a Whiting cupola with a melt rate of 36 t/h, which was built in 1972. The upper section of the cupola shaft is equipped with three air fuel burners to post combust the cupola top gas right at the end of the shaft. The cupola produces grey iron for the US automotive industry. The cupola has six tuyeres and in every other tuyere an oxy – fuel is burner installed.

The objectives at Wheland Foundry for oxy – fuel burner assisted operation are:

- Energy savings and replacement
- Reduction of silicon losses
- More consistent and stable iron production and chemistry

The objectives here demonstrate how flexible the APCOS technology can be applied. In this project it is not intended to maximise production or to inject solids.

The results are as follows:

- Silicon reduction of 15%
- Foundry coke reduction of 10%
- Natural gas savings of afterburners 25%
- Reduced oxygen use of 20%
- Improved stability of iron chemistry in the runner.

The results, as far as silicon and coke reduction are consistent with the results from the project at Fritz Winter Eisengießerei GmbH & Co. KG.

Unfortunately Wheland foundry was closed down in December 2001. However, these two years of continuous operation of the APCOS technology give good insight what values and savings of raw materials can be realized.

SUMMARY

Based on early work that started about ten years ago in 1994, oxy – fuel burner assisted cupola operation is being evaluated to a much larger extend now under the umbrella of the BMBF. It has been demonstrated that this technology has potential to increase production, improve efficiency and reduce emissions to our environment. Here two examples of different objectives, different hot blast cupolas and different results are presented. More work is required in the future to better understand and describe the thermodynamic changes in the centre of the cupola within the coke bed.

Starting from the 70's where much effort was put into using natural gas in a cupola, now a different technology to achieve similar goals is described.

References

- [1] Morawe, F. Sauerstoffanreicherung des Gebläsewindes im Kupolofen Die Giesserei, 7. Feb. 1930, 17. Jahrgang, No. 6, pp. 132-136
- [2] Dahlmann, A.; Schock, D.; Orths, K. Wärmetechnische und metallurgische Gesetzmäßigkeiten beim Einsatz von Erdgas als Zusatzbrennstoff im Kupolofen, Teil 1 Giessereiforschung, 22, Heft 1, 1970, pp. 1 – 14.
- [3] Stone, A. J. Effect of Natural Gas as a Supplementary Cupola Fuel Foundry, October 1965, S. 87–91.
- [4] Frielingsdorf, O., et al. Experience with oxy-natural gas burners at a cupola CP&T, Vol. 19, No. 2, 2003, June, pp. 12-16.

