LOW DROSS GENERATION WITH OXY-FUEL SYSTEM

A. D'Ettorre, R. Giudici, A. Tasca, J. Visus, V.G. Benavides, W.T. Kobayashi

Yield increase in aluminum melting operation is the most challenging goal to achieve. It has been proven that conventional oxy-fuel system can promote significant productivity increase and reduction in specific energy consumption. However, dross formation has been always a concern not only with oxy-fuel burner but also with air-fuel burners.

Praxair developed two new generation oxy-fuel burners for the aluminum industry, the Circular Motion Flame Burner and the Variable Oxidant Burner. The burners developed each one for specific furnace method of operation achieved reduction in dross formation by more than 25%, reduction in specific fuel consumption by up to 50%, 30% higher specific melt rate compared to traditional oxy-fuel process, increase in specific melt rate by a factor of two, and quality improvement.

The Circular Motion Flame Burner, suitable for short heat cycles and continuous furnaces, promotes a non-stationary flame and very uniform heat transfer pattern to the process.

The Variable Oxidant Burner suitable for short melting cycles and long holding cycles can be operated at the minimized fuel consumption by varying the oxygen concentration in the oxidant according to the phase throughout the heat cycle.

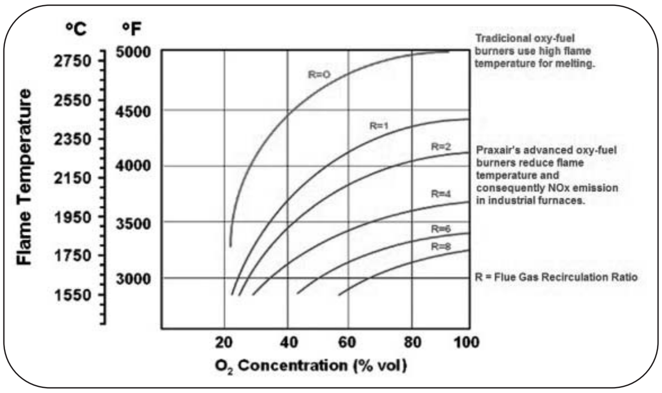
Both burners designed for deep staging promote low peak flame temperature and consequently ultra low NOx emission rate.

KEYWORDS: Oxy fuel burner, circular motion flame burner, low dross generation, yield increase, diecasting, aluminum and alloys, refractories, foundry, process control, numerical simulation, technological innovation, non-ferrous metals, gas and fuels, melting (and remelting), ecology, energy, recycling

INTRODUCTION

Oxy-fuel has been applied over 30 years in aluminum remelting furnaces for both productivity increase and fuel savings due to the elimination of nitrogen. Traditional oxy-fuel burners produce very intense high flame temperatures which can potentially cause damage to the refractory, and mainly hot spots leading to high dross formation.
Praxair developed a low NOx and low peak flame temperature oxy-fuel burner using in-furnace recirculation of flue gas in the late 1970's [1, 2]. The in-furnace recirculation technique or the aspirating burner ("A" burner) demonstrated that the peak flame temperature of oxy-fuel flames could be reduced even below the ones promoted by conventional air-fuel burners (Fig. 1). The "A" burner was successfully implemented in several industrial heating and melting applications such as in steel reheating and aluminum remelting.
In the late 1980's, as an improvement to the "A" Burner

A. D'Ettorre, and R. Giudici
Rivoira S.p.A. - Milan - Italy
A. Tasca
White Martins Gases Industriais Ltda. - São Paulo, SP – Brazil
J. Visus, and V.G. Benavides
Praxair España, S.L. - Madrid - Spain
W.T. Kobayashi
Praxair, Inc. - Tonawanda, NY – USA



▲ Fig. 1 ***Impact of the Aspiration technique on peak flame temperature.***
Effetto del rapporto di ricircolo interno al forno dei gas della combustione sulla temperatura della fiamma.

Praxair designed an innovative oxy-fuel combustion process, Dilute Oxygen Combustion (DOC) technology to produce combustion conditions close to the homogeneous temperature combustion chamber [3]. The concept of this unique combustion system is shown in Fig. 2. The basic concept is to react fuel with a hot dilute oxidant containing 2% to 10% oxygen to pro-

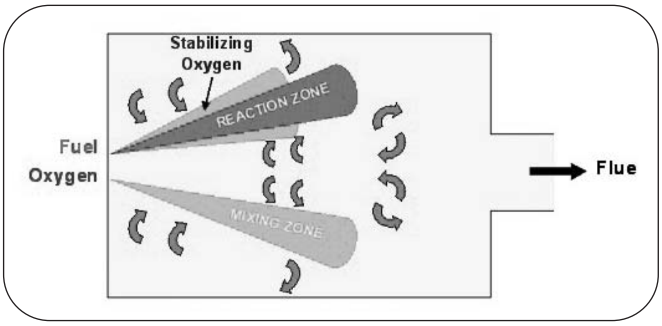


Fig. 2
Schematic of Dilute Oxygen Combustion Technology.
Schematizzazione della Tecnologia di Combustione ad Ossigeno Diluita.

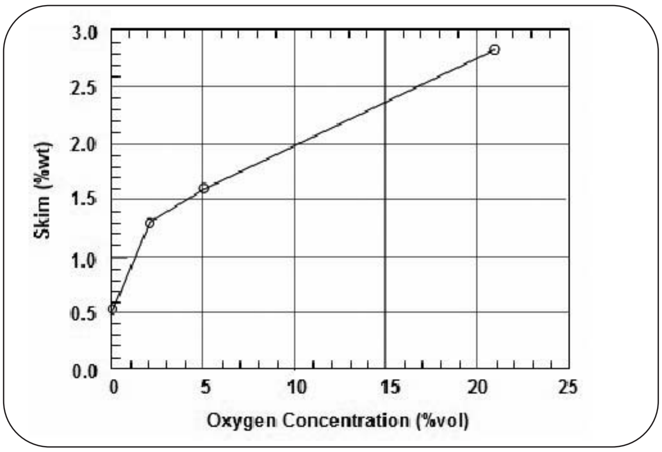


Fig. 3
Impact of oxygen concentration in furnace atmosphere on dross formation measured under controlled operating condition.
Effetto della concentrazione dell'ossigeno nell'atmosfera del forno sulla formazione di scoria misurata in condizioni operative controllate.

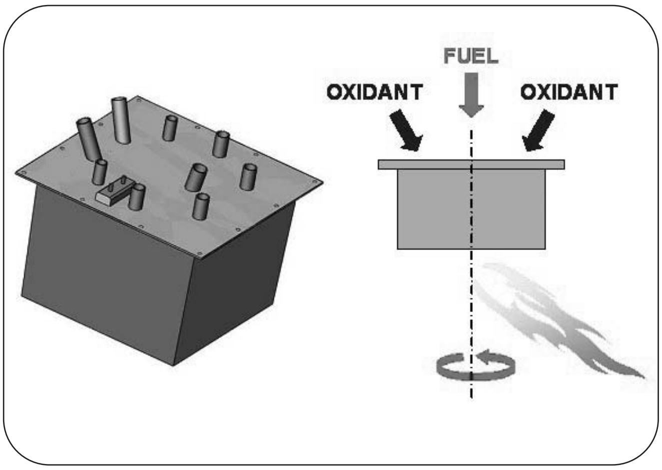


Fig. 4
Schematic and principle of the Praxair Circular Motion Flame Burner.
Rappresentazione e principio di funzionamento del Circular Motion Flame Burner della Praxair.

duce a low peak flame temperature "reaction zone". Oxygen or air is injected into the furnace, separate from fuel, which is diluted by the hot gases in the furnace by jet entrainment.
Oxy-fuel burners based on Dilute Oxygen Combustion technology were also designed and successfully implemented in aluminum reverb furnaces [4] by Praxair.
Being the yield increase in aluminum remelting operation the most challenging goal to achieve, Praxair developed two state-of-the-art oxy-fuel burners specially designed for such operation, both based on the Dilute Oxygen Combustion technology: the Circular Motion Flame Burner and the Variable Oxidant Burner.
Although it has been proven that conventional oxy-fuel burners can promote significant productivity increase by high specific melt rate and reduction in specific fuel consumption, dross formation due to hot spots promoted by high temperature and impinging flames has always been a concern. Dross formation has not been a concern only with oxy-fuel burners but with air-fuel burners as well.
Tight control of oxygen concentration in the furnace has a strong impact on dross formation (Fig. 3). However, that is not the only key parameter for both furnace design and burner location in the furnace. The type of flame, i.e., the burner selection, mainly with oxy-fuel operation has also to be considered to guarantee low peak flame temperature and avoid hot spots on the aluminum surface in order to reduce the dross formation.
Praxair developed the Circular Motion Flame Burner and the Variable Oxidant Burner each one designed for specific furnace method of operation in aluminum melting.
The Circular Motion Flame Burner, suitable for short heat cycle furnaces (dedicated for melting) and continuous melting furnaces (such as side-well type), promotes non-stationary flame and very uniform heat transfer pattern to the process.
The Variable Oxidant Burner, suitable for short melting cycles and long holding cycles (such as melting-holding furnaces or billet casting operation), can be operated at the minimized fuel consumption by varying the oxygen concentration in the oxidant according to the phase throughout the heat cycle.
Both burners designed for deep staging promote low peak flame temperature and consequently ultra low NOx emission rate.
Another positive impact of the oxy-fuel process on the environment is the reduction in carbon dioxide emission rate due to the reduction in specific fuel consumption.

OXY-FUEL BURNERS AND HEAT TRANSFER

Traditional oxy-fuel burners produce very intense high temperature flames. When the first oxy-fuel burner was conceived in the late 1970s to achieve high fuel savings, process concerns on the temperature uniformity and damaging to the furnace refractory were risen due to the high intensity flames. The Praxair "A" (Aspirating) Burners was developed to provide low peak flame temperature comparable to flames promoted by traditional air-fuel burners. The "A" Burner was successfully commercialized for various industrial furnaces, and excellent temperature uniformity and very low NOx emissions were achieved without causing any damage to the process or furnace refractory. The innovative design principle of the "A" Burner was the aspiration of furnace gases using high velocity oxygen jets to promote internal recirculation of the furnace gases diluting the oxygen prior to mixing with fuel. Due to the low peak flame temperature promoted by the

Fig. 5
The Praxair Circular Motion Flame Burner in operation in an aluminum tilting reverb melting furnace.
Immagine del Circular Motion Flame Burner Praxair in funzione in un forno fusorio tilting.

"A" Burner, the NOx emission rate was also low.
The "A" Burner used water cooling to protect the burner components from the radiation; however condensation of volatile species on water-cooled burner face was a concern, mainly to aluminum melting furnaces. To eliminate the use of water cooling and guarantee long life for the burner, the "JL" Burner was designed based on the Dilute Oxygen Combustion technology. The "JL" burner was successfully implemented in aluminum remelting furnaces in early 1990s promoting substantial fuel savings in plants where fuel supply was limited allowing them to operate the furnaces at higher productivity.
Heat transfer efficiency is an important factor for burner and furnace designs. The heat transfer rate through higher flame radiation is improved with high flame temperature and high luminosity flame. A common misconception is that high temperature oxy-fuel flame promotes higher furnace efficiency and that reducing the flame temperature would result in lower furnace efficiency. Actually, it has been proved, both theoretically and in actual experience, that the overall thermal efficiency of an oxy-fuel fired furnace is insensitive to the type of oxy-fuel flame [5]. The cause lies in the effect of heat transfer on the sensible heat loss to the flue gas. Reducing the heat transfer to a furnace load results in an increase in flue gas temperature, and the sensible heat loss to flue gas increases. In an oxy-fuel fired furnace the volume of the flue gas is substantially reduced (by around 75%) compared to air-fuel fired furnaces, thus an increase in flue gas temperature causes only small increase in the sensible heat loss to flue gas in an oxy-fuel system. On the other hand, small increase in the bulk furnace gas temperature causes significant increase in the gas-to-load radiative heat transfer due to the strong temperature dependence of radiative heat transfer. Thus, any loss in heat transfer from a lower temperature oxy-fuel flame is compensated by an increase in the gas-to-load radiative heat transfer promoted by a small increase in the bulk furnace gas temperature. Indeed, oxy-fuel combustion is inherently efficient in radiative heat transfer which is enhanced due to higher concentration of carbon dioxide and water vapor in the furnace atmosphere and the longer gas residence time.

CIRCULAR MOTION FLAME BURNER

High luminous and stationary impinging flames cause hot spots on the aluminum surface and that is the major source of aluminum oxidation leading to high dross formation.
To increase the yield by avoiding the occurrence of hot spots in the aluminum melting operation, Praxair developed the Circular Motion Flame Burner (Patent Pending) (Figs. 4 and 5). The Circular Motion Flame Burner has the following unique characteristics:
- Non stationary flame.
- Multi-directional flame motion.
- Flame can be directed toward desired areas in the furnace, which is very important in the initial stage of the melting cycle. The charge not being uniformly distributed in the furnace, the flame can be directed toward the areas of the furnace where the charge is concentrated and avoid areas where there is no charge. In this way, heat is transferred in preferred zones of the furnace and avoids refractory overheating.
- Flame motion pattern can be determined according to the furnace method of charging, e.g., circular or elliptical.
- Uniform melting.
- Uniform heating.
- Optimized and controlled heat transfer to the aluminum.
- No hot spots both on aluminum and furnace refractory.
- High yield.
- Very low noise level.
- Ultra low NOx emission.
- Roof mounted or up high on side wall mounted.
- High turn-down ratio.
- Non water-cooled.

Due to the flame motion, uniform heat transfer is promoted by directing the flame to specific zones in the furnace at controlled firing rate. The flame motion pattern as well as the firing rate for each zone is programmed in the control system. The staging combustion ensures low peak flame temperature, consequently low NOx emission rate, therefore there is no occurrence of hot spots (on aluminum or refractory surface). In the initial stage of the melting cycle, the pile of charge is not uniformly distributed in the furnace, i.e., there are zone in the furnace where there is a significant concentration of charge (near the door) and some with few (such as near the back corners). In those cases, the Circular Motion Flame Burner control system can be programmed to direct the flame toward the zones where more charge is concentrated and fire the burner at higher firing rate than in zones where there is less charge. Such method can promote an uniform specific heat transfer rate to the charge with uniform melting without causing any risk to the furnace refractory due to combustion taking place where is not required.
Heat transfer pattern can be programmed according to the need of each phase of the heat, and it can be adjusted from heat to heat based on the desired method of operation. For instance for the melting cycle, the flame motion pattern can be set in such way to optimize the heat transfer based on the charge pile distribution.
Another advantage of the Circular Motion Flame Burner in the early stages of the melting cycle is to uniformly burn the volatile organic compounds (VOC) avoiding for instance spikes of carbon monoxide that can happen with stationary flame burners.

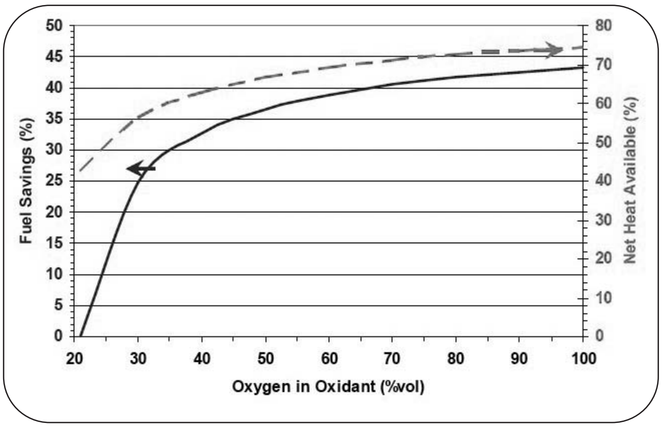


Fig. 6
Fuel Savings and Net Heat Available as a function of oxygen concentration in oxidant in a typical aluminum remelting furnace.
Risparmio Energetico e Calore Netto Disponibile in funzione della concentrazione di ossidante in un tipico forno di fusorio per alluminio.

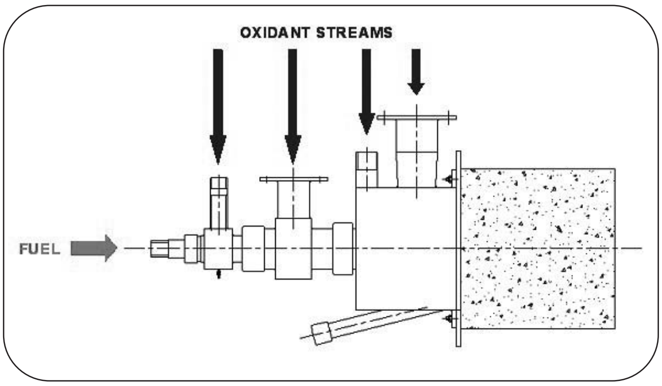


Fig. 7
The Praxair Variable Oxidant Burner.
Schematizzazione del Variable Oxidant Burner della Praxair.

Once the charge is completely melted, the flame keeps moving transferring heat uniformly to the molten bath. Since the flame is non-stationary, there is no occurrence of hot spots which would lead to aluminum oxidation.
The Circular Motion Flame Burner is suitable for the following type of aluminum melting furnaces:
• operation with short holding cycle, such as furnaces exclusively for melting,
• batch operation such as dry hearth, wet hearth, double chamber, and round top type,
• continuous melting furnaces such as side-well type
Due to the flame motion adjustability, furnaces operated with the Circular Motion Flame Burner can have any material (type, size) charged which brings a lot of flexibility to the operation.
The Circular Motion Flame Burner was installed and is being operated since second half of 2006 in an industrial aluminum tilting reverb (melting only) furnace that produces ingots and some molten aluminum is transferred to local aluminum foundries. The material charged in the furnace is basically composed by scrap (wheels, engine blocks, radiators). Once the melting operation in completed, liquid aluminum is transferred to a holding furnace to conduct further steps, such as alloying and superheating.
The design parameters considered to optimize the operation (melt rate), minimize specific fuel consumption and increase yield for such type of furnaces are:
• location of the burner,
• flue port location and size,
• flame motion pattern to promote uniform heat transfer.
Controlled heats for statistical analysis purpose are being conducted to accurately measure the dross formation with traditional air-fuel burners and with the Circular Motion Flame Burner. The following results were achieved the Circular Motion Flame Burner:
• dross formation reduce by more than 25% when scrap is charged,
• specific melt rate 30% higher than what can be achieved with traditional oxy-fuel burners,
• specific melt rate increased by a factor of two,
• specific energy consumption via natural gas reduced to about 500 Mcal/h.
The oxy-fuel combustion control system controls the following variables and parameters to promote the desired flame motion pattern:
• flame motion pattern introducing the guiding jets at the proper sequence,
• frequency of the flame motion,
• firing rate for each location where the flame is directed,
• period of time that the flame is directed to each location in the furnace.

VARIABLE OXIDANT BURNER

The Praxair's Variable Oxidant Burner (Patent Pending) has been designed to operate at any oxygen concentration in oxidant, i.e., commonly from air (20.9% O2) to 100% oxy-fuel. The biggest advantage for such feature is that the burner can be operated at the most economical way, using the exact amount of oxygen required for each step of the heat.
Fig. 6 shows the projected fuel savings and the net heat available as a function of the oxygen concentration in oxidant in a typical aluminum remelting furnace. During the melting cycle where high specific melt rate can be translated to higher productivity oxy-fuel process can practically achieve up to twice of what conventional air-fuel systems can do with substantial fuel savings. However, when the furnace is put in holding mode, the amount of heat available required is low and in that case oxy-fuel is not the most economical way to provide the required energy.
The Variable Oxidant Burner has been designed to operate in aluminum remelting furnaces with short melt cycle compared to the total heat cycle. One typical furnace that falls into such category is the melting-holding ones for billets casting. In those type of operation, oxy-fuel process is advantageous only in the melting cycle in which fast melting can be achieved with minimized specific fuel consumption. For the current market scenario, the fuel savings and the shortening in melt cycle (resulting in higher productivity) can cover the expenditure related to oxygen consumption for melting. In the eventuality of need to reduce the melt rate the oxy-fuel combustion control system can run a dynamic model to calculate the energy input rate required (DQ/Dt) and determine the firing rate and oxygen content in oxidant to guarantee

that the combustion process is conducted at the most economical mode for the rest of the melting cycle.
Once the charge is completely melted and the bath reaches the desired temperature, fuel savings with oxy-fuel process could not be optimized for the further steps since the objective of the combustion system is mainly to maintain the furnace and the molten aluminum temperatures. While in holding mode, the Variable Oxidant Burner can be switched to air-fuel mode and be fired at optimized and constant firing rate. That type of operation deliver constant energy to the furnace and avoid the traditional on-off or high fire-low fire type control that causes temperature cycling which can compromise the furnace refractory life.
If in later phases throughout the heat quick molten metal superheating is required, the oxy-fuel combustion control system dynamically calculates the optimized condition (minimum energy cost) to run the Variable Oxidant Burner to smoothly reach the desired heating rate (DQ/Dt). In such case the Variable Oxidant Burner would run at oxygen enriched mode for the oxidant.
The Variable Oxidant Burner is a non water cooled and robust equipment with low maintenance requirement (Figs. 7 and 8).
The main characteristics of the Variable Oxidant Burner at any oxygen concentration in oxidant are:

- Staged flame.
- Low peak flame temperature.
- Ultra Low NOx emission rate.
- Low momentum flame.
- Luminous flame.
- Stable flame.
- High heat transfer efficiency.
- Uniform heating, which is very important mainly in the holding mode avoiding burners on-off and/or high/low firing rate type operations that caused temperature cycling which can compromise the refractory life.
- Very low noise level.
- High turn-down ratio at any total oxygen concentration in oxidant.
- Non water-cooled.

The Variable Oxidant Burner was installed and is being operated since mid 2006 in an industrial aluminum tilting reverb (melting and holding) furnace that produces 1000 and 6000 series alloys billets for extrusion. The material charged in the furnace is composed by 90% scrap (internal and external) and 10% ingot. The goal defined by the customer in that furnace was to increase the specific melt rate by 40% which was achieved with 40% reduction in specific fuel consumption (as low as 450 Mcal/t with the Variable Oxidant Burner in the melting cycle without stirrer). If required much higher specific melt rate could be achieved with the Variable Oxidant Burner.
The combustion control system of the Variable Oxidant Burner can be operated in that installation as follows:

- Melt Cycle: The Variable Oxidant Burner was operated at high oxygen content in total oxidant, most of the time as an oxy-fuel burner.
- Other Phases: The oxygen content adjusted according to the required heat input rate.

Due to the fact the Variable Oxidant Burner promotes a low peak temperature and low momentum flame, no hot spots on the aluminum surface neither on the refractory surface were observed. Dross formation was reduced and quantitative evaluation under controlled condition for detailed statistical analysis is being currently carried out.

Fig. 8 ***The Praxair Variable Oxidant Burner installed in a tilting reverb (melting and holding) furnace.***
Il Variable Oxidant Burner installato in un forno tilting a riverbero (fusione ed attesa).

QUALITY IMPROVEMENT

In addition to the advantages presented above, reduction in dross formation, increase in specific melt rate, and reduction in specific fuel consumption, the Circular Motion Flame Burner and the Variable Oxidant Burner can improve the quality mainly for billet production.
With Praxair's new oxy-fuel technologies for aluminum melting the following quality improvements were observed:

- Reduction in porosity and bubble size.
- Reduction in large grain size. High specific melt and reduced dross formation inclusions (oxides) avoid recrystallization. Recrystallization is one of the causes of undesired large grain size. Small grain size is related to better quality of the final extruded product.
- Reduction in oxide formation. With the Variable Oxidant Burner, the possibility to run the combustion system more steadily at the proper oxygen content in total oxidant (avoiding on-off and/or low fire-high fire operation) during casting, the oxidized layer is maintained unchanged (no hot spots) improving the quality of the final extruded product.
- Reduction in Hydrogen pick-up. Oxy-fuel combustion process reduces the melt cycle (due to high specific melt rate); however with the Variable Oxidant Burner and Circular Motion Flame Burner low peak temperature flames are promoted reducing the oxide formation as well as hydrogen pick-up.

Reduction in hydrogen pick-up can also be reduced with the Variable Oxidant Burner and the Circular Motion Flame Burner. Hydrogen absorption is increased by a factor of two if the bath surface temperature is increased from 730 to 800 oC. With low peak temperature and non impinging flame burner such as the Variable Oxidant Burner or the Circular Motion Flame Burner, uniform bath surface temperature can be achieved and the bath surface temperature can be maintained within a narrow range (no hot spots) which minimizes the hydrogen pick-up.

CONCLUSIONS

High yield in aluminum melting is not only a matter of tight control of oxygen content in the furnace atmosphere. The type of flame promoted by the burner and the burner location have a strong impact in avoiding hot spots, which with oxy-fuel process is more critical. Therefore, the oxy-fuel burner selection has a strong impact in minimizing the dross formation.
With new generation of innovative oxy-fuel burners designed by Praxair (Circular Motion Flame Burner and Variable Oxidant Burner), to meet the different furnace methods of operation, the following benefits can be achieved in aluminum melting furnaces:
• Yield increase due to reduction in dross formation by more than 25% due to low peak flame temperature, non impinging flame and non stationary flame.
• 30% higher specific melt rate than the achieved with traditional oxy-fuel process.
• Increase in specific melt rate by a factor of two.
• Reduction in specific fuel consumption by up to 50%, or as low as 450 Mcal/h in furnaces not equipped with stirrer.
• Carbon Dioxide emission rate reduction due to the inherent reduction in specific fuel consumption.
• Quality improvement such as reduction in porosity, reduction in inclusions, small grain size and minimization of hydrogen pick-up.
• Uniform temperature and no hot spots on aluminum surface.
• No hot spots on furnace refractory surface.

REFERENCES

1] Anderson, J.E., “Oxygen Aspirator Burner and Process for Firing a Furnace”, U.S. Patent 4,378,205, March 29, 1983
2] Anderson, J.E., and Kobayashi, H., “Fuel Reduction in Steel Reheating Furnaces with a New Oxygen Combustion System” American Iron & Steel Institute Technical Symposium No. 9, “Energy Conversion in the Steel Industry”, Pittsburgh, PA, April 28, 1983.
3] Kobayashi, H., “Segregated Zoning Combustion”, U.S. Patent 5,076,779, December, 31, 1991.
4] Kobayashi, W.T., Francis, A.W. and Kobayashi, H., “Staged Combustion for Reducing Nitrogen Oxides”, U.S. Patent 5,601,425, February 11, 1997.
5] Kobayashi, H., Oxygen Enriched Combustion System Performance Study, Vol. I Technical and Economic Analysis, Report No. DOC/ID/12597, U.S. Department of Energy, Idaho Falls, ID, March 1987.
6] Kobayashi, H., Du, Z., “Dilute Oxygen Combustion – A New Approach for Low NOx Combustion”, American Flame Research Foundation, 1992 Fall International Symposium, Cambridge, MA, October 19 to 21, 1992.

ABSTRACT

SISTEMI DI COMBUSTIONE AD OSSIGENO ALTO POTENZIALE: LOW DROSS GENERATION

Parole chiave: bruciatori oxy fuel, fiamma mobile circolare, riduzione ossidazione a caldo, incremento resa, pressocolata, alluminio e leghe, refrattari, fonderia, controllo processi, simulazione numerica, innovazione tecnologica, metalli non ferrosi, gas e combustibili, fusione e rifusione, ecologia, energia, riciclaggio

Nella presente memoria , è evidenziato come per le fonderie di alluminio la ricerca di soluzioni ad alto potenziale in campo fusorio rappresenti la sfida del prossimo futuro oltre che un obiettivo strategico nel lungo periodo .
Dalle esperienze in ambito fusorio , risulta provato e consolidato che i sistemi di combustione ad ossigeno convenzionali possono promuovere in modo significativo incrementi produttivi e sensibili riduzioni nei consumi energetici specifici.
Ad ogni modo, la formazione e minimizzazione della scoria è sempre stato un problema non solo con i bruciatori ad ossigeno ma anche con quelli ad aria metano convenzionali .
PRAXAIR e RIVOIRA hanno sviluppato due nuove tipologie di sistemi di combustione ad ossigeno ad alto potenziale per la riduzione della scoria, per l’industria dell’alluminio:
• il “Circular Motion Flame Burner” (Bruciatore a Fiamma Mobile Circolare)
• il “Variable Oxidant Burner”.
I bruciatori, sviluppati ognuno per una specifica del forno, hanno permesso di raggiungere:
• riduzioni nella formazione di scoria maggiori del 25%,
• riduzioni dei consumi specifici di combustibile sino al 50%,
• incrementi nella produttività oraria del 30% se comparata con quella dei tradizionali sistemi ad ossigeno,
• aumenti della capacità fusoria (melt rate) di un fattore pari a 2 Vs. sistemi ad aria oltre che incrementi nella qualità del fuso.
Il Circular Motion Flame Burner, progettato per forni continui fusori con elevato rapporto tempo di fusione /tempo ciclo totale , produce una fiamma mobile non-stazionaria e permette di avere una modalità uniforme di trasferimento del calore al processo.
Il Variable Oxidant Burner, studiato per forni fusori di attesa con un elevato rapporto tempo attesa /tempo totale ciclo: può essere sfruttato per minimizzare i consumi energetici variando le concentrazioni dell’ossigeno così da assecondare le esigenze energetiche della fase del ciclo di fusione/attesa in cui ci si trova.
Entrambi i bruciatori sono progettati per realizzare basse temperature di fiamma e conseguentemente fattori di emissione di NOx molto bassi.