

Current Trend in Furnace Technology in the Melting Industries

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Abstract: The aim of this study is to presents some of the current trend in Furnace technology as it pertains to the melting industries. Furnaces are applied in various industries for material processing. Large amounts of energy are usually consumed in the melting industries. The current trend in furnace technology is towards energy conservation, enhanced efficiency and productivity. The reduction of pollutant emissions are also taken into consideration due to their environmental impact. The various materials and processes for furnaces are discussed. The various strategies being employed towards furnace energy conservation, efficiency and productivity, and reduction of pollutant emissions are also discussed. Such strategies include the use of better fuel types such as natural gas; improved insulation and refractory materials; advanced burner designs such as high velocity, regenerative and recuperative burners; new combustion technologies such as air and fuel staging, flue gas recirculation technique. Mathematical modeling is also being employed for analysis and design purpose.

Key words: Burners, combustion technologies, emissions, energy efficiency, furnace technology

INTRODUCTION

Furnace technology comprises the scientifically applied knowledge of the properties of furnace materials, combustion, Thermodynamics, heat transfer, fluid flow and sound engineering principles to the construction and control of furnace and related equipment (Etherington and Etherington, 1961).

A furnace is a device in which energy is released as heat either by consumption of fuel or electricity and the heat is used to raise the temperature of the material within called the "Burden", for the purpose of modifying it or to produce new materials (Gilchrist, 1977).

Furnaces called stoves or ovens are usually employed for low temperature applications, as in processes such as enameling, food processing, drying and low temperature annealing, while others for high temperature are used in foundries and metal industries for melting, heating, reheating, annealing and heat treating. The mineral processing industry also employs furnaces in the production of glass, cement, bricks, refractories and ceramics. They are typically high-temperature heating and melting applications that require a significant amount of energy per unit of production (Baukal, 2004).

Other industries such as the power generation industry employ furnaces in boilers to generate steam for power generation.

Furnaces are built of refractory materials which are heat resisting substances made from selected clay and

other rock, blended, moulded to shape and fired at high temperature. The refractories are assembled and encased in a steel or cast iron framework or shell, burners, flues and other necessary component are included to form the furnace.

Furnaces vary in shape and the shape employed for a furnace may be determined by the physical and chemical changes to be undergone by the burden within the combustion chamber and the need for other operations such as mixing to be carried out. For the conventional fuel-fired furnaces large amounts of energy is usually consumed for melting processes and efficiencies are usually low. For such furnaces also, there is the issue of pollutant emissions which contribute to depletion of the ozone layer, global warming, acid rain and other environmental challenges. Furnace designers are interested in improving the design in terms of energy efficiency and productivity, Bui and Perron (1988), the environmental impact of thermal plants have become a source of concern in recent times. This paper presents some of the current trend in Furnace technology as it pertains to the melting industries.

FURNACE MATERIALS AND PROCESSES

Refractories: Furnace structures are usually built from refractory materials. These are covered with an insulating material and then enclosed in a steel frame.

Refractories are a class of materials, which are able to withstand high temperatures without undergoing much deformation or structural and chemical decomposition (Krivandin and Markov, 1980). Most refractories are ceramic materials made from high-melting point oxides such as silicon, aluminum and magnesium oxides etc. Other materials like carbon, carbides, borides and nitrides are also being developed for high temperature work. Refractories can be supplied either as bricks or monolithic material, which are special mixes or blends of dry granular or cohesive materials used to form joint-free linings.

Burners: The burner is the heat-releasing device used to combust the fuel with an oxidizer to convert the chemical energy in the fuel to thermal energy. Various types of burners are available and may be classified based on method of mixing, fuel and oxidizer types and method of producing draft (Baukal, 2004).

- **Mixing type:** These are either pre-mixed burners, diffusion-mixed burners or staged fuel or oxidizer burners. In premixed burners, the fuel and the oxidizer are completely mixed before combustion begins. They often produce shorter and more intense flames as compared to diffusion flames. This can produce high temperature regions in the flame leading to non-uniform heating of the load and higher NO_x emissions although this is dependent on the specific design.

In diffusion-mixed burners, the fuel and oxidizer flow into the furnace separately and mix together as combustion proceeds in what is sometimes called diffusion flames.

Diffusion burners have longer flames than premixed burners. They do not have as high temperature hot spots and usually, have a more uniform temperature and heat flux distribution. They may also have lower NO_x emission although again, this is dependent on design.

When a portion of the fuel or oxidizer is introduced into the flame downstream of the room of the flame, this is known as staging and the burner becomes either a staged fuel or staged air burner. Staging is often done to control heat transfer, produce longer flames and reduce pollutant emissions such as NO_x . These longer flames typically have lower peak flame temperature and more uniform heat flux distribution than non-staged flames.

- **Fuel type:** These may be solid, liquid or gaseous fuel burners. Solid fuels are not commonly used in most industrial combustion applications. The most

common solid fuels are coal and coke. Coal is used in power generation and coke is used in some primary metals production processes.

Coal is often used in pulverized form, suspended in air stream and injected into the furnace along with a stream of hot air. It is thus treated like a gas. For this purpose pulverized fuel burners are used. Pulverized fuel give luminous flames with correspondingly good heat transfer properties. The problems of sulphur and ash content have limited its use to power generation and cement kilns. Liquid fuel burners are designed to be able to atomize the liquid fuel for proper burning. The atomization may be done using pressurized air or steam.

No vaporization is needed for gas burners.

- **Oxidizer type:** Air/fuel burners are the most common type used in industrial combustion applications. The combustion air may be supplied by a fan or blower. In some applications in glass melting the oxidizer may be pure oxygen for which oxy/fuel burners are used.
- **Draft type:** Burners may be forced draft or natural draft. In a forced draft burner, the combustion air is supplied by a blower or fan while in a natural draft burner the combustion air is induced into the burner by the negative draft produced in the combustor and by the motive force of the incoming fuel which may be at a significant pressure. Natural draft flames are usually longer than forced draft so that the heat flux from the flame is distributed over a longer distance and the peak temperature in the flame is often lower. Most industrial burners are forced draft burners.

Heat salvage equipment: The heat salvage equipments are often used to improve the efficiency of the furnace or combustion system. The two most common types include recuperators and regenerators (Baukal, 2004).

- **Recuperators:** A recuperator is a low-to-medium temperature (up to about 700°C), continuous heat exchanger that uses the sensible energy from hot combustion products to preheat the incoming combustion air. These heat exchangers are commonly counter flow, where the highest temperatures for both the combustion products and the combustion air are at one end of the exchanger and the coldest temperatures are at the other end. Lower-temperature recuperators are normally made of metal, while higher temperature recuperators can be made of ceramics.
- **Regenerators:** A regenerator is a high temperature, transient heat exchanger used to improve the energy

efficiency of high-temperature heating and melting processes, particularly in high temperature processing industries such as glass production. In a regenerator, energy from the hot combustion products is temporarily stored in a unit constructed of refractory firebricks. This energy is then used to heat the incoming combustion air during a given part of the firing cycle up to temperature in excess of 1000°C. Regenerators are normally operated in pairs. During one part of the cycle, the hot combustion gases are flowing through one of the regenerators and heating the refractory bricks, while the combustion air is flowing through and cooling the refractory brick in the second regenerator. Both the exhaust gases and the combustion air directly contact the bricks in the regenerators although not at the same time. After a sufficient amount of time (5 to 30 min), the cycle is reversed so that the combustion gases flow through the cooler bricks in the second regenerator while the hotter bricks in the first regenerator exchange their heat with the incoming combustion air. A reversing valve is used to change from one gas to another in each regenerator.

Sources of heat energy: Fuels are used as source of energy in the industry, transport and domestic life. The heat energy contained in the fuel is released through the process of combustion and used for various processes. Most varieties of fuels are of organic origin and other main components are carbon and hydrogen with small amounts of oxygen, nitrogen and sulphur. Fuels are generally classified as solid, liquid or gases. Melting furnaces for steel, cast iron use electricity in induction and arc furnaces. Non-ferrous melting utilizes oil and gas as fuel.

Heat transfer in furnaces: Heat energy liberated during combustion must be transferred to the stock in the furnace. Heat transfer may occur through conduction, convection or radiation. These may also occur simultaneously but one will often predominate.

In industrial processes radiation is often the dominant mechanism and forced convection also plays an important function (Baukal, 2004). The more efficient the heat transfer processes, the higher will be the overall system efficiency and thus the lower the fuel consumption and emission per unit product.

CURRENT TREND IN HEAT AND FURNACE TECHNOLOGY

The current emphasis in the development of most thermal equipment is towards energy conservation and

efficiency, and reduced pollutant emission. Various strategies are currently employed in the melting industry towards these objectives among which are:

- **Use of efficient fuel type:** The oil embargoes of the 1970's directed attention towards the efficient use of energy in the developed nations, emphasizing this aspect in plant design that previously had not been emphasized (Beohn, 1997). The European industry is facing sustained pressure to improve its production and product quality with strong constraint about pollution emission and energy consumption (Carvalho and Lockwood, 1990).

Currently a high proportion of the world's total energy output is generated from fossil fuels such as oil and coal. It is now universally accepted that fossil fuels are finite and it is only a matter of time before their reserves becomes exhausted.

Estimates of reserves of fossil fuels all reach the same conclusion. Extended use of these reserves will continue for more than some decade to come (Sambo, 2001).

The cost of energy also has a significant impact on the total cost of production. Fuels are burnt to create a high temperature inside furnaces and the melting processes usually consume much energy and efficiency is low often less than 50% (Broadbent, 2001) so that energy conservation has become very important in addition to need for the abatement of pollution that usually accompany these processes.

With the discovery and subsequent distribution of large quantities of natural gas many conversion from oil to gas firing of industrial appliances as well as construction of gas fired plants are taking place or being contemplated (Carvalho and Lockwood, 1990). The safety and environmentally friendly aspect of this source of energy is prompting a steady increase in world gas demand (Sayidiman, 1993).

- **Use of improved insulation and refractories:** The appropriate choice of refractory and insulation materials goes a long way in achieving fairly high fuel savings in industrial furnaces. Heat losses can be reduced by increasing the wall thickness, or through the application of insulating bricks. Outside wall temperatures and heat losses of a composite wall of a certain thickness of firebrick and insulation brick are much lower, due to lesser conductivity of insulating brick as compared to a refractory brick of similar thickness. Firebrick once served the multiple purposes of providing load-bearing walls, heat resistance, and containment. As structural steel framing and steel plate casings became more common, furnaces were built with externally

suspended roofs, minimizing the need for load-bearing refractory walls. Continuing improvements in monolithic refractories, particularly in bonding, have resulted in their steadily increasing usage—now substantially over 60% monolithic (Industrial heating processes, 2011). Energy savings in furnaces are being enhanced through the use of ceramic fibre and ceramic coating. Ceramic fibre is a low thermal mass refractory used in the hot face of the furnace and fastened to the refractory walls. Due to its low thermal mass the storage losses are minimized. This results in faster heating up of furnace and also faster cooling. Ceramic coatings in furnace chamber promote rapid and efficient transfer of heat, uniform heating and extended life of refractories. The emissivity of conventional refractories decreases with increase in temperature whereas for ceramic coatings it increases. This outstanding property has been exploited for use in hot face insulation (Bureau of Energy Efficiency, 2005). Metal and ceramic combinations, also known as cermets have also been developed. They blend the high heat resistance of ceramics with the desirable physical characteristics of steel (Scott, 2011).

- **Waste heat recovery:** The waste heat recovered can be used for preheating combustion air or fuel or both and also to preheat the stock.

Higher process temperatures and air preheating often can be used to increase the overall efficiency, to reduce fuel costs and to lower CO₂ emission (Wirtz and Kremer, 2000). The combustion air is preheated with recirculated flue gas using recuperators or regenerators.

- **New combustion technologies:** In another application of the principle of hot flue gas recirculation, the recirculated flue gas is used to preheat the fresh air to a high temperature and at the same time to dilute the fresh air to a lower oxygen level. This process is known as highly preheated and diluted air combustion technology in industry (Dong, 2000). The use of flue gas recirculation principle has also led to the development of regenerative burners.

Air staging and fuel staging combustion principles have been developed. In air staging method, a part of the combustion air is introduced after the main combustion zone so as to reduce the level of available oxygen in zones where it is critical for NO_x formation.

In fuel staging a part of the fuel is supplied to the combustion zone which is therefore fuel lean. The

remaining part of the fuel is supplied after the combustion zone NO_x formation is also significantly reduced by this method. Economical reasons also favour the use of advanced burner technologies and in-furnace combustion control for the reduction of NO_x (Wirtz and Kremer, 2000).

There are also many high temperature processes that use an oxidizer containing a higher proportion of oxygen than the 21% by volume found in normal atmospheric air this is referred to as oxygen-enhanced combustion and has many benefits including increased productivity and thermal efficiency while reducing exhaust gas volume and pollutant emissions (Baukal, 2004).

- **Mathematical modeling:** Currently, researchers, equipment designers and process engineers are increasingly using Mathematical modeling or Computational Fluid Dynamics (CFD) to analyze the flow and performance of process equipment such as chemical reactors, stirred tanks, fluidized beds, cyclones, combustion systems, spray dryer, pipeline arrays heat exchangers and other equipment. CFD allows for an in-depth analysis of the fluid mechanics and local effects in these types of equipment. In many cases, this result in improved performance, better reliability, more confident scale up, improved product consistency and higher plant productivity (Baker *et al.*, 2001). More and more CFD codes are being developed to meet the need for equipment and plant analysis in industries in developed countries, developing nations can also derive benefits in adopting CFD in the design and development of process equipment.

ESTIMATED IMPROVEMENTS

According to Trinks and Mawhinney (1961), the heat loss for a given extent of wall and for a given furnace temperature becomes less if the wall is made thicker or if the wall is made of a better insulator, or if the outer wall surface is of such a character that it does not readily give up heat to the surrounding media. Studies have revealed that heat loss from a furnace wall 115 mm thick at 650°C amount to 2650 Kcal/m²/h can be cut down to 850 kcal/m²/h by using 65 mm thick insulation on the 115 mm wall (GEDA, 2003). A U.S. Department of Energy, OIT, project identified a potential savings of 5% of the heat load with the use of a new high temperature ceramic refractory.

Ramsell (1998) have reported that recuperative burners recover approximately 40% of the heat in waste

gases to give an efficiency improvement in the order of 30%. The U.S department of energy (DOE, 2003), have also stated that supplying preheated combustion air to burners would recover waste heat and achieve a 5 to 25% fuel savings depending on the firing rate for the burners. Baillargeon *et al.* (1998) also reported an energy savings in the order of 30% for combustion air preheating when combustion air is relatively cold. A 22% savings in energy consumption have been reported by Ighodalo (2010) for a gas-fired furnace for melting non-ferrous metals. The furnace employs a high velocity burner, a metallic recuperator for preheating combustion air and furnace walls were made of refractory castable. An overall thermal efficiency of 36.4% was obtained for the furnace.

Dong (2000), have stated that the possible NO_x reduction by means of fuel staging is about 50% without negative impact on furnace efficiency while the possible NO_x reduction by means of air staging is 20-50% without negative impact on furnace efficiency. He also reported that fuel or energy savings of as much as 50% with a dramatic low NO_x emission level can be obtained if a strong exhaust gas recirculation is reached and the primary air is highly preheated up to 1300K with a lower oxygen concentration of less than 5%.

CONCLUSION AND RECOMMENDATION

Continuous developments in furnace materials and processes are helping to enhance furnace performance. The use of better fuel type, improved insulation and refractory materials, advanced burner and combustion technologies and mathematical modeling in the development of furnaces in the melting industries, are some of the strategies currently being employed to enhance energy conservation, efficiency, enhanced productivity and reduced pollutant emissions. Various degrees of enhanced improvements obtained by the use of these strategies have been reported in different literatures. Most of the efficiencies reported are still below 50%, there is therefore still more room for improvements. It is recommended that in further enhancing furnace efficiency a combination of the above enumerated strategies be employed. Furthermore, the incorporation of control systems in equipment design and the determination of best practices in furnace operations are also recommended.

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