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A Review Paper on Design and Analysis of Movable Heat Shield for Bending Furnace

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***Abstract*—**Based on the entransy dissipation extremum principle for thermal insulation process, constructal design of blast furnace wall is performed in this paper. Optimal construct of the cooling stave in the furnace wall is obtained by using finite element method. The results show that there exists twice optimal axial diameter ratio and optimal cooling water velocity which makes the entransy dissipation rate of the blast furnace wall reach its critical minimum. Moreover, the optimal cross-section shape of the cooling pipe is approximately round. Within the discussed variation range of the axial diameter ratios, the minimum entransy dissipation rate is 2.73% less than the maximum entransy dissipation rate when the cooling water velocity is preset. Constructed designs of multilayer insulation structures of a steel rolling reheating furnace wall are implemented by taking minimum heat loss rate (HLR) as optimization objective. Two boundary conditions of the insulation layers, convective heat transfer and combined convective and radiative heat transfer, are taken into account.

Keywords*-*Furnace wall, Transient heat transfe, Entransy dissipation rate, Blast furnace wall.

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I. INTRODUCTION

As energy crisis is becoming prominent, an effective way to make use of energy is what people chase for. Thermal insulation is an effective way to reduce the heat loss of a thermal system. Therefore, many scholars have shown great interests in the investigations of the thermal insulation problems, such as building enclosure structures, pipeline systems, etc. Constructed theory is a powerful theory for the optimal designs of various engineering applications, and many insulation problems had been solved by using this theory. For the constructal designs of insulation layers of the reheating furnaces, built the plane and cylindrical insulation layer models of a reheating furnace wall, and optimized the distributions of the layers with minimum heat loss rate (HLR). The results showed that the HLR of the insulation layer with optimal thickness was reduced by 12.5% as compared with that of the uniform one, and the heat loss reduction of the plane insulation layer with optimal thickness was larger than that of the cylindrical one.. built a multilayer insulation model of the furnace wall with constant temperature boundary condition, and carried out constructal optimizations of the insulation layers by taking minimum HLR as optimization objective. The results showed that the heat loss of the insulation layer with optimal distributed thicknesses was greatly reduced compared with that of the uniform ones, and the decrement of heat loss would be more obvious when the temperature distribution of the furnace wall was convex. Moreover, they also investigated the optimal distributions of the heaters in the reheating furnace with convective and radiative heat transfers by taking minimal fuel consumption as optimization objective Based on the models in and applied constructal theory and entransy theory. optimized the distributions of the single-layer insulation with constant temperature boundary condition and convective and radiative boundary condition, respectively[1].

They concluded that the optimal distributions of the insulation layers were different from those obtained by HLR minimizations. For the constructal designs of insulation layers of the hot fluid pipes, Bejan built a distributed insulation layer model for a convective heat transfer hot fluid pipe, and optimized the thickness of the cylindrical insulation layer with minimum HLR. The result showed that optimal thickness of the insulation layer was uniform when the amount of the insulation material was fixed.by using optimal control theory, and the results obtained were coincided with those obtained in Moreover, they further optimized the distributions of the insulation layers of the hot fluid pipe with radiativeas well as combined heat transfer boundary conditions, and obtained some different optimal distributions of the insulation layers. For the constructal designs of vertical insulating walls, optimized the internal structures of the vertical insulation wall subjected to a fixed mechanical stiffness and obtained the maximum thermal resistance of the wall. Furthermore, reconsidered the insulation wall model, and optimized the number of air cavities by considering heat flow, strength and wall weight simultaneously[2]..

The constructal optimization of multilayer insulation structures with constant temperature boundary condition was carried out in. Based on the multilayer insulation model in a more actual model of multilayer insulation structures with radiative as well as combined convective and radiative heat transfer boundary conditions will be considered in this paper. Constructal optimizations of the insulation layers of a reheating furnace wall with the two boundary conditions will be carried out by taking minimum HLR as optimization objective. The optimal insulation performance with minimum HLR will be compared to that with average thicknesses of the insulation layers as well as that with minimum maximum temperature gradient. The model will be more generalized, and several heat transfer boundary conditions of the insulation layers will become special cases of this paper

A blast furnace is a key installation of a blast furnace system as well as an important device of the metallurgical production process. As the furnace wall is an important part of a blast furnace, the furnace wall plays an important role in the blast furnace system. Hence, it is significant to perform research on heat transfer performance (HTP) of blast furnace wall and optimizations for the structure of blast furnace wall. Many scholars have performed research on heat transfer problems of blast furnace wall . performed optimization for the cross section shape of cooling channel of a cooling stave based on a convective heat transfer empirical formula, and the results showed that adopting oblate cooling channel could decrease the heat transfer quantity and cooling water usage. performed analyses for the temperature field (TF) of a cast cooling stave, and analyzed the effects of different structure parameters on the TF. established a simplified one-dimensional model of a blast furnace wall, and proposed a method to calculate the furnace wall erosion line and TF. analyzed the effects of cross section shape of cooling channel on the thermal stress of cooling stave. established a 3D model of a blast furnace wall, and analyzed the effects of slag skull thickness on the TF of blast furnace wall[3].

II. CONSTRUCTAL OPTIMIZATION OF MULTILAYER INSULATION STRUCTURES

Consider a simple model of steel rolling reheating furnace wall with multilayer insulation structures, as shown in. The billet steel is heated by the high temperature gas in the inner of the hearth, and part of heat is dissipated to the ambient (ambient temperature $T0$) through the furnace wall. The temperature $T(x)$ ($0 \leq x \leq L$) of the internal furnace wall is specified. A number (N) of insulation layers (thermal conductivity ki, thickness ti, $i = 1, 2, 3,\ldots,N$) are laid outside of the furnace wall to reduce heat loss from the furnace. The length and width of the insulation layers are L and W, respectively. For the simplification of the calculation, the parameters along the third dimension (width direction) are assumed to be not varied. In this case, the heat conduction model in the paper becomes two dimensional, and the width of the insulation layer is fixed at unit width, i.e W= 1.When the thicknesses ti ($i = 1, 2, 3,\ldots,N$) are much smaller than the length of the insulation layers, the heat transfer rate along the thickness direction is much larger than that along the length direction. In this case, the heat transfer along the length direction can be approximately ignored, and the heat conductions in the insulation layers can be simplified as one dimensional .

The models of the multilayer insulation structures with uniform and distributed thicknesses are shown in (a) and (b), respectively[4]..

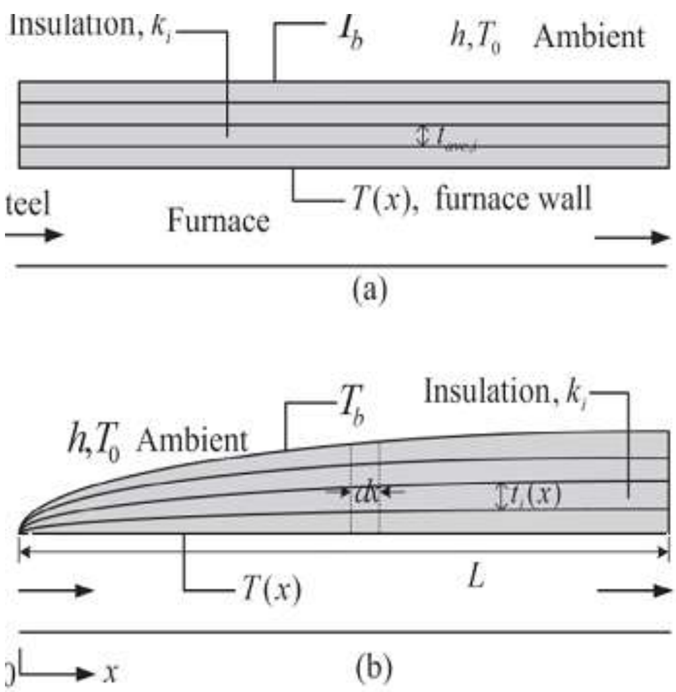

Fig.1. Model of a reheating furnace wall with multilayer insulation structures :
(a) Insulation layers with uniform thicknesses (b) insulation layers with distributed thicknesses

III. FURNACE CONSTRUCTION

The modern industrial furnace design has evolved from a rectangular or cylindrical enclosure, built up of refractory shapes and held together by a structural steel binding. Combustion air was drawn in through wall openings by furnace draft, and fuel was introduced through the same openings without control of fuel / air ratios except by the judgment of the furnace operator. Flue gases were exhausted through an adjacent stack to provide the required furnace draft.

To reduce air infiltration or outward leakage of combustion gases, steel plate casings have been added. Fuel

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economy has been improved by burner designs providing some control of fuel / air ratios, and automatic controls have been added for furnace temperature and furnace pressure. Completely sealed furnace enclosures may be required for controlled atmosphere operation, or where outward leakage of carbon monoxide could be an operating hazard. With the steadily increasing costs of heat energy, wall structures are being improved to reduce heat losses or heat demands for cyclic heating. The selection of furnace designs and materials should be aimed at a minimum overall cost of construction, maintenance, and fuel or power over a projected service life. Heat losses in existing furnaces can be reduced by adding external insulation or rebuilding walls with materials of lower thermal conductivity.

To reduce losses from intermittent operation, the existing wall structure can be lined with a material of low heat storage and low conductivity, to substantially reduce mean wall temperatures for steady operation and cooling rates after interrupted firing.

Thermal expansion of furnace structures must be considered in design. Furnace walls have been traditionally built up of prefired refractory shapes with bonded mortar joints. Except for small furnaces, expansion joints will be required to accommodate thermal expansion. In sprung arches, lateral expansion can be accommodated by vertical displacement, with longitudinal expansion taken care of by lateral slots at intervals in the length of the furnace. Where expansion slots in furnace floors could be filled by scale, slag, or other debris, they can be packed with a ceramic fiber that will remain resilient after repeated heating.

Differential expansion of hotter and colder wall surfaces can cause an inward-bulging effect. For stability in self-supporting walls, thickness must not be less than a critical fraction of height[5]..

IV. TYPES AND CLASSIFICATION OF DIFFERENT FURNACES

Based on the method of generating heat, furnaces are broadly classified into two types namely combustion type (using fuels) and electric type. In case of combustion type furnace, depending upon the kind of combustion, it can be broadly classified as oil fired, coal fired or gas fired.

• Based on the mode of charging of material furnaces can be classified as (i) Intermittent or Batch type furnace or Periodical furnace and (ii) Continuous furnace.

• Based on mode of waste heat recovery as recuperative and regenerative furnaces.

• Another type of furnace classification is made based on mode of heat transfer, mode of charging and mode of heat recovery[6].

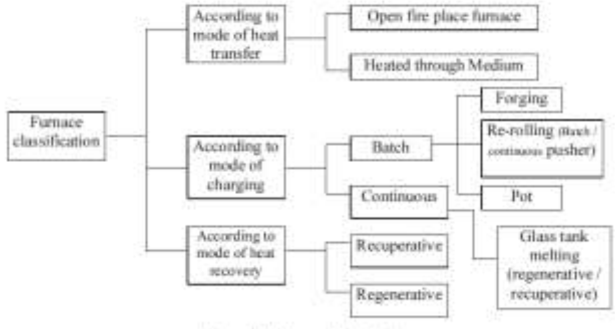

Figure 4.1: Furnace Classification

V. HEAT TRANSFER IN FURNACES

The main ways in which heat is transferred to the steel in a reheating furnace are shown in Figure 4.3. In simple terms, heat is transferred to the stock by:

• Radiation from the flame, hot combustion products and the furnace walls and roof.

• Convection due to the movement of hot gases over the stock surface At the high temperatures employed in reheating furnaces, the dominant mode of heat Transfer is wall radiation. Heat transfer by gas radiation is dependent on the gas composition (mainly the carbon dioxide and water vapors concentrations), the temperature and the geometry of the furnace[7].

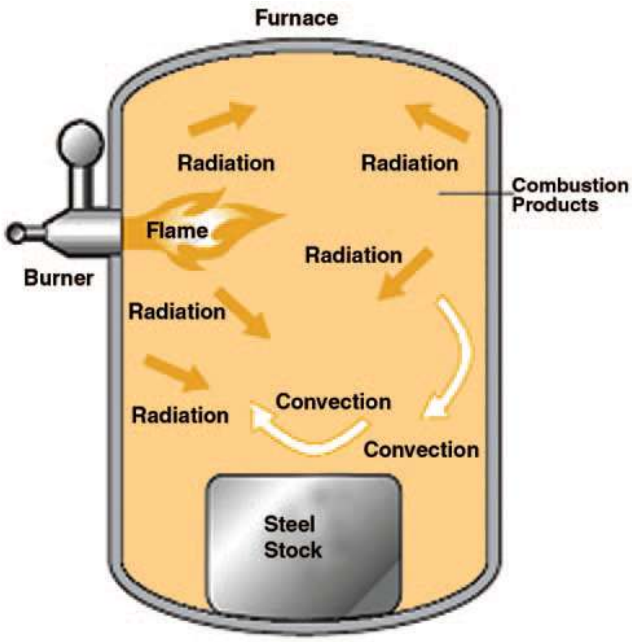

Figure 4.3 Heat Transfer in Furnace

VI. FURNACE TEMPERATURE PROFILES

To predict heating rates and final load temperatures in either batch or continuous furnaces, it is convenient to assume that source temperatures, gas (Tg) or furnace wall (Tw), will be constant in time. Neither condition is achieved with contemporary furnace and control system designs. With

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constant gas temperature, effective heating rates are unnecessarily limited, and the furnace temperature control system is dependent on measurement and control of gas temperatures, a difficult requirement. With uniform wall temperatures, the discharge temperature of flue gases at the beginning of the heating cycle will be higher than desirable.

Three types of furnace temperature profiles, constant *Tg*, constant *Tw*, and an arbitrary pattern with both variables, are shown in Fig. 27. Contemporary designs of continuous furnaces provide for furnace temperature profiles of the third type illustrated, to secure improved capacity without sacrificing fuel efficiency. The firing system comprises three zones of length: a preheat zone that can be operated to maintain minimum flue gas temperatures in a counter flow firing arrangement, a firing zone with a maximum temperature and firing rate consistent with furnace maintenance requirements and limits imposed by the need to avoid overheating of the load during operating delays, and a final or soak zone to balance furnace temperature with maximum and minimum load temperature specifications. In some designs, the preheat zone is unheated except by flue gases from the firing zone, with the resulting loss of furnace capacity offset by operating the firing zone at the maximum practical limit[8].

VII. CURRENT COMPUTERIZED HEAT TRAETMENT FURANCE MODEL

Common to all process heating systems is the transfer of energy to the material to be heat treated. Direct heating methods generate heat within the material itself (microwave, induction, controlled exothermic reaction), whereas indirect methods transfer energy from a heat source to the material by conduction, convection, radiation, or a combination of these functions. In most processes, an enclosure is needed to isolate the heating process and the environment from each other. Functions of the enclosure include, but are not restricted to, the containment of radiation (microwave, infrared), the confinement of combustion gases and volatiles, the containment of the material itself, the control of the atmosphere surrounding the material, and combinations thereof[9].

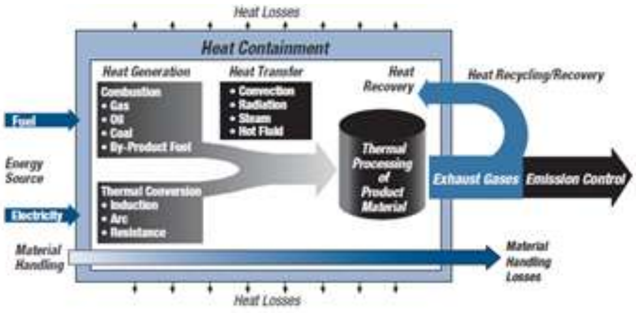

Figure 3.1 - *Key components of a process heating system*

VIII. FURNACE CONTROL

Thermal imaging control of furnaces and combustors developed by Gas Technology Institute The objective of this project is to demonstrate and bring to commercial readiness a near infrared thermal imaging control system for high temperature furnaces and combustors.

The concept used in this project is to provide improved control to high temperature furnaces using a near-IR thermal imaging control system. Initial stages of the Thermal Imaging sensor hardware development were conducted by testing on a laboratory electric furnace. The complete system was then tested on a GTI heat treat furnace. A state-of-theart control system was installed and accepted input for control from the thermal imaging system. The project strategy is to input the thermal imaging system data into a set of control system algorithms that would give secondary control instructions to burners (air-fuel ratios, etc.) for tuning control

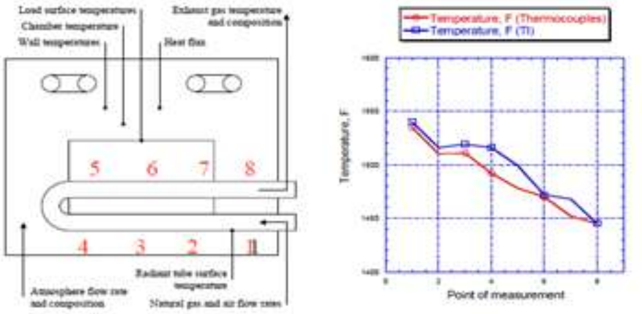

Figure 2.11 – Comparison of the thermocouples with the thermal imaging system and the thermal gradient inside the box type furnace

IX. THE NEED TO MODEL FURNACES

A commonly overlooked factor in energy efficiency is scheduling and loading of the furnace. “Loading” refers to the amount of material processed through the furnace in a given period of time. It can have a significant effect on the furnace's energy consumption when measured as energy used per unit of production (Btu/lb). Certain furnace losses (wall, storage, conveyor and radiation) are essentially constant regardless of production volume; therefore, at reduced throughputs, each unit of production has to carry a higher burden of these fixed losses. Flue gas losses, on the other hand, are variable and tend to increase gradually with production volume. If the furnace is pushed past its design rating, flue gas losses increase more rapidly, because the furnace must be operated at a higher temperature than normal to keep up with production. Total energy consumption per unit of production will follow the curve in Fig. 2.12, which shows the lowest at 100% of furnace capacity and progressively higher the farther throughputs deviate from 100%. Furnace efficiency varies inversely with the total energy consumption. The lesson here is that furnace operating schedules and load sizes should be selected to keep the furnace operating as near

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to 100% capacity as possible. Idle and partially loaded furnaces are less efficient.

In order to achieve maximum efficiency it is required to design the furnace part load to the maximum furnace capacity. A numerical tool with a furnace model helps to achieve this goal. Also another important quality metric in the heat treatment processes is soak time (amount of time a load stays at a given temperature) A furnace model with work piece thermal profile prediction can accurately predict the time required to reach the process temperature and the soak time. So the process can be accurately designed eliminating guesses and removing conservative recipes[10].

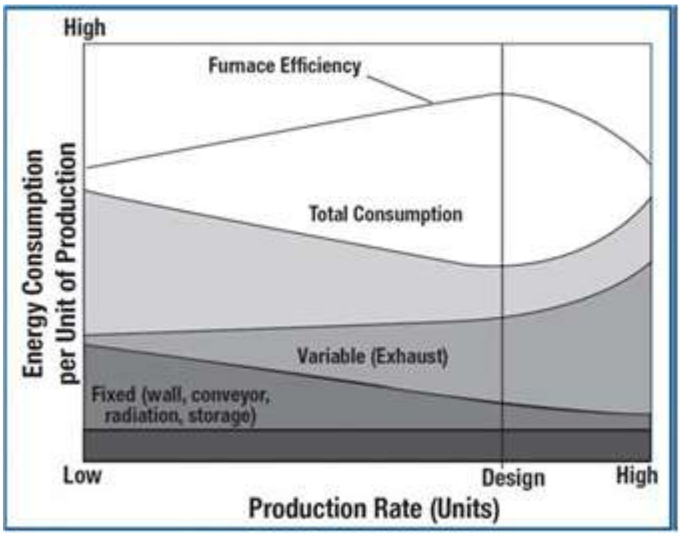

Figure 2.12 - *Impact of production rate on energy consumption per unit of production*

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