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Investigation of Heat Transfer in an Oil Fired Furnace for Melting Aluminium

[#1]Dr. Ramchandra K. Kulkarni, [#2]Abhay A. Desai

[#1]rkk288in@gmail.com
[#2]abhaydesai999@gmail.com

[#1]Department of Mechanical Engineering,
TSSM'S PVPIT, Bavdhan, Pune, India.
[#2]Department of mechanical Engineering,
TSSM'S PVPIT, Bavdhan,Pune, India.

ABSTRACT

This paper focuses on study of industrial oil fired furnace for melting aluminium and in order to improve the performance of furnace for different operating condition of existing ones, the three dimensional heat transfer analysis will carried out and for this, many parameters are used ,these parameters are reviewed and motivation are mentioned about use of computational fluid dynamics software as environmental concerns .The complex geometry and large number of parameters obtained in the furnace, due to this, an analytical solution is difficult, and hence one needs to opt for numerical modeling . So commercial software called ANSYS FLUENT will used for modeling the unsteady-state three dimensional heat transfers in a melting furnace. In that work mainly involves the use of coupled radiation and solidification/melting model to simulate the operational condition heat transfer in melting furnace. The simulated temperatures of charge and furnace flue gas exit point temperature will be compared with the Industrial oil fired furnace data and try to optimize it .

Keywords – Discrete ordinate method , Melting furnace , Radiation heat transfer , Radiation transfer equation , Recuperator

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I. INTRODUCTION

For Manufacturing of castings, Industry uses one main melting furnace and two holding/tilting furnaces. It has separate furnaces for Aluminium and Aluminium Alloy product. And in this paper, we consider only about Aluminium product. So the specification of furnace are as follow .These are taking from one small scale industry.

1.1 Melting Furnace:

The holding capacity of the melting furnace (MF) is 25 tons and it produces 10 tons of liquid metal in a period of 2 hours and 30 minutes. This furnace having two burners to melt the ingots. The air required to burn furnace oil is preheated with the help of recuperator. For running the Melting Furnace, 200 liters/hr (average value) furnace oil is required. Furnace has two doors, one is main door from which charging is done and other is back door from which degassing and drossing operation is carried out. For opening the main door ,there is motor and pulley mechanism. The door is sliding on the wall. The furnace is insulated inside by two layers of refractory material one is insulation brick and other is fire brick each having 200 mm thickness.

1.2 Tilting/holding furnace:

The holding capacity of tilting/holding furnace (TF) is 8.5 tons each. This furnace having two burners facility. For running the Tilting Furnace, fuel consumption is 28 liters/hr (average value). Furnace oil temperature and pressure is same as that of melting furnace. Based on the molten metal present in the furnace the tilting is done so that correct amount of liquid metal is given to continuous casting machine. For tilting the furnace hydraulic mechanism is used. In this furnace also there is provision for flue gases to enter into recuperator.

1.3 Waste heat recovery system (Recuperator) :

Large amount of heat is carried by flue gases. Due to this efficiency of furnace is decreased. To improve the efficiency of furnace waste heat recovery system i.e. recuperator is installed to furnace. It is a double cylinder shell type recuperator. Hot flue gases flows through inner shell which is made of Stainless Steel and air flows between the inner and outer shell in reverse direction so that it is preheated before introducing into the burner.For further improvement in the efficiency of recuperator , it is insulated by glass wool.

II. LIETRATURE REVIEW AND PARAMETERS USED FOR SIMULATION PURPOSE

4.1 Radiation Transfer Equation (RTE)

Though all modes of heat transfer occur simultaneously the heat transfer by radiation is a major contributor hence, the method used to model it should produce accurate results. Thus the choice of methods is also very important. Radiation is handled by radiation transfer equation (RTE). The basic of all methods for the solution of radiation problem is the RTE [4]. The radiative transfer equation is an integro-differential equation, and its solution even for a one-dimensional, planar, gray medium is quite difficult. Most engineering systems, on the other hand, are multidimensional. In addition, spectral variation of the radiative properties must be accounted for in the solution of the RTE for accurate prediction of radiation heat transfer. These considerations make the problem even more complicated. Therefore, it is necessary to introduce some simplifying assumptions for eachapplication before attempting to solve the RTE in its general form.

$$s\nabla I(r,s) = -k(r)\,I(r,s) + Q(r,s) \qquad (1)$$

Equation 1 describes the radiative intensity field, I, within the enclosure, as a function of location vector r and direction vector s; Q represents the total attenuation of the radiative intensity due to the gas emission and the in-scattered energy from other directions to the direction of propagation, and k is the total extinction coefficient.

4.2 Flux model

The radiation intensity is a function of the location the direction of propagation of radiation and of wavelength. Usually the angular dependence of the intensity complicates the problem since all possible direction must be taken into account. It is therefore desirable to separate the angular dependence of the intensity from its spatial dependence to simplify the governing equations. If it is assumed that the intensity is uniform on given intervals of solid angle than the radiative transfer equation can be simplified as the integro-differential RTE equation would be reduced to a series of coupled linear differential equations in terms of average radiation intensities or fluxes. This procedure yields the flux methods [1]. When deciding which flux radiation model for melting furnace is to be used consider the following advantages of each model [5] Optical thickness:The optical thickness αL is a good indicator of which model to use. If $\alpha L >>1$, then best alternatives are the P-1 and Rosseland models. The P-1 model should typically be used for optical thicknesses>1. For optical thickness>3, the Rosseland model is cheaper and more efficient. A second-order discretization scheme is also recommended for high optical thickness cases. The DTRM and the DO model work across the range of optical thicknesses, but are substantially more expensive to use. So use the "thick-limit" models, P-1 and Rosseland, if the problem allows it. For optically thin problems ($\alpha L<1$), only the DTRM and the DO model are appropriate. Scattering and emissivity: The P-1, Rosseland, and DO models account for scattering, while the DTRM neglects it. Since the Rosseland model uses a temperature slip condition at walls, it is insensitive to wall emissivity. Particulate effects: Only the P-1 and DO models account for exchange of radiation between gas and particulates. Semi-transparent walls (interior and exterior): Only the DO model allows to model semi-transparent walls of various types (e.g. glass). Specular walls: Only the DO model allows specular reflection (e.g., for dust-free mirror). Partially-Specular walls: Only the DO model allows specular reflection (e.g., dusty mirror). Non-gray radiation: Only the DO model allows computing non-gray radiation using a gray band model. Localized heat sources: In problems with localized sources of heat, the P-1 model may over-estimate the radiative fluxes. The DO model is probably the best suited for computing radiation for this case, although the DTRM, with a sufficiently large number of rays, is also acceptable. Enclosure radiative transfer with non-participating media: The surface-to-surface (S2S) model is suitable for this type of problem. The radiation models used with participating media may, in principle, be used to compute the surface-to-surface radiation, but they are not always efficient. Gas or oil fired industrial furnaces are localized radiation sources, DO approximation can give better a result for this reason we use DO method to solve radiation heat transfer in industrial furnace.

4.3 Discrete ordinates model (DOM)

If the direction and size of the solid angle are determined from the Gaussian or Lobatto quadratures, a non-uniform flux approximation is developed and resulting expression called Discrete Ordinates (DO) approximation to RTE. As the name suggest (DO) by discretizing the entire solid angle ($\Omega=4\pi$) using a finite number of ordinate directions and corresponding weight factors. The RTE is written for each ordinate and the integral terms are replaced by a quadratures summed over each ordinates [1]. The DO model transforms Equation 2 into a transport equation for radiation intensity in the spatial coordinates which is given by Equation 3.The DO model solved for as many transport equations as there are directions $\bar{s}$.The solution method is identical to that used for the fluid flow and energy equations. The implementation in FLUENT uses a conservative variant of the discrete ordinates model called the finite-volume scheme and its extension to unstructured meshes [6]

$$\frac{dI}{ds}(\bar{r},\bar{s}) + (a+\sigma_s)I(\bar{r},\bar{s}) = an^2\frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\bar{r},\bar{s}^t)\varphi(\bar{s},\bar{s}^t)\,d\Omega \quad (2)$$

$$\nabla.I(\bar{r},\bar{s})\bar{s} + (a+\sigma_s)I(\bar{r},\bar{s}) = an^2\frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\bar{r},\bar{s}^t)\varphi(\bar{s},\bar{s}^t)\,d\Omega \quad (3)$$

FLUENT also allows the modeling of non-gray radiation using a gray-band model. The RTE for the spectral intensity can be written as

$$\nabla.I_\lambda(\bar{r},\bar{s})\bar{s} + (a+\sigma_s)I_\lambda(\bar{r},\bar{s}) = a_\lambda n^2 I_{b\lambda} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\bar{r},\bar{s}^t)\varphi(\bar{s},\bar{s}^t)\,d\Omega^t \quad (4)$$

Here λ is the wavelength, is the spectral absorption coefficient, and is the black body intensity given by the Planck function. The scattering coefficient, the scattering phase function, and the refractive index n are assumed independent of wavelength. The non-gray DO implementation divides the radiation spectrum into N wavelength bands, which need not be contiguous or equal in extent. The wavelength intervals are supplied by user, and correspond to values in vacuum (n=1). The RTE is integrated over each wavelength interval, resulting in transport equations for the quantity , the radiant energy contained in the wavelength band. The behavior in each band is assumed gray. M.F. Modest [7] gives the detail procedure of weighted sum of gray gases model (WSGGM) for arbitrary solution methods in radiative transfer. The concept ofweighted sum of gray gases approach was first presented by Hottel and Sarofim (1967) with in the frame work of the zonal method. The method may be applied to arbitrary geometries with varying absorption coefficients but is limited to non-scattering media confined within a black walled enclosure. M.F. Modest demonstrated that this approach can be applied to the directional equation of transfer and therefore to any solution method for equation of transfer (exact, P-N approximation, discrete ordinates method, etc). In this method the non gray gases is replaced by a number of gray gases, for which the heat transfer rates are calculated independently. The total flux is then found by adding the fluxes of gray gases after multiplication with certain weight factors. He also showed that method may be used in conjunction with any spectral model (line-byline, narrow band, wide band or total emissivity correlations) and carried out to any desired accuracy. Nevin Selcuk and Nuray Kayakol [8] studied the discrete ordinates method (DOM)and discrete transfer method (DTM) were evaluated from the viewpoints of both predictive accuracy and computational economy by comparing their predications with exact solutions available from a box shaped enclosure problem with steep temperature gradients. They find that comparative testing of S4 approximation produces better accuracy in radiative energy source term than in flux density in three orders of magnitude less CPU time than that required by the DTRM. They recommended that the S4 approximation (DOM) can be used in conjunction with CFD codes. R.Viskantha [9] review the literature on methods for solving the radiative transfer equation (RTE) and integrating the radiant energy quantities over the spectrum required to predict the flow, the flame and the thermal structures in chemically reacting and radiating combustion systems. The focus is on four methods (differential approximation, discrete ordinates, discrete transfer, and finite volume) for predicting radiative transfer in multidimensional geometries that meet the desired requirements. Also the methods that are fast and compatible with the numerical algorithms for solving the transport equations using the computational fluid dynamics techniques are reviewed. In the above methods, the interaction of turbulence and radiation is ignored.

III.PROCEDURE TO IMPLEMENT FURNACE

For implementing the furnace, we will first do the heat calculations based on the operating data recorded by the company site. Using these calculation, we will find the current efficiency of the furnace. after that, we have to model this furnace in FLUENT software and by changing various process parameters, we will try to optimize the furnace efficiency. For this analysis, we need to use unsteady state radiation heat transfer. After that we will suggest to the company the process parameters which we got for optimizing furnace efficiency.

IV.FLOW CHART OF CFD TECHNIQUE EMPLOYED FOR REHEATING FURNACE

The melting operation for a charge usually takes two hour and thirty minutes. The physical problem of a melting furnace has been solved using the commercial computational fluid dynamics (CFD) package, FLUENT. The CFD code solves the modeled three 6 dimensional Navier-Stokes equations over a boundary fitted grid using a finite volume pressure correction procedure. The present work is solely concerned with the simulation of the radiation for unstructured grid of melting furnace and charge hanging in air. For further details of the CFD techniques employed see the flow chart Fig.1. The approach adopted in the present work is to assume that the furnace is operating in a SIMPLE unsteady state.

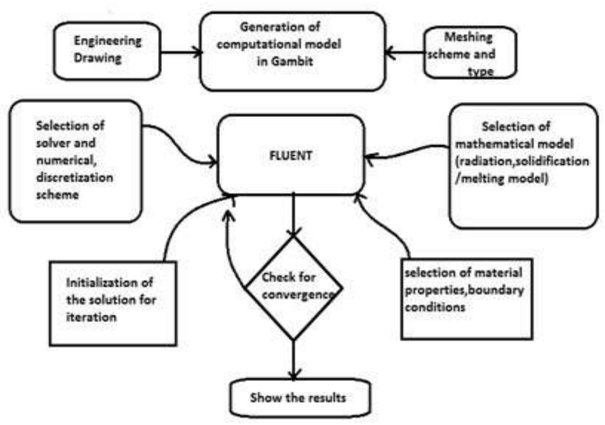

Fig.1. Flow chart of CFD techniques employed for reheating furnace

V. MOTIVATION

Environmental concerns along with the limited world oil resources have caused a decrease of the oil consumption on a percentage basis. This decrease is particularly significant in some industrial sectors, such as power generation. However, in other sectors, such as transports, liquid fuels are by far the dominant energy source. In fact, spark ignition engines, diesel engines, gas turbine combustors for aircraft propulsion and rocket engines generally burn liquid fuels. Moreover, due to the increased world energy demand, the world oil consumption has been increasing, mainly because of the contribution of the developing countries. Therefore, the investigation of liquid fuels combustion, particularly heavy fuel oil, remains an important research topic. The numerical simulation of heavy fuel oil combustion is a challenging task. In addition to the difficulties inherent to gas-phase combustion, namely the need to model turbulence, combustion and radiative heat transfer, heavy fuel oil combustion presents other complex phenomena. A few numerical studies on heavy fuel oil combustion have been published in the literature. These motivations lead to use of Commercial Computational Fluid Dynamics (CFD) software called FLUENT. Because Computational modeling is often much cheaper and faster than building prototype that are usually tested under controlled laboratory conditions before trying them in out actual field installations. Further mathematical modeling is advantageous in terms of simulating the real world problem. Proper mathematical modeling will help to understand logically the complexity involved in melting furnace. In the melting, heat transfer to charge depends on various factors such as the shape of furnace, type of burners, arrangement of burners, burner operating conditions, type of fuel, location of the charge, and the charge"s thermal property. The furnace geometry as well as the installation of burners has decisive role in determining the flow and temperature fields which have direct influence on the heat transfer. As mentioned previously, the major factor to be considered in the working of a furnace is the heat transfer by all the modes, which occur simultaneously. To improve the melting process in existing ones, the heat transfer in the furnace has to be modeled in a way that it resembles a practical situation as closely as possible. With properassumptions and constants, mathematical heat transfer will guide to improve these variables and efficiency of reheating furnace. The best way to use computational modeling is in conjunction with the practical validation.

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