ENHANCED HEATING MECHANISM OF THE ELECTRIC METAL MELTING FURNACE IN TRADITIONAL FOUNDRY

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ABSTRACT

The cost to own a furnace to melt metals is very costly; around RM 60, 000 for a 3 litre capacity diesel furnace and may be higher depending upon the crucible capacity. Due to the high cost of raw material i.e. copper and aluminium, the metal industry has become an expensive industry and a burden, especially for the small operators. Thus, this research aims to modify the shape of the heat chamber in the electric furnace in order to improve efficiency and at the same time being affordable to support the traditional foundry. The electric furnace is designed based on the induction concept and used the coil as the heater to melt the non-ferrous metals, namely an aluminium or brass. The conceptual design of the furnace using Solid Works took several important criteria that have been considered; that is the furnace efficiency, the commercial design, the cost involved, the furnace heating mechanism, the heat chamber shape, the internal combustion flow and the mobility of the furnace. The criteria are then analysed by using the Matrix Evaluation Method (MEM) to find the ultimate design that suits the criteria. From the computational simulation, it is found that the heat flow due to the induction accumulates the entire space in the furnace and is capable to melt the metal completely. Results from the repeated experiments show that the melting time for aluminium is only 45 minutes for the quantity of 1 kg at a temperature of 740 °C. This design of induction furnace turned out to be reasonably efficient (78.53%) and is very economical (RM 5160). Therefore, this furnace can be a good solution in helping traditional foundries particularly in Malaysia.

Keywords: enhanced heating mechanism, metal melting furnace, improved efficiency, traditional foundry.

INTRODUCTION

There are four types of furnaces commonly used to melt the metal; basic oxygen furnace, electric arc furnace and immersion furnace. The blast furnace still maintains its predominant position as mass producer of hot metal from last centuries [1]. There are many experiments and simulation work which have been conducted to improve the performance of blast furnace [2]. Heat transfer analysis is one of the major studies to enhance the performance of the furnace [3]. Blast furnace has a cone-shaped tower height from 20-30 m and a diameter of 5-7 m. It is divided into two parts; which is the combustion chamber and brick construction. Combustion chamber is the place where the gas and fresh air delivered to the furnace for combustion to take place. The blast furnace commonly used to melt iron or to melt steel ingots.

For the basic oxygen furnace it uses pure oxygen in the steel or iron smelting. It can move horizontally and vertically. While the furnace is filled with liquid iron and 30% steel scrap to the furnace in a position tilted and then set up the furnace. This type of furnace could produce high-quality steel that is faster on average in terms of time [4]. For the electric arc furnace, it has a high capacity and easier to handle than the other furnaces because of the low oxygen level in the furnace, it is suitable for producing steel alloy from the mixed metal that does not react with the oxygen. This furnace is widely used and appropriate to the grade of steel and increase the production of tool steel and steel alloys without the aid of high-quality and expensive fuels [5].

The immersion furnace can be divided into two; i.e. Low-Temperature Melting and High-Temperature Melting [6]. The heat is generated by combustion or electrical resistance inside a tube submerged in molten material. The heat is efficiently transmitted to the molten material through the wall of the tube by conduction. Combustion gases are never exposed to the molten metal, reducing oxidation losses and enhancing heat transfer to the molten metal. The efficiency of a zinc immersion furnace is high at 63 to 67% and provides melting rates of up to 1,600 lb /hr.

Although Immersion furnace is well established for melting zinc, it is currently not well-adapted for melting metals with higher melting points. The protective ceramic coatings pose thermal barrier, lowering the melting efficiency. In U.S.A, several Industrial Technology Programmes (ITP) for metal casting projects are currently focusing on enabling this technology commercially. One ITP sponsored project addresses the critical need for advanced materials that are lighter, stronger, and more corrosion-resistant than metals. Work has been done to optimize the nitride-bonded, silicon-carbide-fibre-reinforced Continuous Fibre Ceramic Composite (CFCC) immersion tube burners for application in aluminium and other light metal melting. The project validated that CFCC materials are stable in molten aluminium and in combustion gas for long periods. When tested at an industrial site, the immersion tube survived over 1,000 hours and 31 cycles in an aluminium casting furnace. In another testing, the immersion tube successfully survived for 1,752 hours in the furnace.

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The trend in design of the electric furnace in the past decade had been toward top charge and larger furnaces, with increased transformer capacity for fast melting. In many of the older installations, transformer size is being increased to provide faster melting rates and higher temperatures for steels requiring special treatment. The maximum size of the electric furnace has not been reached, and the possibilities of the really large furnace remain to be proven. However, there is little doubt in most operators' minds that the large electric furnace is practical [7].

The price of metal melting furnace is very expensive depending on the size and capacity of the melting metal. This causes the small-industry casting i.e. foundry does not have the ability to buy or fabricate a better furnace. They were only able to build or purchase a small furnace that need longer time to melt. Therefore, an economical design is needed with enhanced heating mechanism to support the traditional foundries.

METHODOLOGY

Design concept and criteria

Three different conceptual designs of the furnace were developed to analyse the best option of modification. These conceptual designs will be compared with the reference design also known as Datum. Finally, the best design will be selected based on the Matrix Evaluation Method [8]. Some of the modifications that were incorporated into the design are to use two coils to produce electric current and using water cooling system to cool the coils. The most prevalently used electric induction furnaces are mainly of two different types; the coreless furnace and the channel furnace.

The position of the heating coil for the conceptual design 1 and 2 are placed at the side of the crucible as shown in Figures-1 and 2. Meanwhile, for conceptual design 3, the heating coil is wound around the crucible as shown in Figure-3.

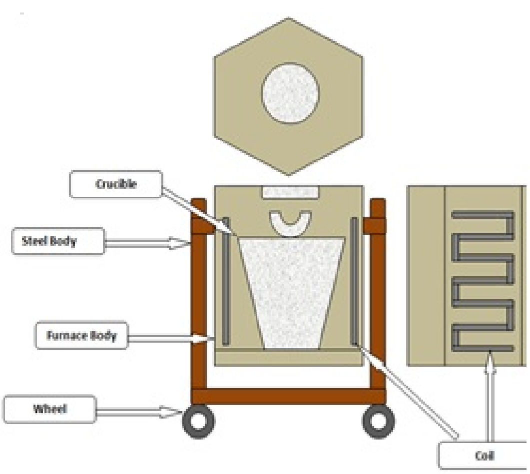

Figure-1. Conceptual design 1.

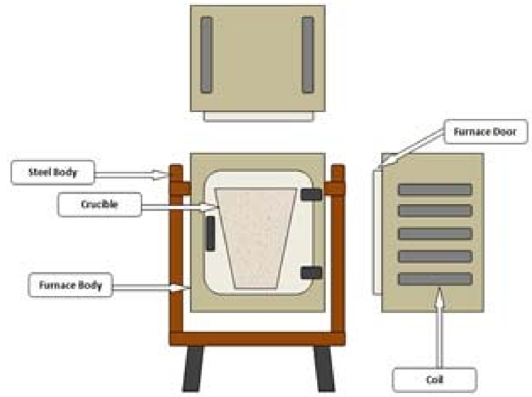

Figure-2. Conceptual design 2.

Concept evaluation and selection

Evaluation and selection were analysed by comparing the concept with the reference concept (Datum). Points were awarded to the value of each concept in order to determine the best concept using the Matrix Evaluation Method (Table-1). The scores were determined from the list of advantages and disadvantages of each design. Thus, any weaknesses determined in the selected design concept can be improved.

Table-1. Comparison between the conceptual designs 1, 2 and 3 with the datum.

No.	Criteria	Interest criteria	Concept 1	Concept 2	Concept 3	Concept reference
1.	Efficiency	5	-	-	S	D
2.	Commercial design	4	-	-	+	
3.	Cost	4	+	+	+	A
4.	Heating mechanism	3	-	-	S	T
5.	Heat chamber shape	5	+	S	+	U
6.	Combustion flow	5	-	-	S	M
7.	Mobility	4	+	+	+	
8.	Total +		3	2	4	0
9.	Total -		4	4	0	0
10.	Total overall		-1	-2	4	0
11.	Total actual		-4	-9	17	0

The selected conceptual design with the highest marks was chosen as the final concept. Conceptual design 3 was selected from Table-1 since it had the highest score (17), so the design with detailed dimensions was produced using Solid Works (Figures-3, 4 and 5).

Design and numerical evaluation

The simulation was used at the design stage to optimize the basic geometry of the furnace. The performances of the furnace were studied according to the heat distribution in the combustion chamber of the

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furnace. Then, the fluid domain, the boundary conditions, the initial guess, the meshing and the solver control were determined by the design parameters given (Table-2). In applying this process, there are several engineering software that were used; i.e. Gambit and Fluent 6.3.

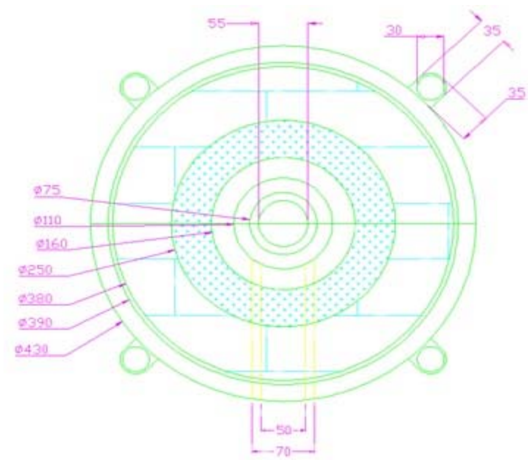

Figure-3. Top view of the furnace.

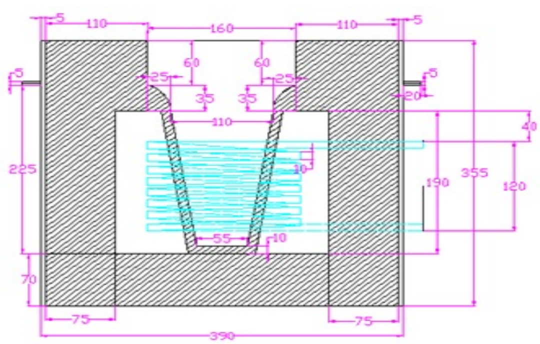

Figure-4. Front view of the furnace.

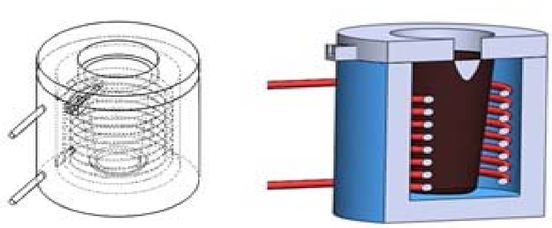

Figure-5. The model of crucible and combusion area inside the electric metal melting furnace.

Table-2. Boundary conditions for the furnace.

Outside wall thermal resistance, R(Fire block) = 0.030 m^2K/W
Bottom wall thermal resistance, R(Fire block) = 0.030 m^2K/W
Upper wall thermal resistance, R(V-Cast Furnace cements) = 0.014 m^2K/W

The fluid domain is selected at the combustion chamber. The fluid is setup at Air at STP at reference pressure 101325 Pa i.e atmospheric air pressure. Type of simulation is assumed as Steady State with Stationary Domain Motion, Laminar Model. Then, the heat transfer model is selected as Thermal Energy with Non-Buoyant.

Furnace fabrication

Figure-6 shows the fabrication process involved in the construction and assembling the induction furnace according to conceptual design # 3. Heating coil with wind diameter 160 mm and coil diameter 8 mm was used. The final completed furnace is shown in Figure-7.

Figure-6. The fabrication process of the furnace (a) V-Cast powder used (b) the lid of the furnace (c) the body of the induction furnace (d) fixing the wires and cables on the spray coated furnace.

Figure-7. The completely fabricated electric metal melting furnace with the thermocouple (Type K) fixed at the bottom of the furnace.

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Performance test

The performance test is to determine the efficiency of the furnace and the specific energy consumption for comparing with design values of this furnace. There are many factors affecting furnace performance such as capacity utilization of furnaces, excess air ratio, final heating temperature etc. It is the key for assessing current level of performances and finding the scope for improvements and productivity. The Infrared Thermometer was used to measure the temperature at the furnace body and inside the crucible. Equation. (1) and (2) are used to determine the furnace efficiency and specific energy consumption. The radiation of heat loss from the surface of furnace is calculated from Equation. (3).

$$Furnace\ efficiency, \eta = \frac{heat\ output}{heat\ input} = \frac{heat\ in\ stock\ (kCals)}{heat\ in\ electricity\ (kCals)} \quad (1)$$

$$Specific\ Energy\ Consumption = \frac{Quantity\ of\ energy\ consumed}{Quantity\ of\ material\ processed} \quad (2)$$

$$Heat\ Loss = quantity\ of\ heat\ release\ \left(\frac{kCal}{m^2.hr}\right) x\ total\ area\ of\ heating (m^2) \quad (3)$$

Experimental run

The actual experimental test was conducted and repeated three times to determine the readings of the temperature at pre-defined locations. The electric furnace was tested virtually and the readings are compared with the simulation results. The simulation gave a very clear view of how the heat distribution through the combustion chamber. It is very useful to determine where the complete combustion occurs in the combustion chamber. There are some assumptions that had been made while conducting the experiment, that is:

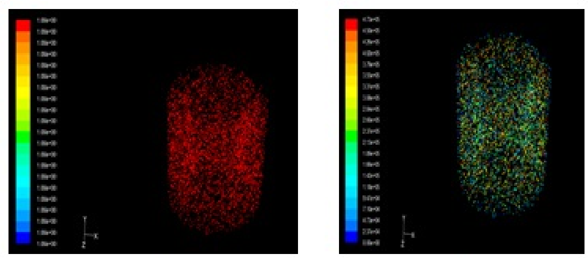
i. The measurement and simulation is done in the closed room.
ii. The voltmeter, ammeter, temperature gauge and thermocouple used are in good condition.
iii. The stability of the airflow in the combustion chamber is good during the reading was taken where in the simulation process it is assumed as the steady state condition.
iv. There is minimal heat loss during the experiment.

1 kg of aluminum was melted in this actual experiment. For every 5 minute interval, temperature measurements were taken from both the thermocouple and the Infrared thermometer. The thermocouple was used to measure the temperature inside the combustion chamber while the Infra-red thermometer was used to measure the temperature inside the crucible until all of the aluminum is completely melted. Data is recorded, graph is plotted and analysed.

RESULTS AND DISCUSSION

Design and computational simulation of the furnace

The computational simulation from FLUENT 6.3 shows that at the beginning of the heating process, the airflow inside the combustion chamber is in random movement. There is no temperature increased involved. After a few minutes, the velocity becomes constant with increasing temperature. Figure-8(a) shows the heat flow vector inside the combustion chamber. Meanwhile Figure-8(b) shows the air flow meeting the entire space in the furnace which is described as the Pathline Colored by the Particles. Overall, there is a movement of the airflow inside the closed combustion chamber. With the best design selected, the heat convection in the combustion chamber is complete for the spiral shaped flow during heating process.



(a) (b)

Figure-8. The simulation at the combustion chamber of the furnace by using FLUENT 6.3 (a) heat flow vector inside the combustion chamber (b) air flow meeting the entire space in the furnace.

Performance test

Table-3 shows the summary of efficiency, energy consumption and heat loss obtained from the experimental runs.

Table-3. Summary of the calculated values of efficiency, energy consumption and amount of heat loss in this electric furnace.

Efficiency	78.53%
Specific Energy Consumption	0.1875 kWh
Heat Loss	26.8785 kCals

Experimental run

The temperature was taken by using two different measuring devices i.e. the fixed thermocouple and the Infra-Red Thermometer. The fixed thermocouple is attached at the bottom of the crucible. The temperature is taken from the inside of the combustion chamber. This thermocouple is used to take the temperature reading inside the combustion chamber only. The Infra-Red Thermometer is a portable measuring device used to take temperature reading directly at the bottom of the crucible which indicates the temperature inside the crucible. The heat convection from heating coil is directly transferred to the crucible because the coil is located around the crucible (wind around). This temperature is the actual temperature of the material inside the crucible. The experiment was repeated 3 times and the average temperature was recorded.

The melting process took only 45 minutes to completely melt the 1 kg aluminum which has a melting point temperature of 660 °C. Figure-9 shows the graph of Temperature, T (°C) against Time, t (min) for two different measuring devices i.e. the Thermocouple and the Infrared Thermometer which were used to measure the temperature inside the combustion chamber and inside the crucible respectively.

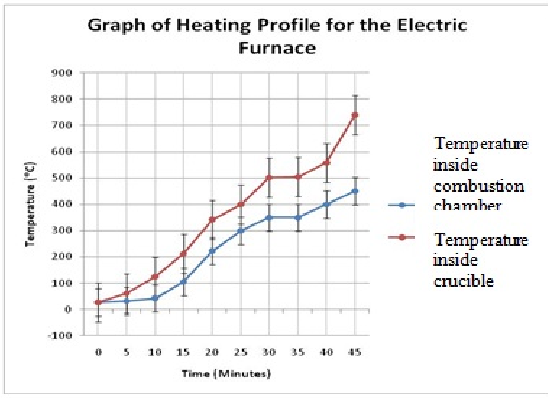


Figure-9. Heating profile inside the combustion chamber measured by thermocouple and the crucible measured by infra-red thermometer while melting the Aluminum.

On the first 25 minutes, the graph shows the temperature increasing directly proportional. On the 30th minute, the temperature had reached at the constant temperature. At this stage, more energy is needed by the aluminum to untie their molecular bonding. Then, at the 40th minute, the temperature continues to increase until 45 minutes. The aluminum is completely melted at the temperature of 740 °C (at 45 minutes).

Based on the results, it clearly shows this electric furnace saves more time than the traditional furnace which uses simple coal-fired stove furnace made by small scaled local foundry. This fabricated electric furnace takes less than 45 minutes to completely melt 1kg of aluminum while the coal-fired stove furnace would easily take about 2 hours to reach the melting point of aluminum (660 °C). Therefore, it can be easily justified that this fabricated design of electric furnace has saved time by 62.5 % and is definitely more efficient than using traditional means of melting by coal fired method.

CONCLUSIONS

The modified electric furnace was successfully designed based upon the conceptual design analysis by taking into account the appearance, the cost involved, the heating mechanism, the static pressure, the maximum temperature and the mobility of the furnace. It is found that from the simulation, the heat flow due to the convection accumulates the entire space in the furnace and is capable to completely melt the aluminum. The process to melt 1kg of aluminum needed only less than 45 minutes, which is 62.5 % faster compared to the normal 2 hours from using traditional method. The cost of producing this modified design of electric furnace is much cheaper since the total cost of materials needed to fabricate this furnace is only RM 5160. It gives the most economical and affordable price for an efficient electric furnace (with efficiency of 78.53%) to be used in the small scaled craft industries.

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