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A Novel Approach For Energy Conservation By Raw Material Preheating In Green Sand Casting

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Abstract: This paper discusses a novel method of mixing metallic raw materials (virgin/scrap) with green sand molds in such a way that the scrap is aligned close to the mold cavity and recovers the waste heat and gets preheated when the molten metal is poured into the mold cavity. When this preheated scrap is loaded into the furnace for the consecutive melting, it is found to take 21 % less energy than it would take to melt normal scrap. This principle has been improvised by insulators, resulting in better heat recovery. In the experiments, it is observed that apart from considerable energy savings, this method also enhances recyclability and conservation of molding sand, and reduced mold emissions, adding to the appropriateness of this method to address the current crisis in the fields of energy and environment. This method has been applied for patent.

Key words: energy conservation; waste heat recovery; scrap preheating; innovation; metal casting.

1 Introduction

Modern economic development programs critically depend on reliable supply of energy. Since the current energy resources are depleting fast and also there is the mounting problem of pollution associated with exploitation of most of the energy resources such as thermal, hydroelectric, nuclear...etc, and the inability of the renewable resources to cater to the intense energy needs of the society in a dependable way, energy conservation has indeed become the need of the hour. Metal casting being one of the most energy-intensive manufacturing sectors as agreed upon by many studies¹⁻³, this paper discusses an innovative way to conserve energy in it. The casting process that was once used to make tools for most essential applications and exotic goods for only a privileged few now contributes to components used in over 90% of manufactured goods in our society today.

Figure 1 and angles⁴.

Figure2 show typical metal casting tacit energy use from different

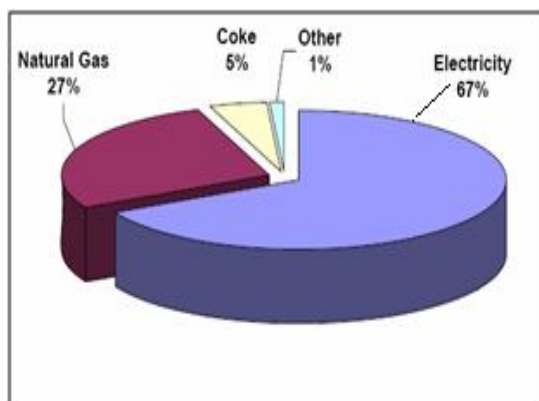


Figure 1 Typical Metal Casting Tacit Energy Resources

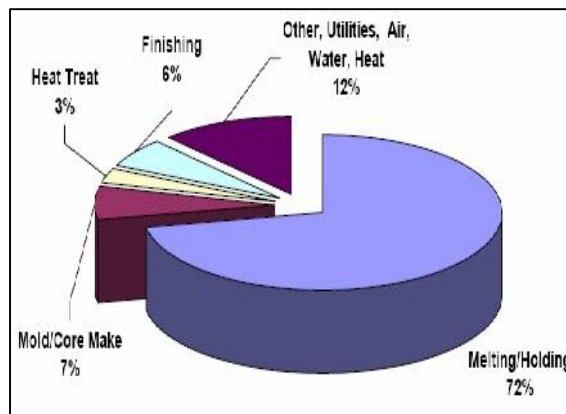


Figure2 Typical Metal Casting Tacit Energy Profile by Process

The impetus for innovation in energy conservation comes not only from economical front, but also from the environmental dangers caused by energy related emissions. Increased use of fossil fuels is responsible for the addition of more than 8 billion tons of carbon to atmosphere each year and has also increased the earth's temperature. If this trend continues, average surface temperatures could rise between 2°C and 6°C by the end of the 21st century^{5,6}, leading to various catastrophes such as melting of polar ice caps, higher ocean levels causing massive movement of people away from low lying land near the seas, shift of agricultural areas, ocean acidification, coral bleaching, irreversible biodiversity loss...etc, all threatening the very existence of this planet. Hence, it is important and urgent to cut down the wastage of energy in all possible ways. With a precursor work by the same author to assess the basic viability of the concept⁷, this paper investigates into the more practical viability of the method by seeking to understand the relationship of insulator thickness with heat gain, economical and ecological aspects.

2 Methodology and Experimental Set up

The methodology is to mix/embed the raw material (which could be virgin billets or scrap) in the mold, closely around the cavity in such a way that the heat dissipated during solidification preheats the scrap. Since the preheated material is going to act as a next charge for the furnace, this preheat achieved through the embedment of scrap in the mold reduces the energy consumption in the furnace. Figure 3 reveals the various steps involved in the proposed method. The shaded blocks represent the steps in the preheating sequence, results of which are reported in this paper. Other blocks are applicable to any conventional casting. A brief explanation of this flow diagram that depicts the proposed methodology is as follows:

Block-1: Raw material is separated from the go-down. **Block-2:** raw material is prepared to be placed into the sand mold, close to the mold cavity by sizing and wrapping with insulation if necessary. **Block-3:** processed raw material is routed for mixing into the sand mold. **Block-4:** raw material is packed around the cavity. **Block-5:** mold is ready with raw materials packed around the cavity. In such a mold cavity, pouring of molten metal is done. **Block-6:** the molten metal in the sand mold cools by giving away its heat to the raw materials that surround the cavity and thus the raw material temperature increases. Now the preheated raw materials are separated from sand. **Block-7:** The preheated raw materials might have sand particles stuck to them. To remove them, it is passed through vibratory platform. **Block-8:** Here, the raw material flow path is maintained at high temperatures so that its heat is maintained; this paper does not discuss the details of this step.

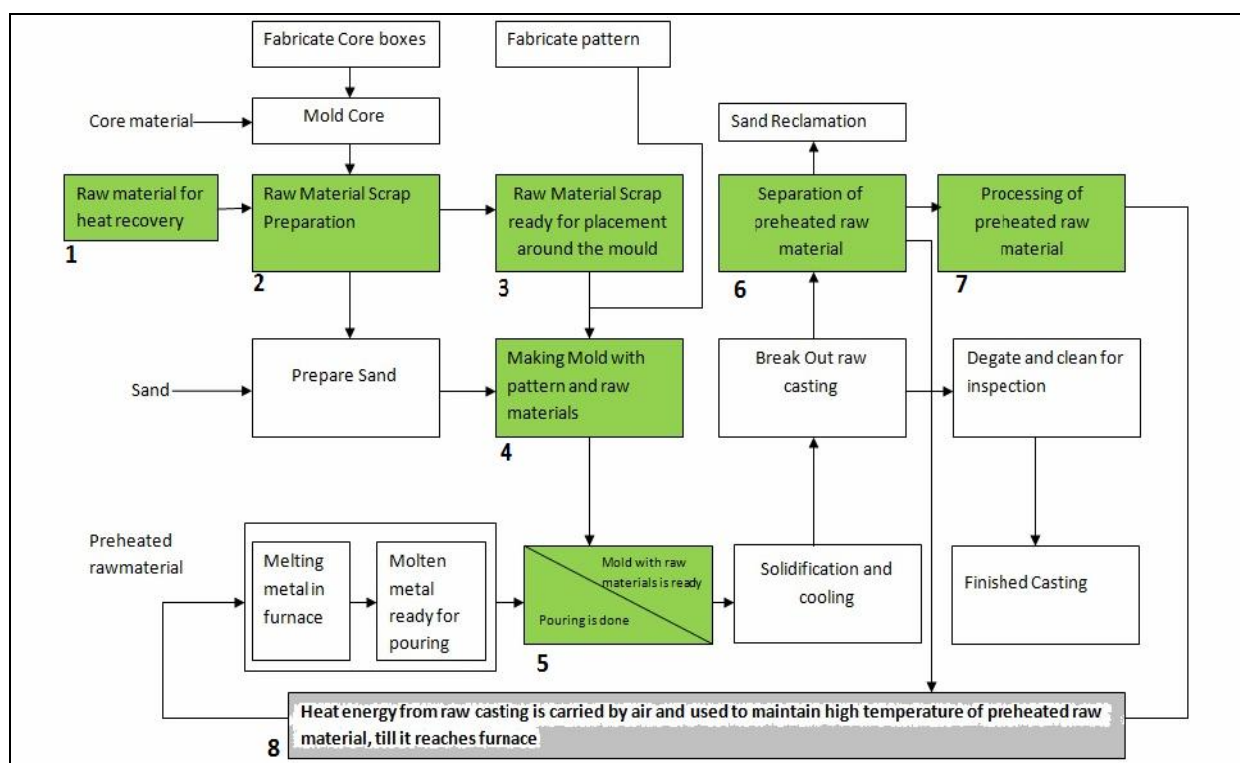


Figure 3 Process Flow Diagram for Raw Material/Scrap Preheating

The implementation of the methodology is shown in Figure 4. This is the experimental set up for conducting various experiments to assess the energy conservation potential of this method. LM 25 grade Aluminium is used for casting. Pouring temperature is around 980 K. Fiber glass wool insulation is used to prevent heat loss from the scrap. K type thermocouples measure the temperature history and the data is logged using data acquisition system. For each experiment, calculations were made on savings in energy, economics and ecological foot print to infer the relationship among them for different insulator thicknesses. The best cases among these results are discussed in the next section.

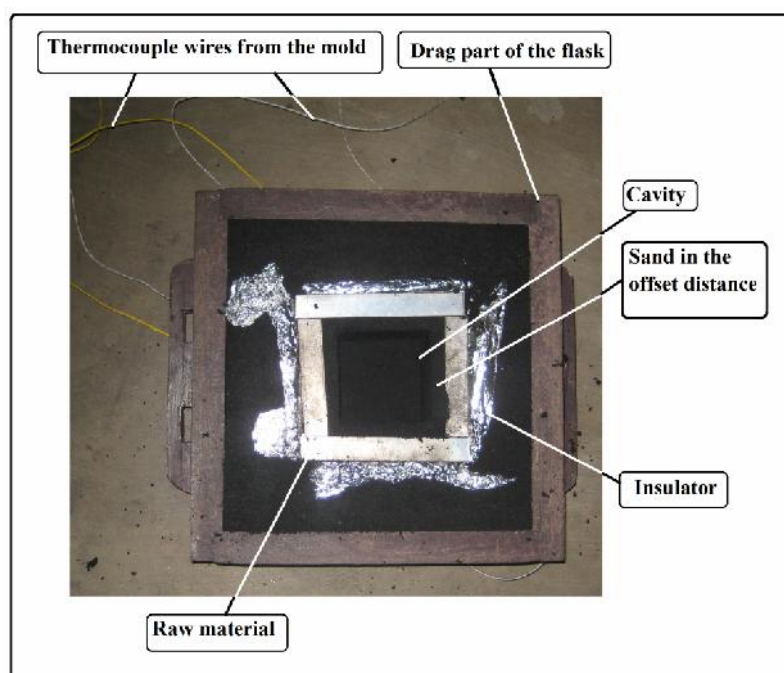


Figure 4 Experimental Set up, Showing the Drag Portion of the Flask with Embedded Aluminium Raw Material, Insulator and Thermocouple Wires Taken from the Back of the Mold at Different Distances from the Mold Cavity.

3 Results and Discussions

Experiments conducted to measure the temperature distribution in the proposed sand mold provide very convincing evidence for recovering the waste heat to preheat the scrap in metal casting. In this section, results are presented starting from proposed method without insulators, then with insulation of various thicknesses, then evaluation of benefits in energy, economics and environment is followed to assess the practical viability.

3.1 Results of experiments on scrap-mixed mold without insulators

Figure 5 presents the temperature rise trend in the molds mixed with scrap for heat recovery. At a particular instance from the time of pouring (400 seconds), let us examine temperature distribution at various locations in the mold. For this time, at 10mm, temperature is 420K, which is higher compared to scrap temperature of 401K; this is because the centre point of the scrap is at around 20 mm from the cavity that carried molten metal. When the distance of a point from the mold cavity is less, that point reaches peak quickly, as it has happened to the point at 10, which reached the peak at around 500 seconds. After reaching the peak, the point gives away its heat to the successive points in the mold and hence its temperature starts declining. The same phenomenon happens to the successive points: when distance grows further, the time it takes for reaching the peak temperature increases and its peak temperature value falls. The reason is the thermal resistance offered by the media (sand and raw material). Only for this case (without insulator), temperature data at 10mm is discussed. In other cases (with insulator), this is not discussed since our main focus is on raw material temperature.

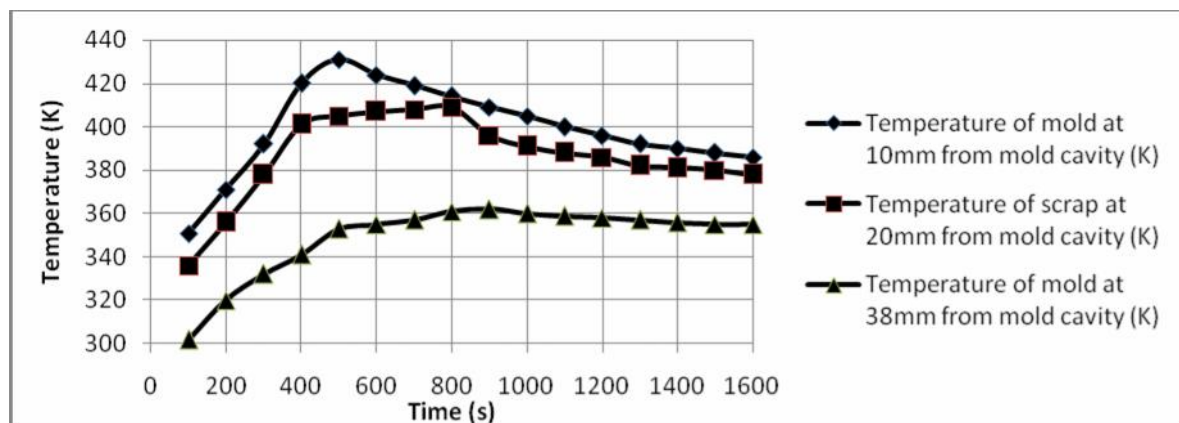


Figure 5 Temperature Rise Trend Line for Scrap-Mixed Mold without Insulators

There are ways of mathematically explaining this phenomenon, but since that is not the focus of this paper, mathematical explanation is restricted to the following governing equation for solidification of a casting which is the conservation of energy equation written in its advection-diffusion form⁸:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(K \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(K \frac{\partial T}{\partial z} \right) + Q' \text{-----} (1)$$

Where,

ρ – density, (kg/m³)

C_p – Specific heat capacity, (J/kg – K)

K – Thermal conductivity (W/m – K)

T – Temperature, (K)

t – Time, (s)

Q' – Inner heat source = $\rho L \frac{\partial f_s}{\partial t}$, (J/s – m³)

L – Metal latent heat, (J/kg)

f_s – Metal – to – solid fraction

From this equation, we can understand that the heat transfer is primarily a function of density, thermal conductivity, enthalpies, and temperature gradient. Since the thermal conductivity of the metal and sand is temperature-dependent, the resulting temperature distribution is non-linear.

3.2 Results of experiments on scrap-mixed mold with insulators

Now, to minimize the escape of heat from the scrap into the sand past it, fiber glass wool insulator of various thicknesses are wrapped around them during molding. Initially a single slab (40mm), then a double slab (80mm) and then a triple slab (120mm) insulation is used to understand the thermal behavior of the mold. A single slab insulated mold is shown in the Figure 4. With each of such set-ups, metal is poured, temperature readings are recorded and analyzed in this section. Figure 6 presents the results of the experiment with single slab insulator.

Because of the usage of insulators, the heat leakage beyond the scrap has reduced and as a result, the amount of heat trapped has improved. The peak temperature achieved by the scrap in this enhancement is 423 K as against 409 K in the previous case, without insulators. This is useful from the standpoint of energy conservation. Another use of reduced heat penetration into sand is reduced sand temperatures (from 362K to 351K), which is very useful in improving the recyclability of the sand and reduction of emissions from sand burning, which is a phenomenon common in foundries. This sand burning causes pollution, discomforts workers and also increases sand consumption rate, which means an entire gamut of things to get sand from the source to the destination-an activity that causes pollution in the entire life cycle.

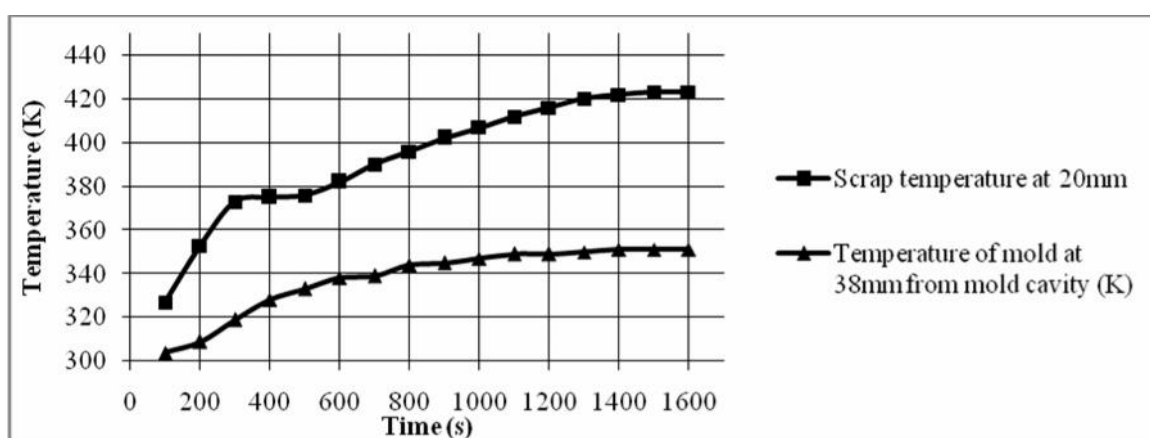


Figure 6 Temperature Rise Trend Line for Scrap-Mixed Mold with 40mm Thick Insulator

Now, the insulator thickness is increased to 80mm. The results are shown in Figure 7. Because of the increased thickness of the insulator, there is a further increase in the heat entrapment by the scrap (from 423 K to 432K) and reduced heat leakage into the sand across the insulator (from 351K to 339K), furthering the cause of sand conservation, emissions reduction and recyclability.

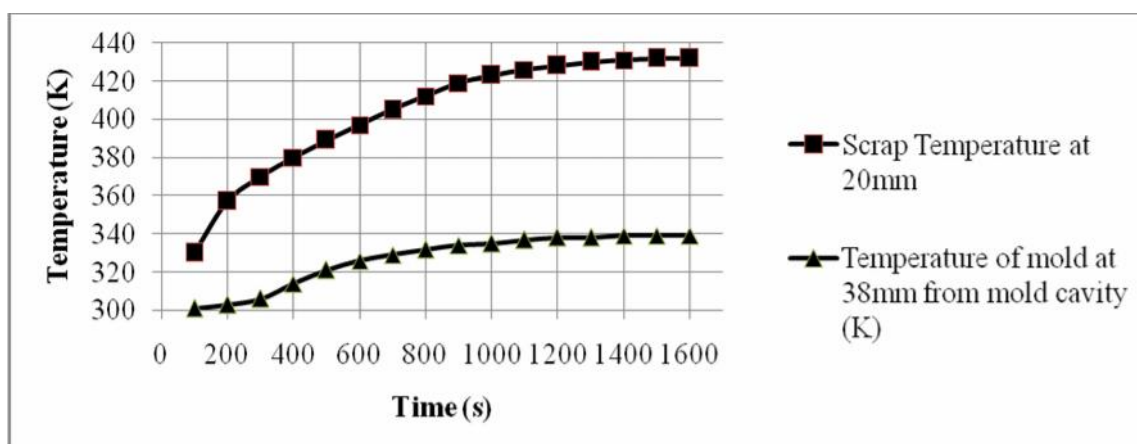


Figure 7 Temperature Rise Trend Line for Scrap-Mixed Mold with 80mm Thick Insulator

Now, there could surface a question as to how much should the insulator thickness be, to be satisfied with the waste heat recovery and sand related emissions. There is no single answer for this question, since the parameters involved are many, necessitating some experiments on a case-to-case basis to ascertain an economic thickness

of insulator. Even though there are some mathematical equations for optimum insulation thickness, they generally deal with temperature characteristics that are different from casting. Key developments in insulation optimization include: mathematical models for arriving at optimal thickness⁹, Complex Finite Fourier Transforms based insulation thickness optimization¹⁰, optimization based on life cycle assessments¹¹...etc. They can't be applied to this research since the heat flow is transient and also the insulation gets compressed during molding, making its final thickness uncontrollable, even though initially we have control over it. This paper does not deal with all those complexities, but gives the reader an idea about the relationship between insulator thickness and thermal behavior in a typical sand casting of Aluminium for 3 different insulator thicknesses.

Now, the scrap is wrapped with 3 slabs of fiber glass insulator to the total thickness of 120mm and mold is prepared with this scrap. Molten metal is poured into the mold and readings are recorded and plotted as shown in Figure 8.

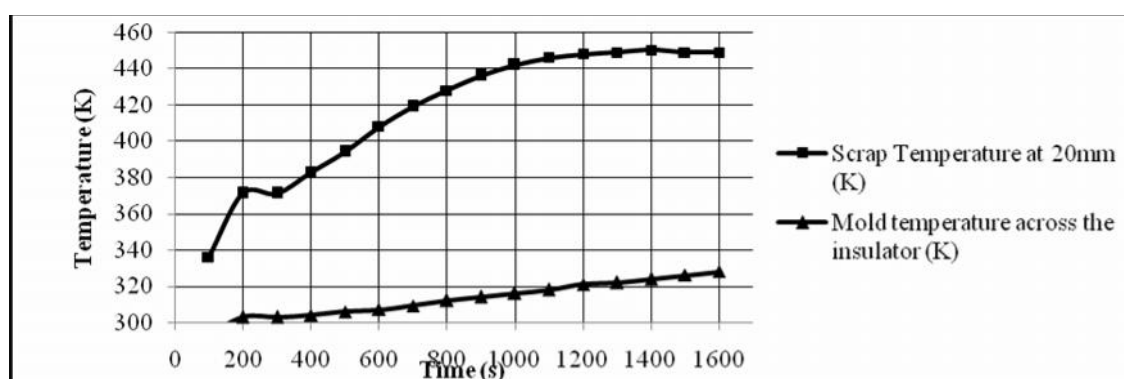


Figure 8 Temperature Rise Trend Line for Scrap-Mixed Mold with 120mm Thick Insulator

Because of addition of one more insulator slab, all the effects discussed previously-such as improved heat recovery, minimized heat leakage, minimized damage of sand and emissions...etc. have been enhanced. The peak temperature achieved by the scrap has improved to 450K. Even though there are advantages from the energy and environment point of view, further increasing the insulator thickness weakens the mold since the mold sand is separated from the central cavity and the scrap by a considerable distance. Authors' practical experience shows that beyond 120mm, preparation of mold becomes very difficult. For this reason, optimal value is set at 120mm. Here, we can observe that moldability overrules mathematical models and equations cited above. Of course, if molding methods improve, more insulation thickness could be allowed.

4 Energy, Economy and Environmental savings by the proposed method

For each of the case discussed above, savings in energy, economics and environment can be assessed. Let us calculate the energy needed for molten metal preparation and energy recovery for each insulation thicknesses, starting from without insulator and finally analyze the economics and environment related parameters for the best case.

4.1 Energy required for preparing the molten metal for pouring

From the basic thermodynamics equations[12], it can be calculated as follows:

$$E = mc T_1 + mL + mc T_2 \text{ ----- (2)}$$

L = latent heat of fusion

T_1 = difference between the melting point and initial temperature of the aluminium

T_2 = difference between the maximum temperature to which the metal is raised for pouring and the melting point

Density of aluminium = 2,700 kg/m³

Volume of molten aluminium used (with 70% yield) = 400 × 10⁻⁶ m³

Mass of aluminium. m = density × volume = 1.1 kg

Specific heat of aluminium, c = 897 J/kgK

Energy required for melting aluminium, $E = 1.1 \times 897(933 - 300) + 1.1 \times 3.98 \times 10^5$

$$+1.1 \times 897 \times (1,003 - 933) \\ = 1131.5 \text{ kJ}$$

4.2 Energy recovery without insulation

Based on the peak temperature acquired by the scrap (409 K) in the case without insulation,

Maximum energy recovery, $Er_1 = mc \Delta T$. (Here ΔT is the difference between peak temperature of scrap and room temperature)

$$= 1.1 \times 897 \times (409 - 300) = 107.5 \text{ kJ}$$

$$\text{Percentage energy recovery} = Er_1/E = 107.5/1131.5 = 9.5 \%$$

4.3 Energy recovery with 40mm insulation

Here, the peak temperature acquired by the scrap is 415 K (from Figure 6)

Using this, maximum energy recovery, $Er_2 = mc \Delta T$

$$= 1.1 \times 897 \times (423 - 300) = 121.36 \text{ kJ}$$

$$\text{Percentage energy recovery} = Er_2/E = 121.36/1131.5 = 10.72 \%$$

4.4 Energy recovery with 80mm and 120mm insulation

Applying the peak temperature acquired by the scraps as 432 K (from Figure 7) and 450 K (from Figure 8), we can get 130.24 kJ and 148 kJ respectively for 80mm and 120mm insulators. This amounts to 11.5% and 13% of energy savings, respectively. If 13% saving is in the scrap, it will translate to 21% savings in the electricity to melt the scrap since furnaces operate at around 60%

4.5 Total energy saved for world's total casting production

Extending this savings to the world's total production of 91,673,839 tons of castings in 2010 [13], we can get a cumulative saving of 6111589267 kWh. Actually, if we optimize this technique by keeping the scrap closer to the cavity and improving the molding methods to increase the insulator thickness, the savings will improve considerably.

4.6 Economics of this method

For a small casting (75X75X50 mm), if we apply this method, we could achieve 148 kJ with 120 mm insulation. For current costs of insulator at Rs.25 per m², flask level breakeven can be achieved in just four castings of the shape mentioned above. This kind of simple but novel method of waste heat recovery and scrap preheating does not require any major infrastructural investment in foundries, except one extra flow line and a few extra labors. Such minimal investments and savings as high as 21% will definitely amount to pay back periods of less than one year if implemented in industries. In one of the industries in Coimbatore in India where this method is being experimented for cast iron castings, savings to the tune of 25% could be achieved. Their electricity bill is Rs.7.5 millions per month; they also suffer very frequent power cuts. If this method is perfected and applied, it will save around 2 million rupees a month to them. For each kWh saved in the user end, there is around 1.25 kWh saved in the power plant, considering transmission and distribution losses[14]. Hence savings are multiplied. These figures give definite impetus to promote such conservation approaches so that government need not invest trillions of rupees on dangerous power plants such as nuclear (which is being massively planned in India right now, when the world is wary about it)

4.7 Environmental impacts of this method

Energy saved by simple conservation methods is always beneficial to environment since it readily cuts down the emission at the production plant. To exactly assess the ecological foot print for conservational methods is a bit complex process, since it involves many factors such as exact generation mix and accurate accounting of emissions in each method of energy generation. Many works have been done in this regard: Resource input-output methods[15, 16], Componential methods with wider accounting[17]...etc. These methods also take into account a particular country's energy generation mix and land use characteristics. Considering the limited scope of this paper in this regard, one of the generic carbon foot print calculators[18] is used to calculate the impact of this work on emissions. This calculator shows that for the total amount of electricity savings of 6111589267 kWh, savings in CO₂ emissions would be around 2627983 tons and offset in the number of trees planted would

be around 15767900. We can extend this to other resources such as land and water, shedding more light on the usefulness of this work.

5 Conclusion

From the studies conducted in this paper, the proposed approach of scrap preheating from the waste heat of solidification proves to be one of such solutions. Even with basic experiments, the potential for energy savings to the tune of 21%, which accounts for 6112 million units of electricity, was perceived by using this method. On economical front, a simple breakeven analysis shows that flask level breakeven point of just four products and additional benefits in sand conservation and emission reductions have been observed. Such a method with multi-faceted benefits did not demand for a massive infrastructural investment. On the environmental front also the benefits offered by this method has been tested: this method can minimize 2627983 tons of CO₂ emission. This means offsetting plantation of 15767900 trees. It was tested in two industries in Coimbatore, India, where the management felt that such solutions are necessary for the current Indian scenario of frequent power cuts in industry. With some more refinements in molding, this method can be actually implemented. There are challenges to bring it to full-fledged industrial practice and efforts are underway to resolve them. The world is undergoing a transition from the days of cheaper energy that was abundant to the days of energy scarcity and energy-related environmental problems, leading to unsustainability of the planet. In such a situation, it is most urgent and important to promote simple and innovative solutions of energy conservation that requires fewer resources and saves more.

Acknowledgement

This work has been registered for patent under the ownership of Amrita Vishwa Vidyapeetham. The first author of this paper is the patent inventor; patent registration number: 3215/CHE/2010.

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