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Reduction of sand handling energy consumption and emissions in foundries by an innovative approach

J.Selvaraj, Dr. K.I.Ramachandran, S.Devanathan, P.Sathish kumar.

ABSTRACT:
The green sand casting process constitutes upwards of 90 percent of the molding materials used[1] and estimates are that less than 15 percent of the 6-10 million tons of spent foundry sands generated annually are recycled. The recycling of spent foundry sand can save energy, reduce the need to mine virgin materials, and may reduce costs for both producers and end users[2]. Hence this paper seeks to conserve energy and natural resources by applying an innovative method of making sand molds by embedding raw materials (virgin/scrap) around the mold cavity in such a way that the raw materials displace sand, absorb waste heat from molten metal, minimize sand temperatures and thus conserve sand quality and quantity. Various experiments conducted for this research show that more than 200 °C temperature reduction in sand is achievable by this method, apart from energy conservation in furnace, which is a side benefit. When sand temperatures are reduced by the presence of raw materials which absorb the heat, it paves way to reduce the mold emissions are improve sand recyclability. Reduced temperatures of sand also reduce the cooling system power requirements. The method has been registered for patent.

Key words:
Innovation, metal casting, sand recycling, mold emissions, energy conservation.

1 Introduction

1.1 Conventional sand casting Process

Sand casting is one of the most common manufacturing processes used around the world for making discrete products. A typical process flow of sand casting is shown in **Error! Reference source not found.**. The salient points of the flow chart are as follows:

- For metal preparation, Raw materials (virgin and scrap metal), flux and additives such as alloying elements, coagulants...etc are mixed and heated by furnace to get the molten metal
- Sand, binder and additives are mixed and molded with a pattern and core (to provide for internal voids).
- Molten metal is poured into the cavity in the mold, cooled in the mold and then removed after solidification. Sand is reclaimed for the next batch of molding.
- Solidified castings removed from the mold are sent to fettling shop for cleaning (degating, shot blasting, parting line removal by grinding...etc).
- Heat treatment for relieving the thermal stresses, to gain uniformity of mechanical properties...etc follows. This step is optional.
- Finally the product is cleaned, painted and shipped.

1.1 Sand in Mould.

Sand is used as a refractory material in sand moulding systems. There is a wide range of sand/binder systems that are used in sand casting. Bentonite clay is used upto 4-10% of the sand mixture in Green sand systems. Water, is added (2-4%) to activate the clay. Carbonaceous material such as charcoal (2-10% of total volume) is also added to the mixture to prevent the metal from oxidizing while pouring. Rest of the composition is silica. The raw sand is obtained from seashore and riverbeds. During the molding process the sand forms the outer shape of the mold cavity. In the casting process, molding sands are recycled and reused multiple times. Eventually, repeated mechanical abrasion and heat from the molten metal makes the recycled sand degrade to the point that it can no longer be reused in the casting process.

At that point, the old sand is displaced from the cycle as, new sand is introduced, and the cycle begins again. In this paper, a new method is proposed to minimize the heating of the sand and associated thermal degradation. By achieving this, recyclability of the used sand is improved. Even though a similar work to recover heat from solidifying molten metal has been attempted in the past[3], it is in continuous casting, whereas this paper focuses on discrete casting in sand mold **Error! Reference source not found.** shows how sand is molded into a flask in conventional method. The lower portion of the flask is known as drag and the upper part of the flask is known as cope. In this figure, photo has been taken after pouring is done, metal solidified in the cavity and then the two halves of the flasks (drag and cope) are separated;n this figure, we can see the solidified product on cope part and the cavity on the drag part, which carried the molten metal till it solidified. The amount of sand used for this mold is around 23 kg.

To reduce the thermal damage of sand and resulting reduced ability for recycling, the proposed method routes the raw material to the furnace through embedment in the mold. This covers heat recovery, preheating, prevention of thermal degradation of sand…etc. Figure 3 delineates the proposed method with more emphasis on sand flow lines. In this self explanatory figure, the raw material routing (shaded blocks) is the new feature, which does not exist in any conventional sand casting.

Error! Reference source not found. shows the experimental set up consisting of conventional molding flask with thermocouple wires inserted in the drag portion to measure the temperature. This is necessary to compare the temperature distribution in conventional method and temperature distribution in proposed method.

mould cavity was 0.075 × 0.075 × 0.056 m. The cope dimensions are similar to that of drag. Aluminium scrap for mixing with the raw material and for molten metal preparation was of LM 25 Grade. Pouring temperature was around 980K. The metal was melt in a crucible furnace with a range upto

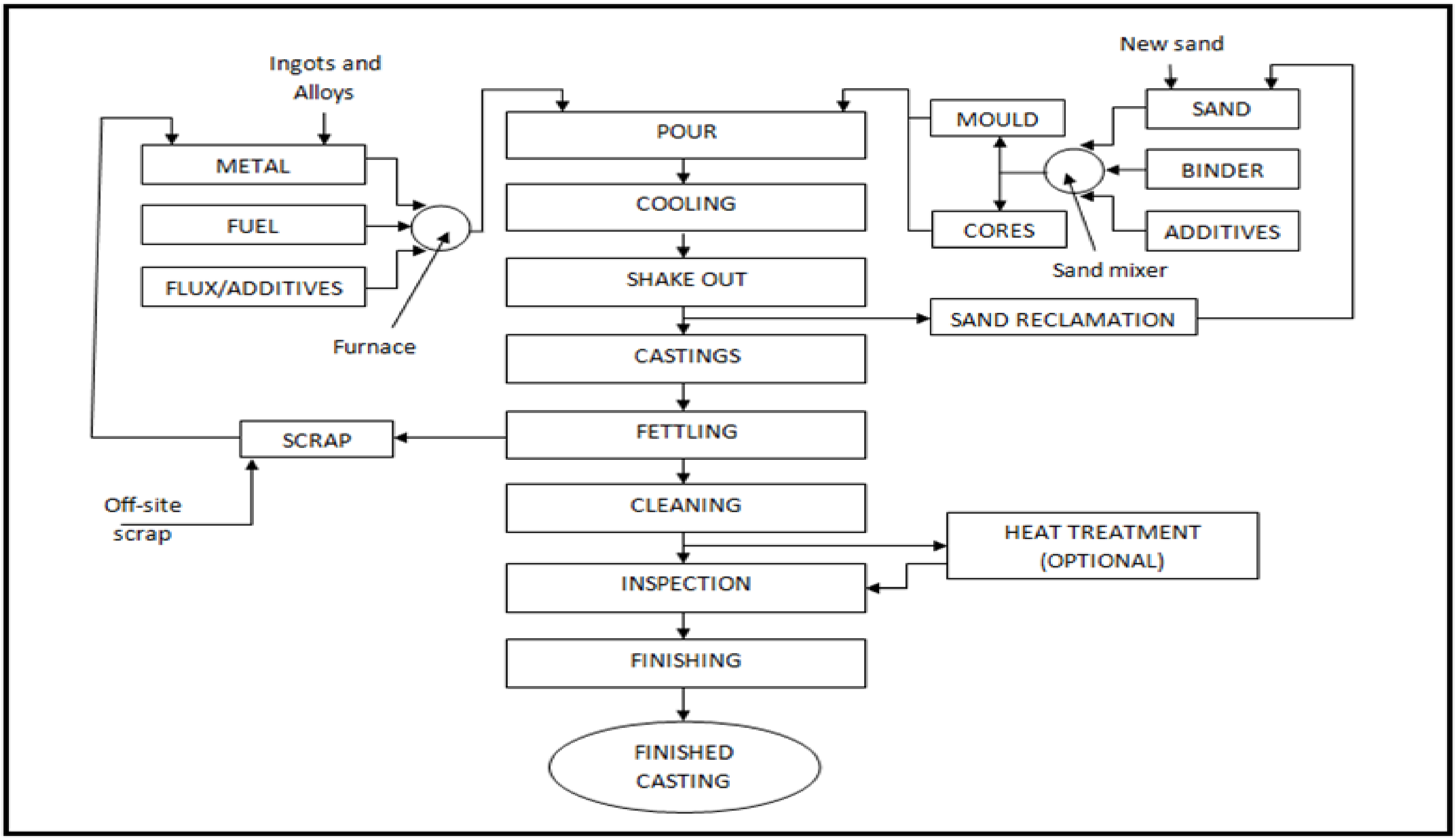

Figure 1 Flow diagram for conventional sand casting

Now, as per the proposed method, raw material scrap is mixed with the sand in the drag portion and molding is done in such a way that the scrap is close to the cavity. Closer is better in terms of heat recovery, but the mold wall gets weaker if the raw material gets very close to the cavity; in our practical experience, we could achieve only 10 mm offset distance between raw material and mold cavity. Figure 5 shows the experimental set up of the proposed method.
There is also a refinement in the proposed method: wrapping the raw materials with insulators so that the heat leaking from the raw materials is reduced enabling improvement in sand cooling, minimization of sand damage and also enhancing waste heat recovery. This set up is shown in Figure 6. The dimension of drag was 0.31 × 0.31 × 0.09 m and the mould cavity was 0.075 × 0.075 × 0.056 m. The cope dimensions are similar to that of drag. Aluminium scrap for mixing with the raw material and for molten metal preparation was of LM 25 Grade. Pouring temperature was around 980K.

The dimension of drag was 0.31 × 0.31 × 0.09 m and the

Figure 2 Sand packed into a flask in conventional method.

1200°C. K- type thermocouples were used to measure the

temperature. Fiber glass insulator pads of 40 mm thick were used.
Multiple experiments, using multiple layers of insulators were done, but what is reported in this paper is the results of experiments using an insulator of 120mm thick, compressed to around 10 mm upon molding. This mold requires around 21 kg of sand. The reduction in sand is due to the displacement by raw material and insulators.

2. PROPOSED METHODOLGY AND EXPERIMENTAL SETUP

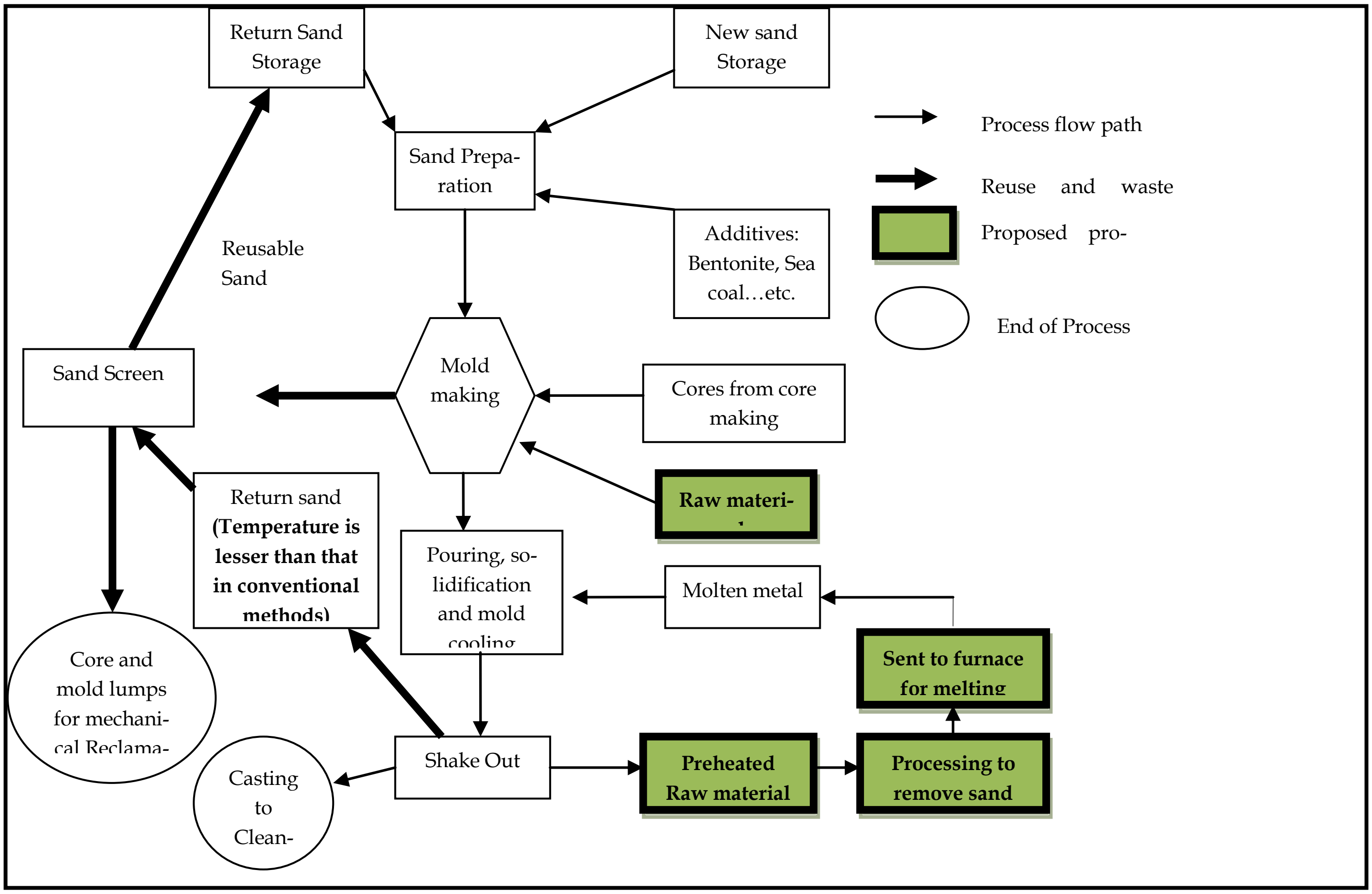

Figure 3 Proposed system of raw material incorporation in sand mold

3. RESULTS AND DISCUSSION

Experiments were conducted to investigate the viability of the proposed method to absorb heat from molten metal by using Aluminium raw materials. The experiments show a clear proof that there are multiple advantages in this proposed method: a) sand beyond the raw material is protected from heat, thus enabling better recyclability, b) waste heat recovery is achieved and c) minimization of sand emissions is possible.

3.1 Results of experiments in conventional method of casting

Experimental result in conventional molding is shown in Figure 7. In this graph, we can observe that the peak temperature at 10mm near the cavity is 638K and is achieved in 500s from the time of pouring. As we go farther along the mold, away from cavity, which is the source of the heat, we can observe reduced temperature due to the fact that sand is offering resistance to heat along its length. The temperatures obtained are on par with similar experimental results of the past research in this field[4, 5], as far as the conventional method is concerned.
The governing equations to the transient heat transfer into sand mold can be written as follows[6]:

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

Where,
$\rho - density, (\mathrm{kg/m^3})$
C_p – Specific heat capacity, (J/kg – K)
$K - Thermal\ conductivity (W/m - K)$
$T - Temperature, (K)$
$t - Time, (s)$
$Q' - Inner\ heat\ source = \rho L \frac{\partial f_s}{\partial t}, (J/s - m^3)$
$L - Metal\ latent\ heat, (J/kg)$
$f_s - Metal - solid\ fraction$

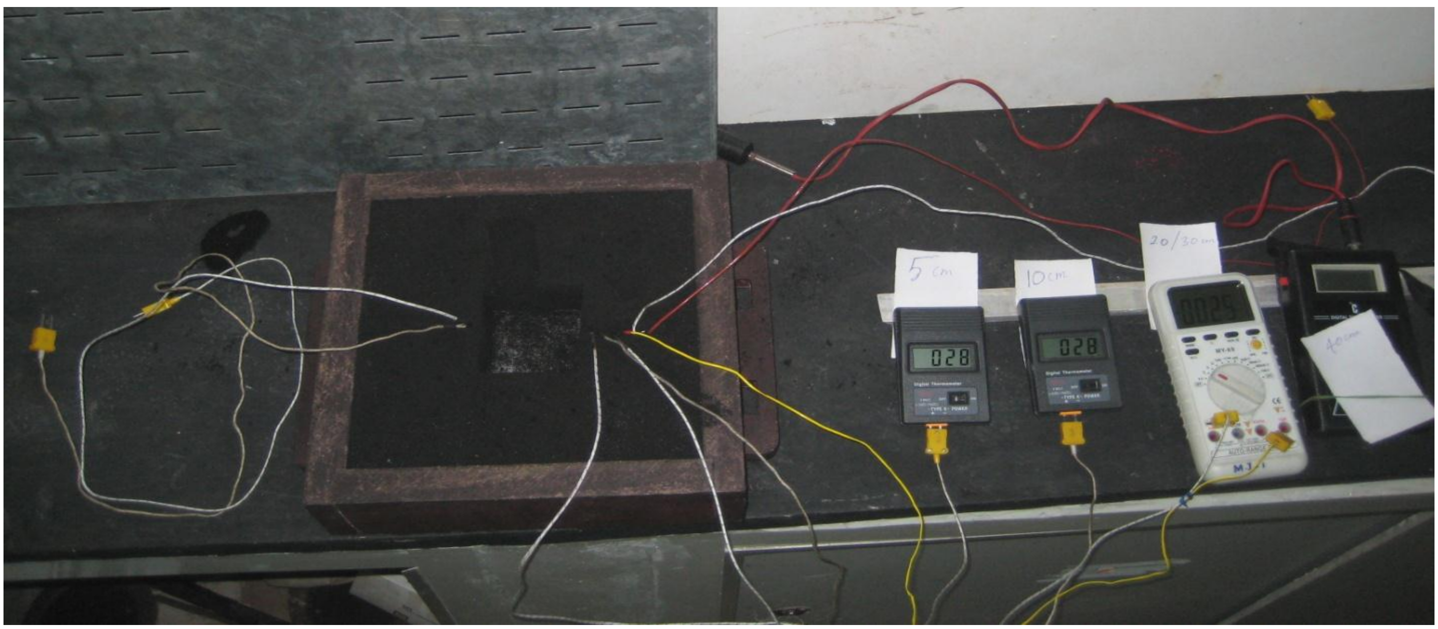

Figure 4 Experimental set up to measure the mold sand temperature in conventional method.

From this equation, we can understand that the heat transfer is a function of thermal conductivity, temperature gradient, density of the molten metal, latent heat of solidification of the molten metal...etc.

3.2 Results of experiments in the proposed method of casting without insulators

Temperature distribution results for the mold with raw materials around the cavity is shown in the Figure 8. It should be noted here that sand is present in the mold till 10mm from cavity and then raw material starts; raw material ends in 30mm from mold cavity, then starts insulation layer, which extends upto 38mm. For these reasons, temperature sensors were kept at 10mm and 38mm. The temperature sensor at 20mm indicates the temperature of raw material scrap. In Figure 8, even though there are no insulators, temperature at 28mm gives mold temperature beyond raw material. Similarly, in Figure 7, even though, there are neither raw materials nor insulators, the temperature at 20mm and 38 mm give the values of mold temperatures. These are helpful to compare in case there are raw materials and insulators.

Compared to temperature distribution history in conventional mold (Figure 7), the proposed mold's temperature distribution characteristics(Figure 8) show a lower peak temperature for sand inside and outside raw material scrap. This is exactly what we wanted: to reduce sand temperatures by absorbing the heat energy of molten metal in some useful ways. As a side benefit (this is actually a main benefit from the point of view of energy conservation), the raw materials that were mixed with the sand have recovered the waste heat of solidification: their temperature has raised upto 409K. These raw materials can be sent to furnace to prepare molten metal for subsequent pouring.

This pouring also will be done in the molds which carry raw materials around their cavities. In this way waste heat recovery, reduction of sand temperature and improvement of recyclability of sand takes place simultaneously. This proposed method can be enhanced by incorporating insulators around the scrap so that heat leakage from the scrap into the molding sand that is beyond the scrap is minimized and heat recovery is improved. Results of that experiment are shown in the **Error! Reference source not found.**

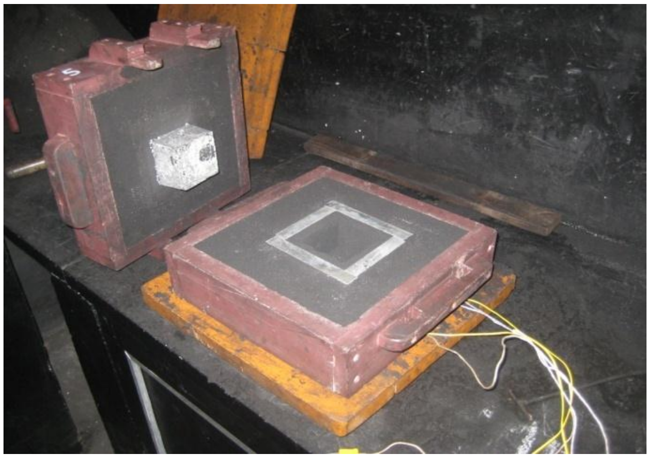

Figure 4 Experimental set up with drag portion of the molding flask embedded with raw materials around the mold cavity

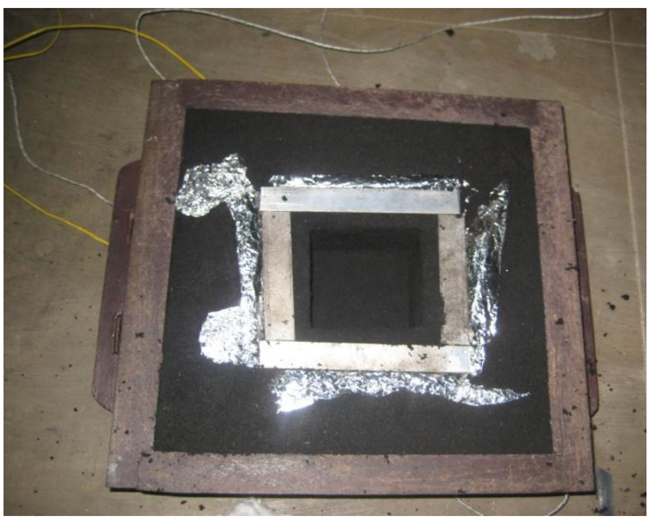

Figure 6 Refinements in the proposed method: Insulated scrap for better sand recyclability.

Because of incorporation of insulators, two interesting phenomena have happened: a) the temperature of the sand beyond the insulators (on the flask's frame work side, farther away from cavity) has further dropped (to 328K) when compared to the case without insulators (362K) and b) the temperature of the sand between the cavity and raw material, which starts at 10mm has increased marginally from 431K to 486K. So, it seems that insulator addition is likely to cause damage to sand in the vicinity of the cavity. But we have to analyze the whole thing from a broad picture. To do that analysis, let us construct a summary table of peak temperatures of all these cases, as in Table 1, which is just the essence of the graphs we have discussed so far.

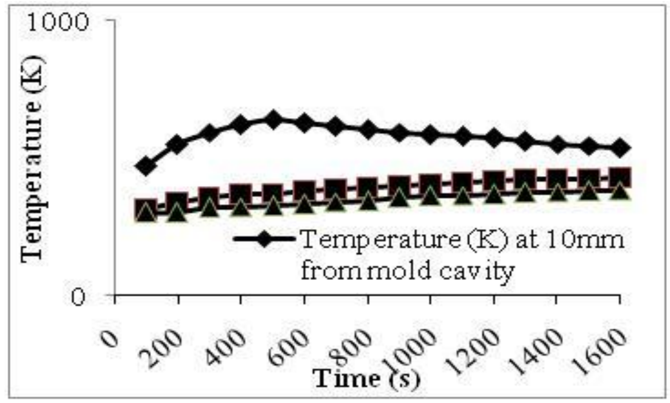

Figure 5 Temperature distribution results in conventional mold (without raw materials in mold)

In this table 2, let us focus mainly the shaded areas since they give the essence of the graphs. We can infer that in the conventional method of molding, the peak temperature achieved by the sand within the confinements of raw material and cavity wall is 638K; this was measured at 10mm from the cavity wall. Of course, if we measure closer to the cavity, the temperature will be higher, but still this measurement is sufficient since we are only making a comparison. The volume of the sand in this confinement is calculated as 190400 mm^3 (based on pattern size of 75X75X56mm and the offset distance of 10mm). This sand's temperature dipped to 431 in the proposed mold without insulators. The reason for temperature fall in the proposed method is because of the presence of raw materials that absorb heat very quickly due to their higher thermal conductivity than that of sand. When the proposed method was further advanced by inclusion of insulators, the temperature in the sand between cavity and scrap rose from the previous case to 486K. The reason for higher temperatures in the sand near cavity in the case of insulated mold is because of the insulators (their thermal conductivity being lowest of all the materials present in the flask), confining heat flow from the raw materials. Insulators have done some damage only to this small amount of sand that is within the raw material and cavity.

Let us analyze the sand outside the raw material and confined within the flask's framework. The volume of the sand is 8636735 mm^3. This is calculated based on the overall dimensions of the flask: 310X310 mm, excluding the volume occupied by the raw materials and insulation. The temperature in this volume in the conventional method is 383K and the proposed method without insulators is 362K and with insulators, it dips to 328K. So, placement of insulators has done major good to this sand of higher volume- at least by 45times! Hence from the overall analysis, it is better to use insulator pads.

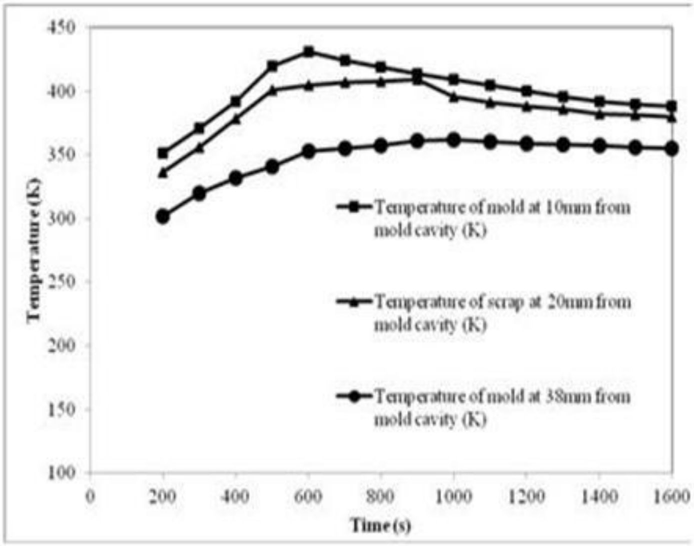

Figure 6 Temperature distribution results in the proposed mold (with raw materials in mold, without insulators)

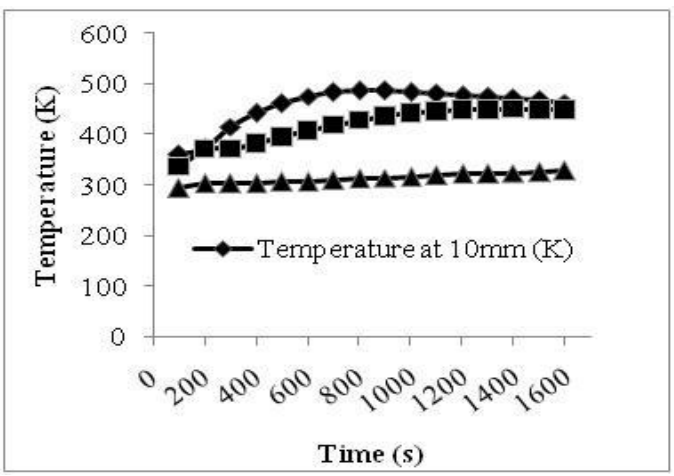

Figure 7 Temperature distribution results in the proposed mold with refinements: Insulators incorporated.

Another important aspect of this work is energy conservation by waste heat recovery. From that angle, the recovery without insulators is only 109K, whereas it is 150K with insulators. Hence, insulators are preferred for that reason also.

4.ADVANTAGES AND LIMITATIONS OF THE PROPOSED METHOD

By this method, improvement in sand recycling is achieved since the sand is heated less. Even though at this stage of research we could not clearly pinpoint- in quantitative terms- about the improvements in recyclability of sand, literatures[7] report that bentonite deterioration starts at temperatures as low as 100 °C. In the Environmental Performance Guide [8] that was prepared for the Environmental Technology Best Practice Programme by Castings Technology International it is reported that; the presence of overheated clay and variable sand temperatures make it very difficult to achieve the optimum sand properties. Hence, if sand temperature variations are maintained minimally, it saves sand's molding properties and recyclability.

If the sand temperature is less, it also helps in reducing the work by the sand preparation plants to cool them down before next molding starts. This translates to enormous energy conservation in foundries. For example, a small sand preparation plant operating at 20-40 tons per Hour will have to spend around 20 units of electricity per hour just to cool the sand[9, 10]. Cumulatively, when accounted for all plants throughout the year, it will be a huge number. Hence, if the proposed technique is used, this sand cooling unit can be completely dispensed with.

The sand mining, transportation and handling (loading and unloading) are environmentally very detrimental. Sand mining severely disturbs the marine and river eco system, as reported by many[11, 12]. Specific problems are listed as under: Destruction of natural beaches and the ecosystem they protect, Loss of habitat for globally important species, Increased shoreline erosion rates and reduced protection from natural events (ocean disasters) and economic losses from tourist abandonment. Hence, this work helps preservation of natural resources that are key to environmental sustainability. Some more environmental advantages are approximately calculated in the following paragraph:

Sand transportation, loading and unloading using vehicles and mechanised equipment is contributing to CO_2 emissions. Let us make a brief assessment: if the case of Coimbatore alone is considered where 30000 tons of castings are produced every month, a simple estimate shows that every year, 186 Million tons of CO_2 emissions can be saved in transporting all the sand from Cochin to Coimbatore through trucks.

This method was experimented in an industry (Unicast Alloys (P) Limited, Pollachi, India) to evaluate its functioning in cast iron foundry environment. Since it was only a simple implementation, only the economic benefits from energy are analyzed as follows: When raw material embedment technique is implemented, there is s saving of 245 kWh per ton, which amounts to a cost saving of Rs. 1470. For the monthly production of 400 tons, this turns out to be Rs. 588000 and yearly savings would be to the tune of Rs. 7056000.

Investment required for implementation is analyzed as follows: The proposed method needs one extra flow line with trolley or conveyor for transporting the scrap. For the industry's layout, it needs about 225 feet length of rail guided trolley travel between the scrap yard and furnace. Implementation of a suitable material handling system consisting of structural frameworks for rails, purchase/fabrication of rail guided trolleys, purchase of electromagnetically operated cranes for loading and unloading the scrap, conveyor for transporting preheated scrap, etc would cost around 45 lakh rupees. Scrap processing station (a hydraulically operated bundling machine with tooling) would cost around 11 lakh. This totals to Rs. 56 lakh. These are all fixed costs. Variable costs include electricity charges for the cranes and bundling machines, extra man power charges for scrap handling and embedding, annual maintenance charges, etc, which comes to the tune of 10-12 lakh per year. Totaling both fixed and variable costs, it is around 67 lakh rupees. So, in the very first year of the implementation of this technique, the industry incurs a loss of around 67 lakh and a gain of around 70 lakhs. So, it can be concluded from this simple analysis that the payback period is less than a year. Of course, it is very simplified analysis without considering factors such as interest for the investment, depreciation, etc. But it is apparent that even if those factors are considered, the pay back can't go beyond 2 years, which is an attractive number for such industries.

Many foundries transport sand from Gudur, Andhra (which is more than three times longer than to Kochi). If we actually calculate costs and emissions for this case, it would be much more than what has been reported here. Other advantages include prevention of silicosis which is related to sand handling[13], savings in respiratory problems due to minimized coal dust [14].

Limitations of the proposed method primarily include some investments in the equipment in the foundries to incorporate raw materials in the mold. This necessitates an extra flow line with flask trolleys and a few extra labors; but their investment is much less compared to the benefits from minimized electricity bills and sand bills. A rough estimate made in the energy conservation research by the same author[15] proved that the breakeven could be achieved in around one year time.

Although the increasing energy crisis, emissions and biodiver

sity loss cause significant concern for the world, the foundry industry continues to maintain its status quo in inefficient resource utilization and efforts are still slow towards exploring the possibilities of innovative ways of conservation of resources such as silica sand, furnace energy resources and minimize the life cycle emissions and costs in various operations in the foundries. This is in contrast to the importance of innovation for sustainability of firms- a well acknowledged fact shown by many studies, such as the one in Netherlands[16]. The proposed method of minimizing the sand temperature by incorporating raw material scrap into the sand molds and absorbing heat of molten metal in a productive way has proven to be advantageous in so many ways: minimized sand temperatures, better sand recyclability, reduced mold emissions, reduced sand demand and associated savings in life cycle cost and environmental impacts. Even though all the claims could not be quantitatively verified, proof of concept on qualitative terms has been made. Considering the increasing problems in the environmental front in the form of resource depletion, emissions and ecological imbalances in marine and river ecosystems, this method is found to promise a solution to mitigate these problems and to reduce costs in foundry sector. This is apart from other advantages that accrue through energy conservation by extracting the waste heat. This work has given sufficient reasons to actively pursue further research to quantify all the claims to estimate viability in all its dimensions. As the study quoted above emphasizes on innovation for small and medium enterprises for survival, it is appropriate to promote such innovations in foundry sectors which are dominated by SMEs

Table 1 Summary table of results for peak temperatures.

S.No	Type of molding	Peak temperature achieved by the mold at 10mm from mold cavity (K)	Time of peak temperature achievement (K)	Peak temperature achieved by the mold at 38mm from cavity (K)	Time of peak temperature achievement (K)	Temperature reduction in sand by the application of the new method (K)		Scrap temperature gain, for the room temperature of 300K , (K)
						Between the cavity and raw material	Beyond the insulators	
1	Conventional mold	638	500	383	1600 (still on rise)	NA	NA	NA
2	Proposed method without insulators	431	600	362	1000	**207**	**21(still improving)**	109
3	Proposed method with insulators	486	800	328	1600	**152**	**55**	150

5. CONCLUSION

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7. PATENT:

A patent titled, 'Heat recovery process in metal casting' has been registered under the ownership of Amrita Vishwa Vidyapeetham during October, 2010. The first author of this paper is the patent inventor. The patent is about an innovative approach to waste heat recovery from solidifying molten metal in sand casting and using that recovered heat to preheat the incoming raw materials. Patent registration number: 3215/CHE/2010.