# Energy Saving and Performance Improvement Opportunities in Small Scale Foundry

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**Abstract** - *In foundry industry, energy accounting is necessary to determine where and how energy is being consumed and how efficient is the energy management system. There are many opportunities for improving energy efficiency in most foundries. Some of these, such as optimizing the efficiency of ancillary services can be achieved at minimum cost and make a valuable improvement to the bottom line. Reports from many foundries suggest that energy efficiency is one of the most significant cleaner production options still to be addressed in the industries. The study reveals that the two thirds of the energy consumed in a foundry are used for metal casting and holding operation. Considerable energy saving can be achieved by proper attention to this process with proper energy management. This paper gives an idea of the current energy consumption of the foundries, which can be compared with standard norms and can be used to implement in Indian foundries.*

***Key Words***: **ANOVA, heat losses and energy consumption, energy consumption pattern, Energy Management etc.**

## 1. INTRODUCTION

Energy is the primary and the universal measures of all kinds of work by human being and nature. Electrical energy is a high-grade energy in all sorts of energy available in nature. Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. Areas of application of energy conservation are power generating station, transmission and distribution system, consumer's premises. Steps are to be taken to enhance the performance efficiency of generating stations. Energy conservation technology adopted in transmission and distribution system may reduce energy losses, which were in tune of 35% of total losses in power system. Acceptance of energy conservation technology will enhances the performance efficiency of electrical apparatus used by end users. Implementation of energy conservation technology will lead to energy saving which means increasing generation of energy with available source.

## 2. LITERATURE REVIEW

2.1 Konstantinos Salonitis et al. [1] studied the challenges for optimizing the casting processes with regards their energy efficiency was discussed. Casting is one of the oldest, most challenging and energy intensive manufacturing processes. A typical modern casting process contains six different stages, which are classified as melting, alloying, molding, pouring, solidification and finishing respectively. At each stage, high level and precision of process control is required. The energy efficiency of casting process can be improved by using novel alterations, such as the Constrained Rapid Induction Melting Single Shot Up-casting process. Within the present study the energy consumption of casting processes is analyzed and areas were great savings can be achieved are discussed. Lean thinking is used to identify waste and to analyze the energy saving potential for casting industry.

2.2 M.S.Prashanth et al [2] did the research investigates into the possibilities of finding a solution towards reducing the energy wastage in foundries. An energy audit was conducted towards this purpose by identifying key areas, which were compressed air, raw materials and furnace. The audit started by studying the compressed air system. The faults present were identified and remedial measures were arrived upon. The audit then focused on the raw materials where the inventory and raw material usage was studied. Sand wastage was found to be a significant problem, which was tackled by developing and using a new system, which eliminated the problem. The thermal aspect of the audit was then conducted by observing the energy consumption of the furnaces. The energy wastage due to various factors was then quantified and improved designs were created, showing better energy usage. These simple initiatives taken in a small-scale foundry could give rise to cost savings of around 10 Lakh rupees per year and energy saving of 58 MW h. Such initiatives prove that scope for energy conservation in foundries is immense and simple steps are sufficient.

2.3 Dr.Jack Wallace et al.[3] proposed that metal casting industry is one of the most energy-intensive manufacturing sectors with the melting process accounting for over half (55%) of its energy consumption. Although its high-energy expenses have been a significant concern for metal casters, the industry continues to use melting technologies with poor energy efficiency. The purpose of this study is to explore "Grand Challenge" or breakthrough opportunities that might dramatically reduce melting energy and to identify potentially energy-saving R&D areas based on the findings. The study was conducted to guide the Metal Casting subprogram of the Industrial Technologies Program (an initiative of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy) in pursuing its energy reduction goal. The scope of the study includes current and emerging melting technologies in the industry worldwide, along with experimental technologies, retrofits for existing systems, and best practices

2.4 M.Arasu and L.Rogers Jeffrey [4] proposed that energy accounting is necessary to determine where and how energy is being consumed and how efficient is the energy management system. An energy accounting method should define the areas of high-energy use, energy waste and should point out areas in which energy saving can be accomplished. To arrive at the energy consumption pattern is the main part of the energy audit process. Energy pattern can be used to understand the way energy is used in a foundry and helps to control energy cost by identifying areas where waste can occur and where scope for improvement may be possible.

2.5 A. N. Makarov et al. [5] calculated data for the relation between the energy technological parameters and the electric energy consumption and the measures took to decrease the consumption of energy resources for the manufacture of electric furnace steel in electric furnaces operating with scrap, hot briquetted iron, and pellets and in electric furnaces operating with scrap and liquid cast iron.

2.6 Somnath Bhattacharjee and N.Vasudevan [6] did energy audit at cupola furnace and calculated heat input, heat losses. They had given recommendation for improvement in cupola furnace which include operating practice used for charging, the dimension of cupola well depth. They suggested retrofitting of existing conventional unit with divided blast would result in a coke saving of 25 %.

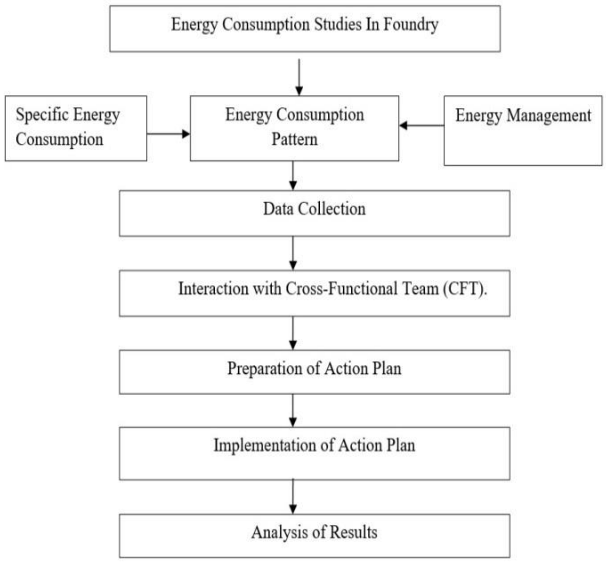
2.7Yu. M. Mironov and V. G. Petrov [7] analyzed dependences of the heat loss power and the energy efficiency of arc steel melting furnaces with a refractory lining on the arc current and length the energy stored in a lining varies cyclically during a heat: it decreases to the middle of the heat and increases during heating of a liquid metal. When the energy balance is analyzed throughout a heat, the energy stored by a lining can be neglected and the heat losses through the lining can be included as irrevocable heat losses. The losses are now calculated mainly using the method of steady state heat conduction through a multilayer-lining wall. For analysis, they developed mathematical model for the interaction of an arc with the environment.

2.8 S. Ravichandran et al. [8] analyzed effect of process parameters for energy conservation in spheroid graphite iron (S.G. Iron) manufacturing in induction furnace. Analysis of variance (ANOVA) is performed to test the statistical efficacy of the model. The use of bundled steel and cleaned scrap is found to significantly reduce the power consumption in induction furnace. The use of unclean scrap with its rust and sand impurities consumes more time for melting and removal of slag. Further, it reduces the lining life of the furnace. Bundled steel and cleaned scrap is major determinants of minimizing power consumption in the induction furnace.

2.9 O. A. Olasupo and J. O. Borode [9] did experimentation on insulating material which consists of clay, silica, mica, bentonite and calcium, aluminate cement. Rammed samples tested for such properties as apparent porosity, volumetric firing shrinkage, and cold compression strength, and green compression strength, loss on ignition, thermal shock resistance and refractoriness. They found eight ramming cycles were just enough for the production of the ramming masses. Two optimal ratios obtained from the experiments have a refractoriness of 15000C, good compression strength and excellent thermal shock resistance.

2.10 S. Wang et al. [10] explained development of the ramming material, recounts its chemical composition, physical property and application characteristics. Because of its high MgO contents and fine sintering property, the ramming furnace bottom has the properties of good refractory, monolithic construction and thermal shock resistance. The development of magnesia ramming material for ferroalloy furnace is based on the use of unshaped refractory used in steel making electric furnace.

## 3. METHODOLOGY




## 4. CONTROL PARAMETERS

4.1 Holding of metal:-Unnecessary superheating of metal to high temperature costs to energy significantly. Depending on final pouring temperature of a component and temperature loss during transfer of metal to pouring zone, superheating temperature should be decided. In every heat metal bath temperature should be measured and monitored to get optimum energy saving.

4.2 Power Input:-Furnace should be run at maximum power since beginning. There are some misconception of running furnace at low tap initially and then gradual increase to higher tap. Maximum power input increases rate of melting and hence reduces cycle time of a heat. Power factor is to be maintained near to one. Drop of voltage from the source also to be monitored for better energy efficiency.

4.3 Furnace lining:-Lining material, thickness and its sintering play important role in energy saving. Thick lining reduces furnace volume and hence the metal output resulting high specific energy consumption. Thin lining, though it improves the power density, promotes heat loss from the sidewall. Lining material with high thermal conductivity causes more heat loss. Lining material with long sintering cycle time consumes much energy for the first heat to get ready. Improper lining causes premature failure. Therefore, it is important to do lining as prescribed by the furnace manufacture to get optimum result for energy consumption. Use of pusher block to remove old lining in place of manual breaking contributes in reducing cycle time of lining hence overall specific energy per MT of liquid metal.

4.4 Transfer of metal:-Once metal is ready for tapping there should not be single minute delay in it. Metal carrying ladles either hanging on crane or vehicle should be ready. After the tapping, there should not be any obstruction in movement of ladle. It is to be ensured that transfer ladle is adequately preheated. It is better to take out metal completely in one go for early start of next heat

4.5 Quality of scrap:-Dirty charge also wastes energy that can be utilized for melting the charge. Sand for example has twice the heat content of iron. Therefore, every kilogram of sand in the charge heated with the metal uses the same amount of energy as it would take to melt two kilogram of iron.

4.6 Buffer stock:-Due to product mix of light and heavy castings, situation arises when rate of metal consumption is less than the rate of metal generation. In such situation, there are all chances of metal held up in furnace causing wastage of energy. It is better to have a holding furnace as buffer stock in between melting and pouring to avoid such situation. Holding of metal also helps in consistency of metal chemistry and temperature through homogenization of metal with some variation coming from melting furnace.

4.7 Scrap charging:-Size of scrap is an important parameter in reduction in energy consumption. The scrap charge should be as dense as possible. Lesser the air pocket between scrap pieces, more is the power density, higher the heat conductivity, faster melting with least energy consumption. It is better to use small pieces of scrap to get optimum result. Weighting of scrap in every heat to maintain proportion of charge mix is required for consistency in quality as well as energy consumption. Scrap should be free from rust, sand etc. to avoid formation of more slag causing heat delay hence high-energy consumption. Scrap should be charged continuously as the melting proceeds. Continuous charging helps in preheating the scrap at the top. For off days furnace should not left empty rather it should be charged to full level to utilize heat content of the furnace.

## 5. EXPERIMENTAL WORK

5.1 Energy consumption pattern

-Power supply-500 KW

-Material- Cast Iron (Ductile, Nodular, Spheroidal CI)

-Capacity- 500 Kg per 40 minute.

-Maximum capacity 5-6 ton per day

-200-220 ton per month

5.2 Electricity consumption -

-To melt 500 kg CI 290-310 kWh electricity required.

-For 1 ton 600 kWh Electricity required.

-In 1 month 220-225 ton CI melts.

-Total consumption for month is 132000-132500 kWh or Units for each induction furnace so total electricity consumption for furnace is 264000 Units (kWh) per month.

Table 5.1 Energy Consumption pattern for Induction Furnace

| Sr. No. | Consumption | Units(kWh) | Percentage |
|---|---|---|---|
| 1 | Furnace | 264000 | 74.45% |
| 2 | Line No.01 | 30141.03 | 8.5% |
| 3 | Line No.02 | 31204.83 | 8.8% |
| 4 | Cooling Pump | 22623.50 | 6.38% |
| 5 | Other | 6631.02 | 1.87% |

## 6. HEAT LOSS CALCULATION

In order to find the heat model of the furnace, we use the heat balance equation of the furnace for consideration. The pattern of heat balance equation is as follows.

Heat input = Heat output + Heat loss

Heat input = 500 kW

Table 6.1 Materials used for furnace charging.

| Sr. No. | Material | Weight(Kg) |
|---|---|---|
| 1 | Runner Riser of C.I. | 215 |
| 2 | M.S. Scrap | 85 |
| 3 | Pig Iron | 190 |
| 4 | Ferrosilicon | 2.5 |
| 5 | Ferromanganese | 1.5 |
| 6 | Petroleum Coke | 4 |

M= Mass (Kg)

L= Latent heat (kJ/kg)

Cp= Specific heat capacity (kJ/Kg K)

Mw= Flow rate of cooling water (kg/sec)

Cpw= Specific heat capacity of water (kJ/KgK)

T1= Temperature of liquid cast iron (K)

T2= Temperature of solid cast iron (K)

Δt =Melting time (sec)

R= Heat resistant of furnace lining (kW/K)

ε= Emissivity of red hot body

σ= Stefan Boltzmann constant = 5.669 x $e^8$ W $m^2$ K

A = C/S area of the furnace

6.1 Heat given to Cast Iron

$$QCI= \frac{M \times L}{\Delta t} + \frac{M \times Cp \times \Delta T}{\Delta t} \quad \text{................. (6.1)}$$

QCI = 85.01 kW

6.2 Heat given to M.S. Scrap

QMS= 45.38 kW.

6.3 Heat given to Pig iron

QPI= 79.81 kW.

Heat given to Ferrosilicon, Ferromanganese and Petroleum coke =1- 2 kW approximately

6.4 Heat loss calculation

Calculation of resistance R = ln (r2/r1) / 2 Π Lk

Total resistance ∑R = R1+R2+R3

1. Conduction losses Q = (Ti – To) / ∑R

2. Radiation losses Q = ε × A × σ × ($Ti_4$-$To_4$)

3. Heat loss to cooling water = Mw × Cpw × Δt

6.4.1 Heat loss due to Conduction

$$Q\ conduction = \frac{(T1-T2)}{\sum R} \quad \text{................. (6.2)}$$

Q conduction=52864.39 W = 52.86 kW

3.3.3 Heat loss due to radiation

Q radiation = ε × A × σ × ($Ti^4$-$To^4$).......... (6.3)

$$Q\ radiation = 0.43 \times \frac{\pi}{4} \times 0.502 \times 5.667 \times 10^8 \times (1500^4 - 40^4)$$

Q radiation= 24222.35 W= 24.22 kW

3.3.4 Heat loss to cooling water = Mw × Cpw × Δt ... (6.4)

= 108.86 kW

3.3.5 Unaccounted heat loss = 103.86 kW

Most of energy supplied is utilized for melting. Heat loss through furnace wall is calculated by considering resistance analogy. Heat loss from furnace include conduction loss, radiation loss, heat gained by cooling water, Also there is significant loss of energy considered as unaccounted heat loss.

## 7. ACTION PLANS FOR FOUNDRY

Table 7.1 Action plan for foundry

| Sr. N | Issue/Problem | Action Decided |
|---|---|---|
| 1 | Melt rate per hour at cupola and induction furnace | Study of melting rate per hour at cupola and induction furnace. |
| 2 | Quality of scrap | Tumbling barrel for foundry return scrap, raw material as per |
| 3 | Tapping temperature is more | Setting of proper tapping temperature |
| 4 | Life of lining | Use Electro herm machine for ramming |
| 5 | Furnace lid randomly used | Continues use of furnace lid |
| 6 | Coke to metal ratio less | Good quality of coke |

### 7.1 Use clean raw material

During the melting process, slag is generated from oxidation, dirt, sand and other impurities. Slag can also be generated from the scrap, erosion and wear of the refractory lining, oxidized ferroalloys and other sources. In a coreless induction furnace, slag normally deposit along the upper portion of the lining or crucible walls and above the heating coils. Almost every vessel that holds or produces liquid iron is lined with refractory materials and is susceptible to refractory erosion by slag. In other circumstances, slag can combine with refractory materials to form accretions that hamper production. The consequences of refractory problems, loss of production and the cost to replace the refractory can be serious. Thus, extending the life of a refractory lining is an important consideration.

### 7.2 Use bundled steel

Size of scrap is an important parameter in reduction in energy consumption. The scrap charge should be as dense as possible. Lesser the air pocket between scrap pieces, more is the power density, higher the heat conductivity, faster melting with least energy consumption. It is better to use proper size pieces of scrap to get optimum result. Scrap should be free from rust, sand etc. to avoid formation of more slag causing heat delay hence high-energy consumption. Scrap should be charged continuously as the melting proceeds. Continuous charging helps in preheating the scrap at the top. Table 3.6 shows the values of the selected process parameters, two parameters with four levels of each parameter. All these values are selected on the basis of literature review

Table 7.2 Process parameters

| Sr. No. | Process Parameters | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|---|
| 1 | Clean Raw Material (Weight in %) | 10 | 20 | 30 | 40 |
| 2 | Bundled Steel (Weight in %) | 5 | 10 | 15 | 20 |

Table7.2 shows that furnace loading chart used in foundry which contains information about use of materials for charging. Weight measurement of materials is carried out on weighing machine and it is noted in the chart before charging.

Table 7.3 Furnace loading chart

| Trial No. | C.I. Scrap (Kg) | M.S .Scrap (Kg) | Pig Iron (Kg) | Ferrosilicon (Kg) | Ferromanganese | Petroleum (Kg) | Total Weight (Kg) | Units (kWh) |
|---|---|---|---|---|---|---|---|---|
| 1 | C.R. = 50 | B.S. = 25 | P.I. = 190 | 2.5 | 1.8 | 4 | 498 | 304 |
| 2 | C.R. = 49 | B.S. = 54 | P.I. = 190 | 2.4 | 1.6 | 4 | 495 | 301 |
| 3 | C.R. = 50 | B.S. = 74 | P.I. = 189 | 2.3 | 1.5 | 4 | 496 | 302 |
| 4 | C.R. = 50 | B.S. = 96 | P.I. = 188 | 2.5 | 1.5 | 4 | 498 | 297 |
| 5 | C.R. = | B.S. = 27 | P.I. = 198 | 2.4 | 1.7 | 4 | 498 | 297 |
| 6 | C.R. = | B.S. = 52 | P.I. = 190 | 2.5 | 1.6 | 4 | 499 | 295 |
| 7 | C.R. = 99 | B.S. = 76 | P.I. = 190 | 2.5 | 1.8 | 4 | 496 | 290 |
| 8 | C.R. = 98 | B.S. = 94 | P.I. = 190 | 2.4 | 1.6 | 4 | 490 | 285 |
| 9 | C.R. = | B.S. = 27 | P.I. = 188 | 2.3 | 1.8 | 4 | 498 | 285 |
| 10 | C.R. = | B.S. = 50 | P.I. = 190 | 2.5 | 1.5 | 4 | 500 | 283 |
| 11 | C.R. = | B.S. = 75 | P.I. = 188 | 2.4 | 1.6 | 4 | 499 | 280 |
| 12 | C.R. = | B.S. = 96 | P.I. = 188 | 2.5 | 1.6 | 4 | 498 | 276 |
| 13 | C.R. =200 | B.S. = 26 | P.I. = 190 | 2.4 | 1.6 | 4 | 494 | 272 |
| 14 | C.R. =204 | B.S. = 50 | P.I. = 190 | 2.4 | 1.6 | 4 | 496 | 270 |
| 15 | C.R. =200 | B.S. = 76 | P.I. = 188 | 2.3 | 1.8 | 4 | 492 | 266 |
| 16 | C.R. =202 | B.S. = 96 | P.I. = 190 | 2.5 | 1.5 | 4 | 496 | 264 |

## 8. RESULTS OF EXPERIMENTS

### 8.1 Analysis of units per ton-

Analysis of how much electricity required in units (kWh) is given in Table 8.1. It shows that clean raw material and bundled steel both significant parameters for units per ton. Electricity required per ton decreases with increase in % of clean raw material and bundled steel. Similar trend is observed by S.Ravichandran et al. [08] they tried with two combinations bundled steel and loose steel charge mix; cleaned and un-cleaned scrap charge mix. The reason behind this is if foundry return raw material having sand attached with it if this material used furnace charging it requires more heat compared to clean raw material because sand having double heat capacity compared to cast iron.

Table 8.1 Results of Experiments

| Sr. No. | Clean Raw Material (Weight in %) | Bundled Steel (Weight in %) | Units per Ton(kWh) |
|---|---|---|---|
| 1 | 10 | 5 | 610.4 |
| 2 | 10 | 10 | 608.0 |
| 3 | 10 | 15 | 608.8 |
| 4 | 10 | 20 | 596.3 |
| 5 | 20 | 5 | 596.3 |
| 6 | 20 | 10 | 591.1 |
| 7 | 20 | 15 | 584.6 |
| 8 | 20 | 20 | 581.6 |
| 9 | 30 | 5 | 572.2 |
| 10 | 30 | 10 | 566 |
| 11 | 30 | 15 | 561.1 |
| 12 | 30 | 20 | 554.2 |
| 13 | 40 | 5 | 550.6 |
| 14 | 40 | 10 | 544.3 |
| 15 | 40 | 15 | 540.6 |
| 16 | 40 | 20 | 532.2 |

### 8.2 Cost analysis of tumbling barrel and bundled steel

Capacity of tumbling barrel is 3 ton. Power required for tumbling barrel is 15 Hp i.e. 11.19 kW per hour. It requires one hour to complete tumbling operation cost is i.e. 11.19 units. Cost of 1 unit is 10.7 Rs, operating cost is 120 Rs. Manpower and transportation cost 500 Rs and 250 Rs respectively. Total cost of cleaning 3 ton raw material is 870 Rs, cost of cleaning 1 ton raw material is 290 Rs and extra expenses on bundled steel are Rs 2.5 per Kg. With use of 40% clean raw material and 20% bundled steel energy required about 532 units per ton. As we have seen above saving of 80 units for 1 ton. It requires 420 Kg clean raw material and 200 Kg bundled steel. The expenses for use of 420 kg clean raw material and 200 kg bundled steel are 122 Rs. and 500 respectively. Total Expenses for 1 ton is 622 Rs i.e. 58.13 units.

| Sr.No. | Saving | Expenses |
|---|---|---|
| 1 | 80 Units per ton | For 1 ton it is around 58.13 units |
| 2 | Net saving is 21.86 units per ton. Net saving for 5 ton is 109.3 Units per day | |

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