Technical Article

Energy Audit and Cost Saving in an Aluminum Sand Casting Foundry

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Abstract

The aim of this investigation was to audit and assess the energy consumption and energy efficiency of casting process in an aluminum sand casting foundry. Energy measurements took place by meter readings, on daily and weekly basis and by half hourly electricity readings provided by the supplier. At the same time all foundry operations were monitored closely to follow variables with the help and explanation of operators and the managers. The yield was also measured by dividing the final weight of castings with the input weight of the material. Data analysis took place through calculating and comparing the energy consumption of the foundry on a daily and weekly basis. Observations and calculations suggest that for this foundry energy efficiency can be increased and cost of production may reduce by adjusting daily production to a minimum of 300 kg of finished product per day. This study also shows further energy saving is possible by management control and personnel awareness, changing the foundry layout and speeding the casting operation to avoid delays, insulating furnace walls and covering the top when the furnace is not in use and keeping furnace temperatures as low as possible during melting and holding and avoiding unnecessary holding overnight and at weekends. The yield within the foundry varied from 40% to 55%. Casting operation can improve to higher yield of about 55% if simulation used more often to its full capacity with potential material and further energy saving.

Keywords: Aluminium, Sand Casting, Foundry, Energy, Cost.

1. Introduction

Aluminum with a density of 2.7 g/cm^3 is the second most abundant element on earth after silica. The properties of aluminum that makes this material and its alloys attractive for a wide range of applications, are light weight, fabricability, physical and mechanical properties and corrosion resistance. Among the most outstanding characteristics of aluminum is its versatility. Range of physical and mechanical properties can be developed by addition of principle alloying elements, copper, magnesium, silicon, manganese and zinc [1]. Addition of alloying elements also plays decisive role on alloy behavior during melting and casting processes. For example, copper improves strength but reduces fluidity of the alloy which requires higher super heat when casting. On the other hand, silicon, improves strength, resistance to wear, machinability, fluidity and cast ability of the aluminum alloys at lower melting point and therefore require lower super-heat. Aluminum melting point is about 660 ^{0}C, with addition of silicon, melting point drops to eutectic temperature of 577 ^{0}C [1]. In foundry operations melting and casting temperatures are well above the actual melting point of the alloy to allow improved fluidity and mould filling. This increase in temperature is accompanied by higher energy consumption and lower efficiency.

At the same time furnaces are designed to melt certain amount of metal per hour. value, the less energy efficient the melting becomes [2]. Despite controlling melting and pouring operations, some variation related to the operator behavior is The highest energy efficiency is attained when the furnace is operated at or near the designed melting rate. Consequently, the further away operating conditions are from design observed.

Variation also can be attributed in part to the quality, size and shape of charge materials, melting and pouring time intervals, cold start and composition adjustment [3]. In theory, aluminums and its alloys require between 280-310 kWh energy per tonne of casting [4].

Previous research indicates about 50-75% of efficiency for induction furnaces [5]. Bublik et al, reported the specific energy consumption of melting for a 500 kg capacity induction furnace at the best measured value with the load of 499 kg, was 650.6 kWh/tonne, in 82 minutes. [6] However, aluminum sand casting foundries have been reported to consume energy in a wide range between 8000-36000 kWh per tonne of shipped casting [7], indicating huge energy waste and inefficient operation. The purpose of this investigation was to audit, measure and understand the energy flow in these type of foundries, enabling solutions to be found to overcome energy waste and minimize the production cost.

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2. Materials and Methods

The audited foundry produces about 40 tons of aluminum casting annually using 4 electric furnaces with 300 kg capacity, 8 hours a day and 5 days a week. Electricity readings for the month of October 2016 were taken on an hourly and daily basis for the foundry and half hourly excel sheet data provided by the electricity supplier. The percentage yield was also calculated for the foundry by dividing the weight of the final casting (before shipment) with the weight of the charge, (before melting). Monthly energy consumption and production was also provided by the account manager on request. At the same time all activities in the foundry were monitored on daily basis and operation variables distinguished. Regular discussions with operators, operation manager, maintenance manager, and foundry directors aided the identification of the operations in more detail. Calculating and comparing daily and weekly consumptions against each other analyzed the data collected from the above activities.

3. Results and Discussions

3.1. Audit Results and Analysis

Table. 1. Shows process steps consuming energy in the foundry. Electricity consumption of individual process steps was calculated using half hourly data provided by the energy supplier, Fig. 2. and Fig. 3. At this stage the most intense energy consuming steps such as melting, holding and heat treatment were under investigation. Fig. 1. and Fig. 2., show the weekly electricity consumption trend of audited sand casting foundry during October 2016.

Table. 1. Foundry process steps.

Core Making	Moulding	Melting	Holding	Casting	Fettling	Heat Treatment	Inspection

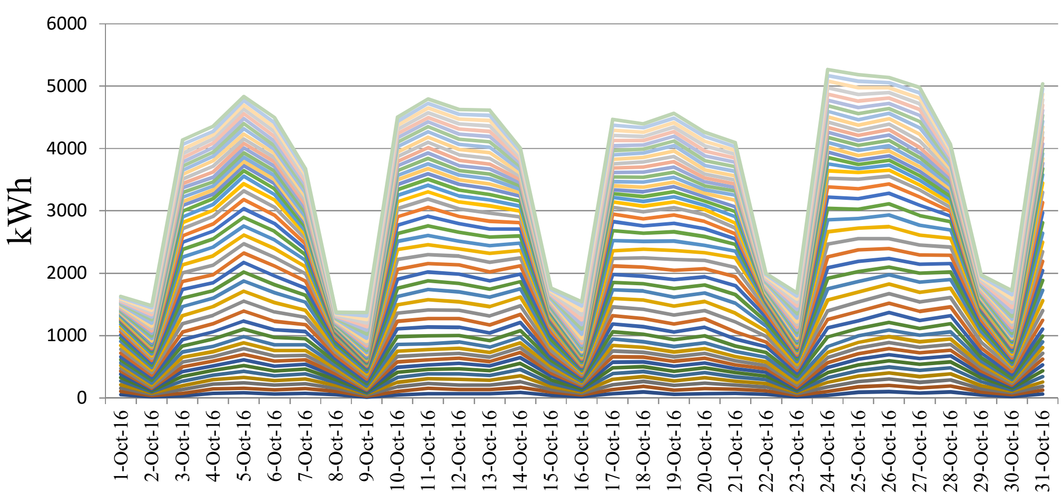

Fig. 1. Weekly Foundry Electricity Consumption Trend (October 2016).

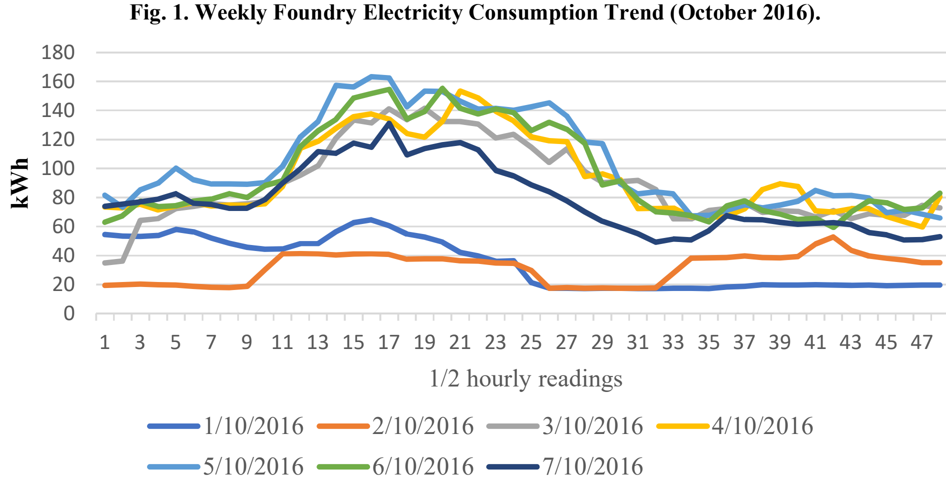

Fig. 2. Electricity Consumption (Week 1) October 2016.

It can be seen that energy consumption varies throughout the week with this figure being at its lowest during the weekend due to holding. Energy consumption increases throughout the week up to Wednesdays when it starts to drop again. Total of 85105 kWh (about 306 GJ) of electricity was consumed during October. Fig. 3. shows the amount of energy (electricity) each step of the process consumed for casting, holding, heat treatment, dressing and miscellaneous.

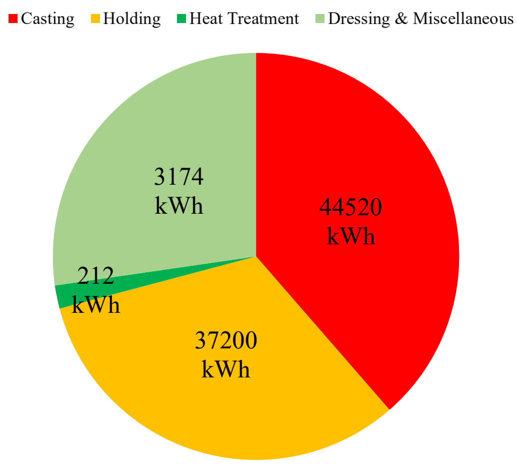

Fig. 3. Foundry Process Steps Energy Consumption (Electricity) October 2016.

The analysis of the energy consumption of the visited foundry suggests that the main energy consumption steps in this foundry are melting and holding by 52.3% and 43.7 % respectively. Heat treatment, 0.25% and fettling and miscellaneous consume 3.7% of the energy.

3.2. Specific Energy Consumption (SEC) of Casting

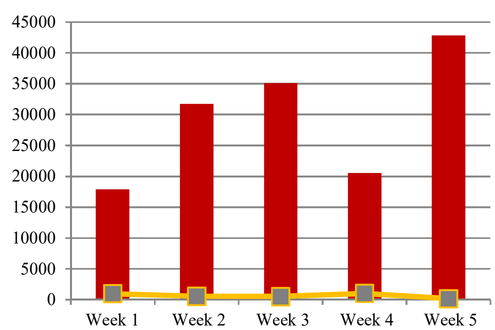

Fig. 4. Foundry Weekly Specific Energy Consumption of Casting (kWh/tonne) and Production (kg), October 2016.

Fig. 4. shows October electricity consumption in kWh for each tone of good casting (SEC) and the weight of production in the foundry. This foundry on average consumed 26182 kWh per ton in that month. However, further detailed measurement shown in Fig. 4. and Fig. 5. Indicate energy consumption variations in each week and day of the month, respectively.

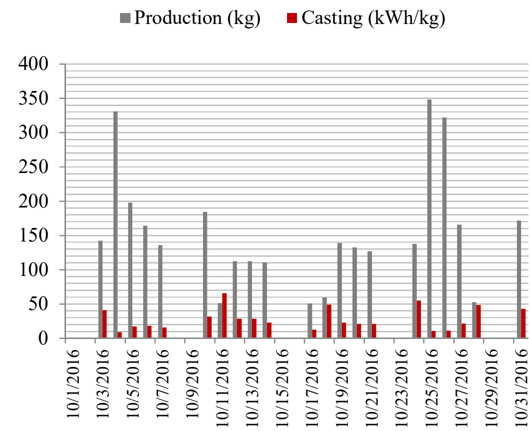

Fig. 5. Foundry Daily Specific Energy Consumption of Casting (kWh/kg) and Production (kg), October 2016.

According to Fig. 4. and Fig. 5., kWh/tonne reduces as the weight of production increases. The best performance is achieved at casting above 300kg (net weight) in a day. However, casting less than 100 kg a day is accompanied with huge energy waste due to long holding time over night and due to radiation at high casting temperature (superheat) with no lid on, during the operations. Table. 2. given the kWh/kg and cost for lowest and highest production weight during October.

Table. 2. Daily production and cost/Kg in the foundry.

Daily Production (kg)	50.8	110.4	197.67	348.1
Energy Consumption (kWh/kg)	125.58	22.816	17.203	10.725
Energy Cost (9.5 pence/kg)	£11.93	£2.16	£1.63	£1.01

3.3. Yield

The average yield of the casting operation in this foundry was measured between 35-55% depending on the shape and size of components. Increasing the yield by 10% will save 4000 kg of material for every 40000 kg of Aluminium (Table. 3.). At the same time 4000 kg less melting, holding and fettling reduces energy consumption by about 60 MWh, saving around £5700 cost of energy for every 40000 kg good casting.

Table. 3. Materials and energy saving by increase in yield.

Yield (%)	Material Saving (kg)	Energy Saving (kWh)	Cost Saving 9.5 pence/kWh
10	4000	60000	5700

4. Energy Efficiency and Cost Saving

This research shows, Aluminium sand casting foundries can improve their energy efficiency and reduce cost of production per kilogram of good casting by producing more, at their highest operational capacity day-to-day. Energy consumption in a foundry is largely influenced by the efficiency of the melting operation [8]. This may vary depending on the furnace type and melting process used. A key and important requirement in melting shop is the quality of metal produced by melting and holding enabling to reproduce a uniformly high quality of the melt, continuously. This requires following procedures, such as controlling raw material, melting operation, correct treatment of the charge and maintenance of the melting and holding equipment. For large production volumes crucible furnaces are not an economic option mainly due to the relatively high specific energy consumption of melting and manual operation of the furnaces. For batch producing foundries, the advantages of crucible furnaces are the simple operation and maintenance and the low capital investment involved. With crucible furnaces, foundries can produce different alloys in small batches according to the customer requirement. There are no restrictions as the type of alloy and melt can be treated right in the crucible and if necessary, the alloy can be easily and quickly exchanged. However, these processes are time consuming and if not controlled causes consumption of excessive energy and increase the specific energy of melting and cost of production. Most aluminium foundries use gas crucible furnaces due to lower capital investment and gas price rather than electric furnaces, with the melting efficiency of only 7-19% and energy consumption in the order of 1600-4800 kWh, and considerable metal loss due to oxidation and dross formation. Electric furnaces with higher efficiency between 50-75% produce relatively clean melt with energy consumption around 400-650 kWh per tonne. However, as mentioned previously, for furnaces to operate at the design melting rate all conditions must be prepared and planned. Some electrically heated crucible furnaces were reported to require an energy input of 400 kWh for melting 1 tonne of aluminium to a temperature of 720 ^{0}C [9]. Time needed to melt a complete crucible charge is an important factor for the melting operation efficiency. For this small foundry melting and holding operation takes place in 4×300 Kg electric furnaces at superheat temperature between 800-900 ^{0}C. The specific energy consumption of casting for the month of October was found to be about 26182 kWh for every tonne of aluminium. Audit analysis show, on average 1041 kWh per tonne is used for heat treatment, fettling and miscellaneous, and 25141 kWh consumed in melting and holding per tonne in October.

However, weekly and daily analysis show variation in specific energy consumption of casting in this foundry and its effect on the cost of production, Fig. 7., and Table. 2. According to these results, increase in weight of daily production, lowers daily specific energy consumption of casting, cost of production and finally increase the overall foundry efficiency. Therefore, foundries can benchmark their own energy consumption by monitoring and comparing daily specific energy consumption of casting for optimum operation efficiency, and adjust to their highest operational capacity.

5. Control of Melting Operation

Potential increase in energy efficiency identified by producing 300 kg net weight of casting is accompanied by specific energy consumption of casting of about 9000 kWh. However, this foundry may reduce this value even further by following melting operation instructions obtained by simulation and process design. This may include the minimum melting and holding temperature, appropriate charging of material and minimising temperature loss, covering the furnace at all-time possible to avoid heat loss due to radiation, minimising aluminium exposure to the atmosphere reducing oxidation and dross formation, avoid unnecessary holding by turning the furnaces off and maintain them on regular basis by repairing the linings and the lids which may end up saving another 10% of overall melting operation [10].

6. Management Control

It is essential to use the energy information collected by auditing in order to avoid waste, production disruption and therefore increase efficiency. Energy management is very important as it deals with adjusting and optimising energy, using systems and procedures so as to reduce energy requirements. Knowhow and a good knowledge of processes and variables together with information collected from auditing and energy measurement help foundry managers to improve energy efficiency of the plant by making prompt and on time decisions to avoid losses due to inefficient operations by personnel or equipment.

7. Personnel Awareness

Focusing on the behavior, which surrounds technology and the operation is an important criterion for energy efficiency improvements in a foundry. Personnel behavior and attitude towards foundry operation can help foundries to operate at higher rate of efficiency and save energy and material at the same time. Personnel training and awareness of the energy consumption, waste reduction and planned program is an energy saving solution, which is a rewarding investment.

The key is to work smarter rather than working harder. The objective is to dynamically engage the staff to adapt to new changes, the work culture and right practices so that they contribute in foundry energy efficiency by reducing specific energy consumption.

8. Simulation

Use of simulation in foundries is not new and has found its place in design of gating, risers, melt flow and solidification, which aids defect reduction, quality and repeatability. Use of simulation can aid foundry select the appropriate super-heat and casting temperature to save energy as well as repeatability. Heat capacity of molten metal increases with increasing the tapping temperature; similarly, heat loss is proportional to melting temperature. Considering conduction and radiation losses during inoculation and pouring, superheat temperatures can be assessed using simulation. Optimisation of gating and runners also lead to less material per casting and therefore less energy requirements for melting. Higher casting yield, the lower scrap rate, shorter cycle time and savings in tooling and materials are achievable through utilisation of casting process simulation. Simulation can assist optimisation of heat treatment process time, and save energy of about 100-200 kWh per metric tonne of castings. If simulation is utilised throughout the entire casting and related processes, a 10% energy efficiency improvement is possible.

9. Conclusions

Energy audit aids foundries to understand quality and quantity of materials and energy used in each step of their process and deal with any inefficiencies and variations during casting operation. Material weight can be measured simply after each step of the process, so the overall yield is quantified by their sum. However, energy consumption of each step of the process needs to be measured regularly on a daily, weekly, monthly and annual basis. Energy consumption patterns are the main part of the audit process. These patterns are used to understand the energy flow in a foundry and help control their cost by identifying areas where waste can occur and where scope for improvement may be possible. This foundry annually can save 310,000 kWh of electricity worth about £30,000 by adjusting daily weight of production to the optimum 300 kg or above. Further savings can be achieved through continuous improvement and adapting a Lean culture by increase yield, increase furnace efficiency by lowering furnace temperature to the lowest possible during melting and holding, design and use appropriate lids for furnaces, keep the furnace lid on at all times possible, regular furnace insulation and maintenance, changing layout to speed up casting operation and avoid unnecessary holding.

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