Optimization of Energy Consumption at a Billet Foundry

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Abstract

Increases in energy costs for industrial consumers can have undesirable effects on operations and production profit. In the aluminum industry, these increases are particularly significant given the high amounts of electricity required, directly and indirectly, for the production of metal. Those currently at risk of energy cost increase are smelters and foundries that do not have a subsidized energy contract and which are subject to more volatile profit margins given their lower yearly production yields. An aluminum foundry located in Quebec specializing in the production of various types of alloyed billets fits the aforementioned criteria. Their recent installation of a water cooler system resulted in a one (1) Megawatt (MW) increase in electrical consumption and a subsequent impact on profit. A study was thus performed to determine technical solutions to eliminate at least 1 MW worth of rated power and therefore allow the required water cooling system installation and conservation of their original energy contract.

Keywords: Aluminum casthouse, energy efficiency, billet casting, peak energy usage.

1. Introduction

A billet foundry specializing in the production of several different alloys sought to identify energy savings opportunities with desirable payback periods of 2 years or less. Exploiting these opportunities was of particular interest given electricity consumption and peak power utilization increased dramatically after the installation of a new 1 MW water cooling system. In addition, the cost of electricity was also increased considerably by the utility provider, creating a challenge with respect to annual electricity expenditures and production profit margins. The present study aimed to eliminate at least 1 MW of power utilization at the foundry to allow for the installation of new equipment and conservation of the original energy contract.

1.1. Process Description

The billet foundry originally consisted of a complete aluminum smelter equipped with Søderberg technology in operation since 1942. In 2013, it was decided to close down the potlines given the obsolescence of this technology and the prevalence and efficiency of the newer prebaked smelters. Nevertheless, all equipment pertaining to the casting and thermal treatment of billets was kept in place and remains in production to this day.

The facility now receives aluminum in solid or liquid form from external suppliers and is immediately transferred into either the remelt furnace (if solid) or into tilting furnaces. In these tilting furnaces, the metal is heated to around 800 °C and alloying elements are added in preparation for casting. Once the metal reaches the target temperature and alloying elements have dissolved, the metal is cast using a single direct chill casting table into billets of various quantities. Between 8 and 15 casting drops are performed each day (24 hours) of up to 40 different types of aluminum alloys.

Having cast the billets, it is essential that alloy elements are evenly dispersed throughout the metal to guarantee uniform mechanical properties for the intended clients. To reduce segregation, billets are inserted into batch homogenization furnaces which heat the alloy to a set temperature (stage 1) then are soaked for a specified period of time (stage 2). Each family of alloys possess its specific homogenization regime depending on composition, diameter, etc. As the alloys complete their soaking cycle in the furnace, the batch is subsequently taken out of the furnace and placed in cooling chambers for a controlled cooldown to complete the homogenization process (stage 3). The billets are then finally loaded on train wagon or truck to be shipped to clients.

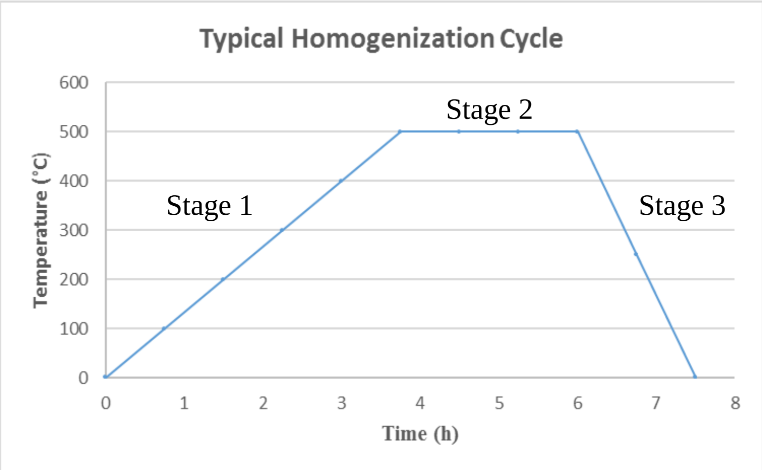

Figure 1. Typical homogenization schedule for aluminum billets including 3 stages.

2. Current Electrical Consumption

2.1. Electrical Usage Analysis

Total electrical capacity for equipment at the billet foundry amounts to 7.5 MW. This only accounts for electricity, natural gas consumption is not included in this study. There are 4 major electrical power consumers at the foundry:

- Homogenization furnaces utilize up to 5.7 MW of electricity, representing 76 % of the total plant electricity usage.
- Electrical motors with rated power superior to 25 HP utilize a total of 1.14 MW of electricity, representing around 15 % of the total plant usage.
- Space heating utilizing 420 kW (6 %).
- Building lighting which consume 207 kW (3 %).

It is clear that opportunities with greatest impact will necessarily target the homogenization furnaces consuming the majority of electricity at the foundry. Additionally, in contrast with the current state of electrical usage, the additional future installation of a water cooling system having a peak power usage of 1 MW represents a major increase with respect to the current total capacity of 7.5 MW. Figure 2 represents a summary of current major equipment electrical utilization.

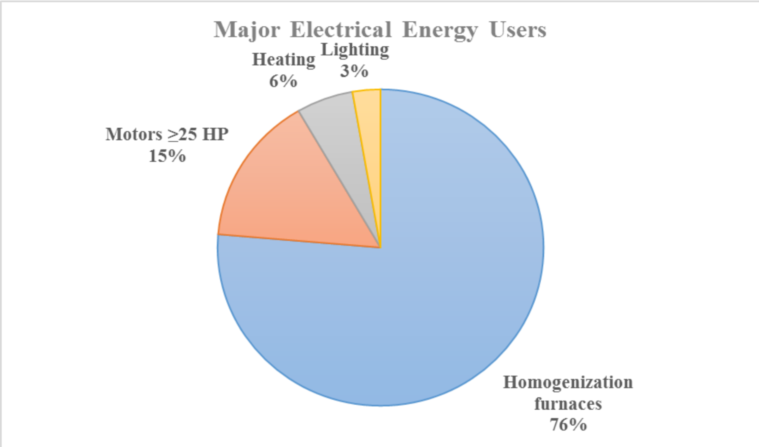

Figure 2. Summary of major electrical power utilisation at billet foundry.

2.2. Electricity Costs and Tariffs

Starting 1 January 2017, the billet foundry has been ascribed a new electric supply contract with new tariffs based on high power consumers. This new contract represents a major increase in costs with respects to the original contract and comprises two categories of electrical consumption subject to billing. The first category consists of the total energy consumed during a given timeframe, measured in kWh. The second category is the maximum power utilization in kW measured over a period of 15 minutes. For power utilization over a monthly period, for example, the peak utilization would be determined by the maximum power utilized for a minimum time of 15 minutes, which would consequently become the power utilization for billing purposes.

The new electricity service contract negotiated represents an increase from 2.56 ¢/kWh to 6.69 ¢/kWh in energy costs and a substantial increase from 0 $/kW to 13.67 $/kW of power utilization both between 2014 and 2022. In order to allow the foundry to adapt to this new contract, a transition period of 6 years shall be applied thus coming into full effect in January 2022. Assuming that electrical requirements would remain the same, table 1 gives an estimate as to how the cost of electricity would increase.

Table 1. Costs for energy consumption and power usage from 2015 to 2022.

Year	Peak power billed (kW)	Yearly energy consumption (kWh)	Peak power rate ($/kW)	Energy rate ($/kWh)	Total electricity cost before tax
2015	3730	26 707 485	0	0.0256	683 711.62
2016	3730	22 200 521	0	0.0256	568 333.34
2017	3730	22 200 521	12.38	0.0349	1 328 926.98
2018	3730	22 200 521	12.63	0.0408	1 471 100.06
2019	3730	22 200 521	12.88	0.0470	1 619 933.29
2020	3730	22 200 521	13.14	0.0534	1 773 654.22
2021	3730	22 200 521	13.40	0.0600	1 931 815.26
2022	3730	22 200 521	13.67	0.0669	2 097 084.05

The new electricity tariffs negotiated will eventually cause an increase of four times the amount spent in electricity. This is principally attributed to the introduction of billing peak power utilization. Directly targeting and exploiting opportunities that reduce peak power utilization would therefore have the greatest effect on cost savings and allow for a quicker payback period for any investments intended to improve energy utilization and efficiency.

3. Energy Savings Analysis and Opportunities

3.1. Methodology

Energy saving opportunities were explored to find solutions that are cost effective with a quick payback period. Opportunities were determined using a set methodology that can be divided into 3 main sections:

1. Preparation of analysis scope and definition of battery limits.
2. Implementation of the analysis and identification of main electrical energy users, consumption patterns, energy balance analysis (waste heat) and cost effective alternative energy sources.
3. Reporting of analysis findings with action plan and financial breakdown including payback period.

This methodology led to the determination of 3 opportunities that were worth executing and described in detail in the following sections. They included:

1. Peak Energy Management of Homogenizing Furnaces.
2. Replacement of Electrical Elements for Natural Gas Radiant Tubes.
3. Utilization of Cooling Chambers for Space Heating.

3.2. Peak Energy Management of Homogenizing Furnaces

3.2.1 Opportunity Description

Prior to the installation of the water cooling system, the foundry has never surpassed 3.75 MW of peak power utilization. It is possible to create an operating sequence that meets production requirements and minimizes peak power usage to a maximum of 3.25 MW by eliminating sudden peaks in power demand, resulting in savings of substantial operating expenses. The red curve represented in Figure 3 shows instantaneous total plant power usage during a typical day of operation. It is the addition of all equipment power usage (represented by all other curves below it). A quick analysis shows that the high power requirements of the homogenizing furnaces and their occasional simultaneous operation will have an impact on total plant utilization and can be represented by the peaks of the red curve (see arrow 1).

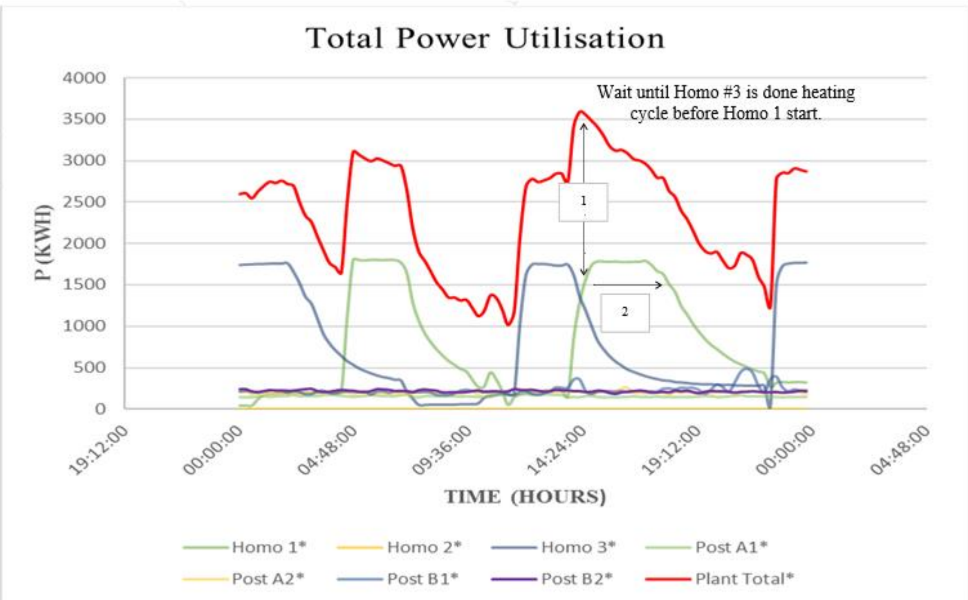

Figure 3. Foundry power utilization for all equipment on 1 December 2016.

By ensuring that the homogenizing furnaces never operate simultaneously (see arrow 2) and speeding up "Stage 1" in the homogenizing sequence (heat up) will result in the stabilizing of total foundry power usage and minimize operating costs for little to no capital investment.

3.2.2 Implementation, Installation and Setbacks

Operators are currently tasked with manually operating the furnaces, resulting in inefficiencies in operational sequences and energy consumption. Eliminating the simultaneous usage of high power consuming furnaces and liberating operators from this task will require the implementation of a software algorithm via plant PLC to operate and optimize furnace peak energy usage and maintain productivity at the highest possible level. Implementation of this automated system is of particular interest due to the minimal capital costs and the high returns expected from the elimination of peak energy consumption by 500 kW.

Challenges arising from the implementation of this option consist of the production constraints imposed by the variable daily production sequence. Billet production at the foundry does not follow a set schedule every day and is dynamic. Creating an algorithm that is agile and can adapt to different production scenarios will be the main challenge faced by implementing such a system.

3.3. Replacement of Electrical Elements for Natural Gas Radiant Tubes

3.3.1. Opportunity Description

Lower peak energy usage can be achieved through the installation of 500 kW radiant tube burners in each of the 3 purely electrical homogenizing furnaces, rendering them "hybrid energy" furnaces. As seen in Figure 4, these tubes are inserted in the furnace as heating elements, similar to their electrical equivalents, and allow for a flame to burn within them to radiate heat. By replacing 500 kW of electrical power in each furnace with a cheaper (30 ¢/m^3) gas fired heat source, peak electricity usage costs can be lowered substantially where 2 or 3 furnaces are operational simultaneously.

Figure 4. Radiant tubes used in homogenization furnaces.

3.3.2 Implementation, Installation and Potential Setbacks

The interior layout of the furnace must be rearranged given the introduction of the radiant tubes. To replace 500 kW of electrical power, eight vertical "U tubes" will need to be installed from the roof of the furnace. The advantage with this layout, and not one that is horizontal, is protection against deformation from gravity during furnace operation. Figure 5 represents the general dimensions of the radiant tube burners to be installed for the replacement of 500 kW worth of electrical energy.

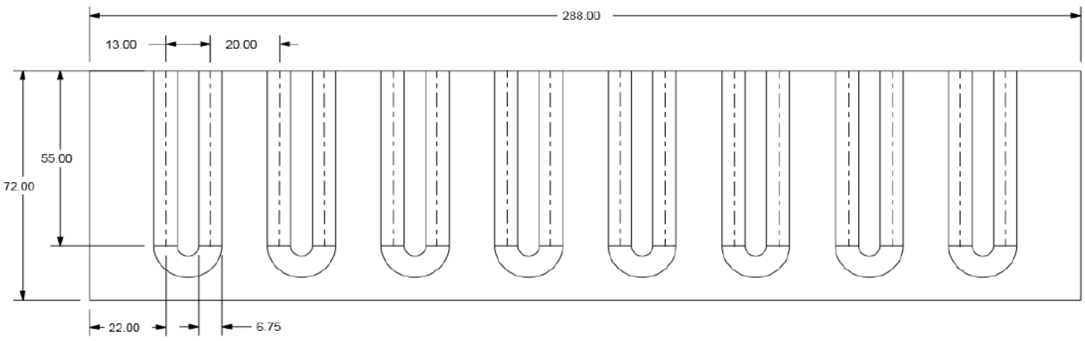

Figure 5. Dimensions of the radiant "U-Tube" burners installed for 500 kW power.

The challenges this option presents can be associated with local standards and regulations that need to be handled by adding a combustion functionality to an existing electrical furnace. The applicable environmental and emission regulations when performing the retrofit are numerous and need to be studied in detail. A gas exhaust is also necessary and is potentially difficult to install given the layout of the foundry and lack of proximity to outer wall. Though an opportunity can be exploited by using the waste heat of the furnace exhaust chimney process for use elsewhere in the foundry (ex: SOW ingot preheat). Finally, to ensure the installation of the tubes does not constrict the flow of forced air convection within the furnace, a more comprehensive feasibility study is recommended.

3.4. Utilization of Cooling Chambers for Space Heating

3.4.1 Opportunity Description

Waste thermal energy recovered from a process can supply heat to render the foundry warm for the winter months. As shown in Figure 2, electrical consumption associated with heating the foundry accounts for only 6 % of overall electrical consumption, and though not a significant portion of the electrical utilization of the billet foundry, the abundance of waste heat in the process presents a savings opportunity. When billets are removed from the homogenizing furnaces, they are immediately placed in cooling chambers used to lower the temperature and remove the heat in preparation for shipping. Some cooling chambers evacuate the heat from the billets directly into the roof of the building, stratifying the evacuated thermal energy. One cooling chamber channels the heat from the billets directly out of the foundry through ductwork already installed. By modification of this ductwork and additional equipment for the controlled dispersal of this waste energy, the elimination of electrical utilization associated with heating the building can be effectively achieved.

3.4.2 Implementation, Installation and Potential Setbacks

The existing installation consists of a fresh air intake hood on the roof of the foundry connected to a duct that is led directly into the side wall of the cooling chamber. The cool air, introduced into the chamber, then passes through the hot billet stack and subsequently exits the duct system again through the roof of the foundry. Figure 6 represents a basic process flow diagram of the current and proposed design that would allow to exploit the waste energy for space heating purposes.

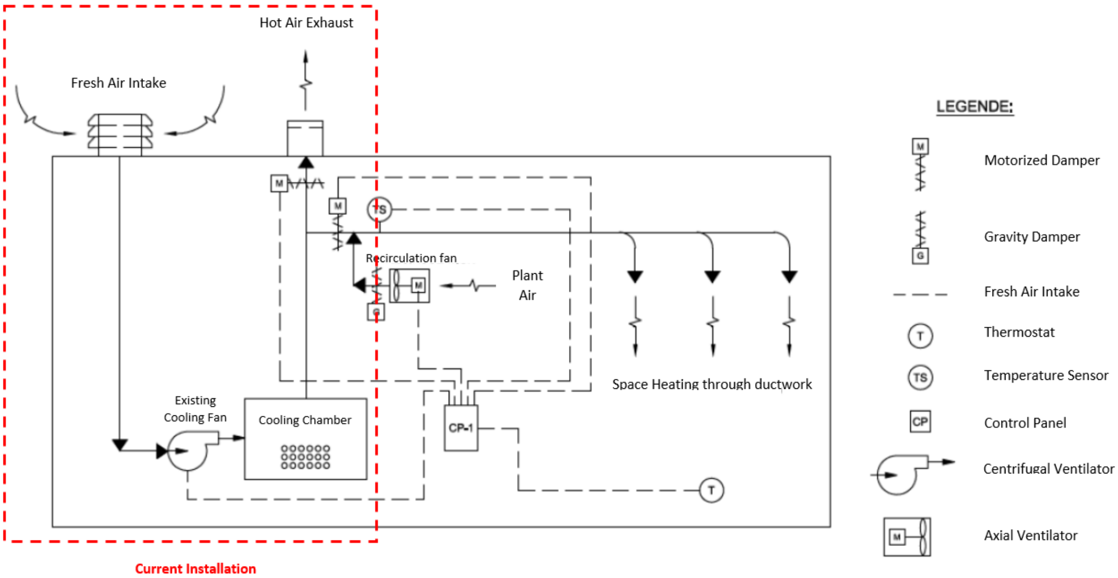

Figure 6. Process Flow Diagram of the current and intended heating system.

To utilize this waste energy for space heating considerations, a fraction of the available energy must be used at the start of the cooling cycle given that directly channeling all available heat from the hot billets (500 °C) into the workspace can be dangerous and can compromise the health and safety of the operators. Billets will progressively decrease in temperature from around 550 °C down to 60 °C throughout their cooling cycle and the importance of utilizing two air streams (cool plant air and hot billet air) of variable mixtures must be stressed. The motorized damper installed just below the hot air exhaust is intended to control these air mixtures by means of a control panel/thermostat and will open relative to the heat and volume of air evacuated from the chamber. With the correct air mixture and temperature reached, it can then be sent through the installed ducts for the intended purpose of heating the billet foundry during the winter.

The challenges presented by this option are primarily associated with the long payback period (around 9 years without government subsidies) due to the capital costs of installation. Long ducting distances at high elevations involve large capital investments that will not justify the elimination of 420 KW of energy utilization. Government subsidies can be applicable for this type of project however and may be taken into account when calculating the ROI of 2 years or less.

4. Conclusion

Energy savings opportunities were identified to reduce consumption and power utilization and to maximize the savings of operating costs. By implementing an operating sequence algorithm to minimize peak energy usage of homogenizing furnaces, it was seen that 500 kW of power utilization could be eliminated. Additionally, the installation of radiant tube burners and the exploitation of the cooling chambers were also seen to potentially cut 1.5 MW (for 3 furnaces) and 500 kW respectively. As not one option will surmount the challenge of increased consumption and energy costs alone, it is important to consider a combination of the above solutions to find an equilibrium between investment and benefits.

Therefore, this study aimed to highlight a sound action plan to rapidly minimize energy consumption and power usage and keep similar primary metal producers competitive in an ever changing global environment.