Optimisation of the Melting Furnace Unit in an Italian Aluminium Foundry to Reduce Gas Methane Consumption

Jessica Rossi(✉) and Augusto Bianchini

Department of Industrial Engineering, University of Bologna, Via Fontanelle 40, 47121 Forlì, Italy
`{jessica.rossi12,augusto.bianchini}@unibo.it`

Abstract. The foundry industry is one of the most energy-intensive industrial sectors. Consequently, the energy cost can reach 7–15% of the cost of the operations. Among all the types of energy used, the most significant part of energy consumption is associated in Italy with gas methane in different typologies of melting furnaces. According to the treated material (e.g., aluminium, steel, cast iron), the foundry process can vary; however, some operations characterize the entire sector, such as the metal melting phase, which is the most energy-intensive stage of the process (it can account up to 70% of the total energy consumption of the foundry). The energy crisis, which has affected companies in these years, determines instability and volatility in energy availability and costs and requires implementing some improvements to optimize energy efficiency and reduce consumption. With the aim of investigating the potential energy reduction in the foundry sector, an Italian aluminium foundry has been considered. The analysis consisted of three main activities: (i) Analysis of the process and mapping of energy and resource consumption at the factory level and in each unit; (ii) Quantification of energy and resource consumption at the factory level according to the ViVACE® method; and (iii) Addressing the critical points (energy consumption) to improve the environmental impact of the foundry. According to this methodology, the optimization of the melting furnace unit has been addressed, allowing the potential saving of gas methane up to 13%.

Keywords: Foundry · Methane · Aluminium · Optimization · Energy efficiency

1 Introduction

The foundry is a key sector able to product numerous typologies of products, which can interconnect different supply chains, such as automotive, mechanical and aerospace industry, agricultural machines, energy production plants and construction sector [1]. At the basis of foundry process, there is the material melting, which requires very high temperature, e.g., about 700 °C for aluminium and 1500 °C for steel, determining very high energy consumption. It makes the foundry sector one of the most energy-intensive industrial sector. In particular, in 2021, in Europe, the foundry sector consumed about

H. Kohl et al. (Eds.): GCSM 2023, LNME, pp. 782–790, 2025.
https://doi.org/10.1007/978-3-031-77429-4_87

100,000 GWh (NACE 24.5, included 24.41 and 24.43), corresponding about to the 13.9% of the total energy consumption [2]. According to a previous analysis [3], it has been evaluated that energy consumption in a foundry can reach up to 15% of the total costs. In this context, energy consumption optimization and savings become crucial aspects, above all in the current historical period, characterized by a high and instable growth of energy price (both electricity and gas methane) that determines a huge economic impact on the industries.

In the entire pattern of energy consumption in foundries, the melting phase, where different types of furnaces can be used, generates the greatest part of energy consumption, reaching rates up to 70% of the total energy consumption [4, 5]. Consequently, paying the attention on the use of melting furnaces could generate relevant energy savings for foundries. In the scientific literature, the studies about the energy consumption reduction in foundry sector are limited: in [6], it has been explained that there could be numerous areas of investigation to reduce energy consumption, such as ventilation, and compressed air, and it is highlighted that a possible problem related to the lack of strong and repetitive procedure and techniques to use the furnaces; in [7], an experimental innovative burner unit is described with the potential to reduce energy consumption of about 36%, energy costs of 48% and CO_2 emissions of 41%; in [5], insights about correct feedstock condition, avoiding over-heating and heat losses; and, finally in [3], it has been investigated how small adjustments to the tolerance limits of multiple process variables in furnaces could make a saving of 60 kWh/ton of liquid metal. According to melting furnace constructor [8], there are four main activities that can be applied to reduce furnace energy consumption. (i) Checking and optimizing the fill: material typology and mix (ingots and foundry returns) and distribution could generate up to 4% of energy savings. (ii) Optimizing load efficiency during low utilization avoiding short melting periods and longer holding ones could reduce energy consumption by up to 20%. (iii) Adjusting the air-fuel ratio in the burner could save up to 2% of the energy used in a furnace with an excessive air utilization. (iv) Closed liquid metal holding and dosing system could avoid up to 66% of unnecessary energy consumption in foundry. Other studies on aluminium melting furnaces, such as [9–11], are focused on the identification of combustion performance according to some conditions, such as the type of fuel and the air-fuel ratio, however, this approach is more useful for furnace construction optimisation, since the users of the furnaces cannot optimise these parameters during the furnace usage. Finally, in [12] different solutions have been explained to optimise the consumption of gas methane in aluminium melting furnaces through flues gases heat recovery, which could be a downstream solution.

In this paper, with the aim of investigating the potential energy reduction in the foundry sector, an Italian aluminium foundry has been considered. The industrial process of the foundry has been analyses in detail and the consumption of the main resources (energy, waste generation, water and transport) were quantified, according to the ViVACE® method, an innovative quantitative tool developed by the authors [13, 14], able to assess the environmental sustainability of the companies. This methodology allowed to identify that, also in this case, melting furnace unit represents the most energy consumer unit of the foundry, proposing an improving way in using furnaces to reduce their energy consumption.

2 Methodology

The methodology applied in this paper consists of three main phases (Fig. 1): (i) Analysis of the process and mapping of energy and resource consumption at the factory level and in each unit; (ii) Quantification of energy and resource consumption at the factory level according to the ViVACE® method; and (iii) Addressing the critical points (energy consumption in melting furnaces) to improve the environmental impact of the foundry.

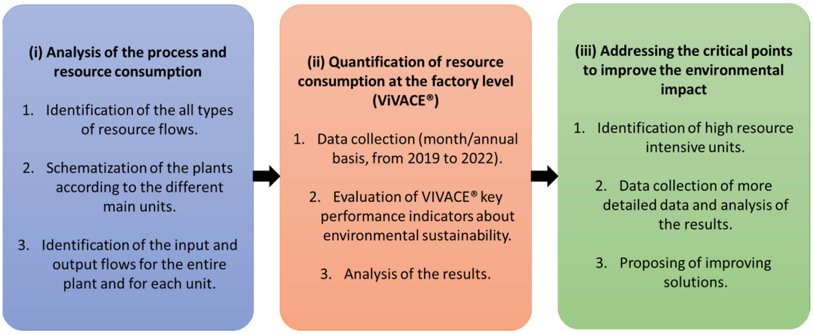

Fig. 1. Methodological approach applied to investigate the potential energy consumption reduction in the analyzed Italian aluminium foundry.

2.1 Analysis of the Process and Resource Consumption

The analyzed company is a die casting foundry, which produces aluminium components starting from their design and simulation, then their industrialization and production up to the delivery to their customers. The foundry production process is divided in five units: the melting unit, two units with the die casting machines (one unit contains old generation machines and the other contains new generation machines), quality lab, the unit which contains a specific mechanical operation for the final products and the unit which contains several types of general plants (compressed air, boilers, wastewater treatment plant, conditioning systems, solid/liquid particle emission filters). According to this structure, the entire plant has been schematized with twelve blocks. For each block, all the types of involved resources have been identified.

The main resource flows that involve the environmental sustainability and interest the typical industrial processes, independently on the specific sector, mainly fall in five categories, which are: (1) materials, (2) waste, (3) energy (electricity and thermal energy), (4) water and (5) fuels. In this specific case of the foundry, 39 resource flows have been identified and associated with their relative blocks and the with the entire factory. Each flow has been classified with a name, a numeric code, a colour and its relative category. Finally, the respective input and output flows have been associated to each single block, as in Fig. 2, which represents the block of the entire plant and consists of the reference for the following methodological phases.

2.2 Quantification of Resource Consumption at Factory Level by ViVACE®

According to the reference [9], in 2019, tools to proper quantify circular economy business models and company environmental sustainability lacked in literature (both scientific and grey literature), but were necessary to support the process management and company decision-making process. For this reason, ViVACE® has been defined. In these years, the ViVACE® tool have been further developed and it derives a practical and consolidated tool and software to assess environmental sustainability of companies in different sector. Now, the ViVACE® tool is applied and continuously updated and improved by a spin-off of the University of Bologna (Turtle Srl). Some IT management tools that manage data and indicators for sustainability exist on the market for 10–15 years [15], but their use is not widespread due to their complexity that binds them only to large companies. ViVACE® tool is simple and can be adapted to all sectors and company dimensions thanks also to the support in systematizing and interpreting the necessary data starting from specific company structures. The case study presented in this article represents the first application of ViVACE® tool to a foundry, consequently the academic approach has been necessary to address the adaptation of the tool to the sector.

According to ViVACE® tool steps and methodology, for each flow of resources, the quantitative value has been assessed through the data collection phase and registered according to: type of data, source(s), involved corporate function(s), recording methods, any potential critical issues.

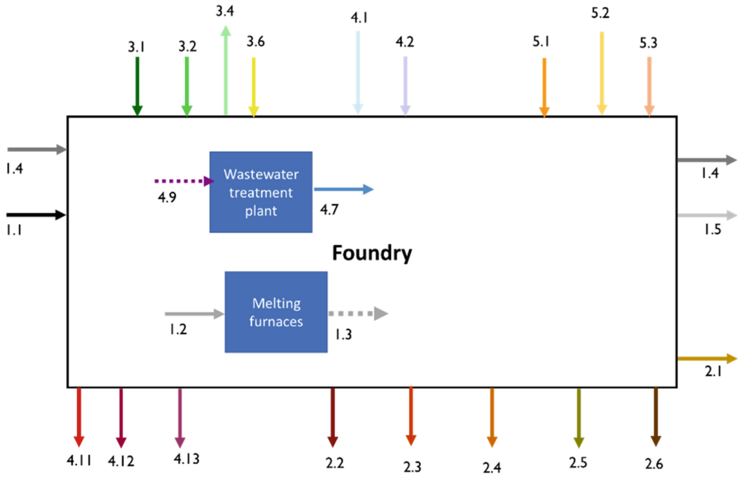

Fig. 2. Qualitative schematization of the foundry (plant level) and identification of all the codified input and output resource flows.

To understand the possible evolution of the company on the path towards sustainability, the data has been collected for the period 2019–2022. In this way it was possible to verify the situation before the Covid-19 pandemic, noting potential effects of the pandemic itself on production and evaluating the post-covid recovery in the two-year period

2021–2022. The data was collected on a monthly and/or yearly basis, depending on their availability. The data collection involved numerous company functions (administration, purchasing office, logistics office, industrial accounting, etc.) as the data necessary for quantifying sustainability are already present in the companies, but are currently managed for different purposes. Finally, Excel sheets have been prepared to continue collecting data also in the future: in particular, the Excel sheets have been structured to process the data in the form in which they are currently managed, but also to process the ViVACE® indicators and dashboard.

In fact, all the collected data have made it possible to calculate some operational KPIs relating to the consumption of the main resources (energy, water, fuel for transport on the vertical axis) and the flux of material and generation of waste (on orizontal axis) according to the ViVACE® method. Table 1 summarize the main indicators monitored through ViVACE® divided in four classes: (i) energy, which considers the energy (electrical and thermal) consumed by all the company's processes and services, and that self-produced internally, and it also includes the energy used for internal logistics or similar to it (electricity or produced from fuel); (ii) waste, which considers both industrial and urban waste, produced by the company, and it also includes materials valued as by-products; (iii) water, which considers the water consumed by all processes and services within the company and assesses the type of disposal, consequently special liquid waste falls into this category (and not in waste one); and finally (iv) transport, which considers the fuel consumption due to the transport of company vehicles, but it does not involve the logistics associated with the material purchase, the delivery of finished products and the disposal of waste.

Table 1. Table captions should be placed above the tables.

Category	Indicators	Unit
Energy	– Annual energy consumption	kWh/year
	– Rate of electricity/thermal energy	%
	– Rate of renewable energy	%
Waste	– Annual waste generation	kg/year
	– Rate of waste sorted by typologies	%
Water	– Annual water consumption	m^3/year
	– Rate of water sorted by wastewater treatment	%
Transport	– Annual travels sorted by fuels	km/year

2.3 Addressing Critical Points to Improve Environmental Sustainability

This last methodological phase is based on the concept to focus the attention on the resource consumption that emerges as critical from the analysis in previous methodological phase, in terms of CO_2 equivalent emissions. Consequently, the sub-methodological steps are always the same (identification of high resource intensive units/machines/processes, more detailed data collection and identifying improving solutions), but there are practically defined and applied in different ways, according to the resultant criticalities (e.g., in the energy field as in this specific case).

3 Results and Discussions

The results of the quantification of environmental sustainability of the analyzed foundry are expressed in terms of the main indicators listed in Table 1, sorted by category. Then the annual consumption of each resource is transformed in CO_2 equivalent emissions to identify the most impactful resource (Fig. 3 – 2022 data are the reference).

Energy. In 2022, the foundry consumed more than 35 GWh/year of energy. The thermal energy generated by the combustion of gas methane is the first energy source (73.8%), followed by electricity (26.1%). Fuel consumption for energy generation makes up a small part (0.1%). Starting from 2021, a portion of the electricity consumed comes from the photovoltaic system installed on the roof of the foundry plant. This portion constitutes 3.3% of the total electricity consumption, and is almost entirely self-consumed by internal processes ($>$ 99%).

Waste. In 2022, the foundry generated about 1000 tons of waste. On average, the main type of waste is determined by aluminium waste (35%), followed by waste from production activities (24%) and finally by aluminium by-products (22%).

Water. In 2022, the foundry consumed about 18000 m^3/year of water. The main wastewater treatment methodology is its recovery through the internal wastewater treatment plant, which allows the reuse of the 30% of the incoming water. This is followed by civil wastewater (from bathrooms and changing rooms), equal to 15%. However, most of the water consumed (48%) is not found in the outgoing liquid flows, as it evaporates during the process.

Transport. In 2022, the foundry car park made more than 2000 km/year. The Covid-19 pandemic has certainly changed the methods of communication between people, determining procedures which then consolidated over time (e.g. telecommunications, video telephony), causing a drastic drop in travel and therefore in fuel consumption ($-$65% from 2019 to 2022).

According to these data, it derives that the CO_2 equivalent emissions of the foundry production process are mainly generated by energy and waste, while water and transport have a negligible impact (Fig. 3). Surely, the energy determines almost all the emissions, consequently, in this specific case, it consists of the most critical resource to be deeply analyzed to improve the environmental impact of the foundry.

According to this evidence, a more detailed analysis of energy consumption has been conducted. Since the methane consumption consists of about the 74% of the entire energy consumption, it has been chosen to focus the attention on this resource. In particular, confirming the literature data [4, 5], it derived that, also in the analyzed foundry, the furnace melting unit is the greatest user of gas methane: in particular, the entire unit, constituted by 3 operating furnaces, generates the 48% of the gas methane consumption of the entire foundry.

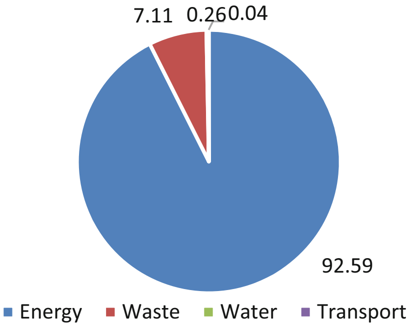

Fig. 3. Composition of the CO_2 equivalent emissions generated by the production process of the analyzed foundry sorted by category of resources.

With the aim to deeply understand the composition of this consumption in the furnace melting unit, further data collection and analysis have been conducted. In particular, thanks to the availability of gas methane sensors on each furnace, it was possible to monitor the consumption over the time (data are available with a sample time of 20 min), and associating them with the number of aluminium spills (spill means the collection of a certain and fixed quantity of molten aluminium – 500 kg in this case – from the furnace) from each furnace, which is an information that is still manually registered. From this analysis, a correlation between the number of spills in a work shift and the corresponding average specific gas methane consumption of the furnace, assessed in mc/kg (Fig. 4), that is the quantity of gas methane (mc) associated to each kg of molten aluminium. This trend is opposite of the gas methane consumption in a work shift (measured in mc), which increases with the number of spills. Consequently, the specific gas consumption measure refers to the quality of the melting phase and its optimisation.

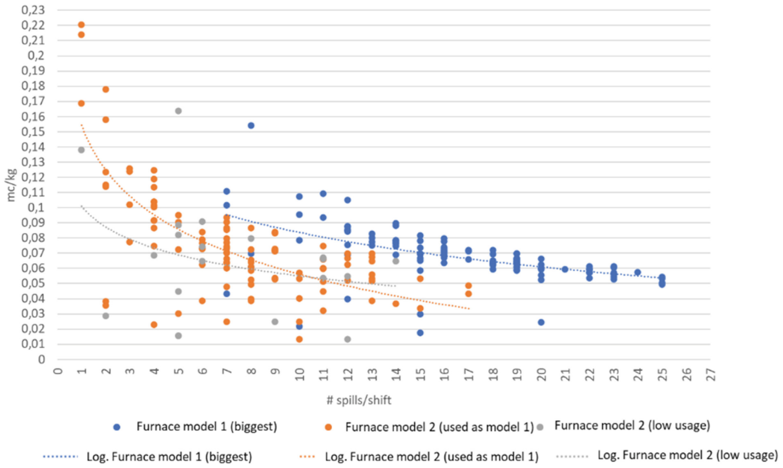

Fig. 4. Trends of the specific gas methane consumption (mc/kg) in each work shift for each of the three furnaces, according to the number of spills in the same work shift.

These results confirm the indications of furnace constructor about the optimization of the load efficiency during low utilization avoiding short melting periods and longer holding ones [8]. In fact, it derives that when a limited number of spills is made by each furnace, the specific gas methane consumption increases. It allows the identification of a minimum number of spills for each furnace in a work shift to guarantee to optimize its use and reduce the energy consumption. This operation, which does not involve any kind of investment, but only a different procedure in making spills from furnaces, could be reduce the average specific gas methane consumption of the entire furnace melting unit from 0.071 to 0.062 mc/kg (− 13%). Considering that, in 2022, the foundry melted more than 11 Mkg of aluminium, it could determine an economic saving of about 100 k€/year (considering a gas methane price of 1 €/smc – dec-2022 data) and a reduction of CO_2 equivalent emissions of about 200 ton/year.

4 Conclusion

The foundry is one of the most intensive sectors, above all for its high gas methane consumption for metal melting, which is a fossil fuel determining high CO_2 equivalent emissions. However, potential solution to reduce this consumption are still lacking in literature. Following some rules given by the furnace constructor, it is possible to optimize the use of this equipment and hence reduce its energy consumption. To make it possible, it is necessary to have data and information, since quantify the resource consumption and some key performance indicators allows the design of the sustainability transition of the companies. Quantifying the sustainability and defining the improving steps are the main objective of the ViVACE® tool, which starts from the numerous data that the companies already manage. With these steps, in the analyzed foundry it was possible to find an improved procedure to use the furnaces without any other investment.

References

1. Riedel E, Ahmed M, Hellmann B, Horn I (2023) Foundry 4.0: digitally recordable casting ladle for the application of Industry 4.0-ready manual casting processes. Proc CIRP 116:95–100
2. Authors' elaboration from Eurostat dataset: NRG_D_INDQ_N
3. Arjunwadkar SH, Ransing MR, Ransing RS (2015) Seven steps to energy efficiency for foundries. Technical 143(3):24–29
4. Arasu M, Rogers Jeffrey L (2009) Energy consumption studies in cast iron foundries. In: Transactions of 57th Indian foundry congress. Recent Advances, Kolkata, India, pp 331–336
5. Lazzarin RM, Noro M (2015) Energy efficiency opportunities in the production process of cast iron foundries: an experience in Italy. Appl Therm Eng 90:509–520
6. Fayomi OSI, Agbola O, Oyedepo SO, Ngene B, Udoye NE (2021) A review of energy consumption in foundry industry. In: Proceeding of international conference on energy and sustainable environment. IOP Publishing, pp 1–6
7. Scharf S, Sander B, Kujath M, Richter H, Stein N, Felde J (2022) Sustainability potentials of an innovative technology and plant system in non-ferrous foundries. Proc CIRP 105:758–763
8. StrikoWestofen: 5 ways to save energy when melting and transferring metal. Available online at: https://www.strikowestofen.com/en-gb/foundry-efficiency/cut-furnace-costs, last access on 27 July 2023

9. Nieckele AO, Naccache MF, Gomes MSP (2011) Combustion performance of ana aluminium melting furnace operating with natural gas and liquid fuel. Appl Therm Eng 31(5):841–851
10. Brewster B, Webb BW, McQuay MQ, D'Agostini M, Baukal CE (2001) Combustion measurements and modelling in an oxygen enriched aluminium-recycling furnace. J I Energy 74:11–17
11. Adeniji TA, Waheed MA (2021) Evaluation of the energy efficiency of an aluminum melting furnace for a Nigerian cast-coiled plant. Fuel Commun 9:100027
12. Bratu V, Stoian EV, Florina VA (2016) Natural gas consumption reducing in aluminium melting furnaces by heat recovery of flue. Sci Bull Valahia Univ Mater Mech 14(11):17–22
13. Bianchini A, Rossi J, Pellegrini M (2019) Overcoming the main barriers of circular economy implementation through a new visualization tool for circular business models. Sustainability 11(23):1–33
14. Bianchini A, Rossi J (2021) An innovative visualization tool to boost and monitor circular economy: an overview of its applications at different industrial sectors. In: Product life cycle—opportunities for digital and sustainable transformation. IntechOpen
15. Startup Stash, Top 27 corporate sustainability tools, 1 Nov 2022. Available online: https://startupstash.com/corporate-sustainability-tools/, Accessed on 25 Sept 2023