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Energy efficiency status-quo at UK foundries: the "small-is-beautiful" project

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Abstract

Energy efficiency is a critical issue for all manufacturing sectors. In the present paper the energy efficiency of UK foundries was assessed. In the context of this research 80 foundries were studied, 60 were contacted and 10 were visited. General energy data were collected using structured questionnaires, interviewing energy managers and process operators. A number of foundries are operating to a good standard, by employing energy managers and regularly auditing; they are in control of their process and working rigorously to improve their efficiency. Simultaneously though, smaller foundries have not adjusted to the new market demands and are not operating in the most energy efficient manner. Important barriers to energy efficiency in these foundries include lack of knowledge on auditing methods, poor knowledge in managing energy consumption, the inefficiency of individual process steps, production disruptions, aging equipment, personnel behavior, inadequate maintenance and lack of investment, automation and research.

Keywords: Energy efficiency; sustainability; UK foundries

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Introduction

Manufacturing sector accounts for one third of the total energy consumption in the United Kingdom [1]. Casting processes are among the most energy intensive manufacturing processes. Although, casting sector has a very long history, as being among the first manufacturing processes that humans mastered, the focus and thus research has been on improving the quality of the process (for example through the famous “10 rules of castings” [2]), and obviously not on the energy efficiency. However, energy efficiency has become important for a number of reasons; to name a few is the energy cost, the green movements, and the improved environmental consciousness. Foundries thus, will have to control and eventually decrease their energy consumption, in order to follow this trend. Further to just following the trends, legislation is also becoming stricter, posing specific requirements to foundries around the world. Indicatively, the Climate Change Agreement published by the U.K. Government [3] required that the foundries have to attain an energy burden target of 25.7 GJ/tonne by 2020. However, the average energy burden for the UK foundry sector in 2013 was 55 GJ/tonne.

In the UK, there are more than 400 foundries [4], with most of them being small and medium enterprises, and as such face great challenges when trying to implement energy efficiency initiatives [5]. Furthermore, no study has been undertaken, to reveal the current status of the UK foundries with regards to energy efficiency. Under this environment, The Engineering and Physical Sciences Research Council (EPSRC), who is the UK's main agency for funding research in engineering and the physical sciences, has funded a research grant to Cranfield University for addressing this research gap. The funded project, under the title “Small is Beautiful” launched on March 2015 and will end on December 2016. The principal objective of the study is to “develop a new philosophy/methodology and a software tool incorporating metrics for the handling of materials and energy throughout the process in foundries using computer numerical process simulation to support the decision making”. The project can be considered of composed of two phases, with phase one being the assessment of the energy efficiency status-quo at the UK foundries, and phase two the development of a software tool that will allow the foundries to implement energy efficiency initiatives.

In the present study, the results of phase one of the “small is beautiful” project will be presented that will lead to the research currently undertaken for completing phase 2. In the context of this research 80 foundries were studied, 60 were contacted and 10 were visited. General energy data were collected using structured questionnaires, interviewing energy managers and process operators. The outcome of these communications with the foundries will be presented and discussed. Important barriers to energy efficiency in the foundries are identified and will be discussed.

Research Methodology

In order to capture the current practices in the foundries in the UK, a survey was undertaken. As a starting point, working closely with Cast Metals Federation (CMF) allowed for identifying foundries to be contacted and interviewed. In figure 1, the foundry sector business in the UK is outlined. There are 426 foundries in the UK producing 523,000 tonnes of casting with a turnover of £2.2 Bn [6]. In 2014, global production of casting increased to more than 105 million metric tonnes, an increase of 2.3% to the previous year [7].

Figure 1: Foundry sector in UK

In total 60 foundries (across a number of casting processes and cast alloys) were contacted over 6 months. The foundries were asked for access to their facilities, and a questionnaire was sent for collecting information. Ten foundries (17% response rate) provided information on the energy consumption profile, materials handling and waste streams. The ten foundries included two investment, four sand and four die casting foundries. These foundries represent a diverse cross-section of the sector in terms of alloys cast, type of products, annual tonnage of casting produced, types of melting and furnaces and the degree of automation.

Furthermore, a total of 100 papers, reports, articles and books have been reviewed as well as attending GIFFA 2015 at Dusseldorf, Germany for five days interviewing various foundries and suppliers to the foundries.

Key findings

Energy consumption monitoring

The visits at foundries and interviews with production and foundry managers revealed that foundries do not monitor the energy consumption in detail, but rather focus in energy bills. One of the key reasons for such practice, as identified by these interviews, is that foundries do not know how to measure the energy consumption of their installed systems. Typical data recorded by foundries are shown in the form of a graph in Figures 2 and 3, where the energy consumption and the production are shown for two different foundries. Such a graphical representation can help foundries focus in periods of time that the performance was better and investigate if practices were different as to establish a cause and effect relationship. However, this level of information (energy consumption on factory level) cannot provide detailed information on the performance for example of various assets in the factory. For example questions such as: “which process step is the most energy demanding so for the foundries to focus in controlling it?”, “how can improvements be assessed if the measured data are on a monthly basis?”, etc. cannot be answered. This is not a problem though of only foundries; most manufacturing companies face similar challenges.

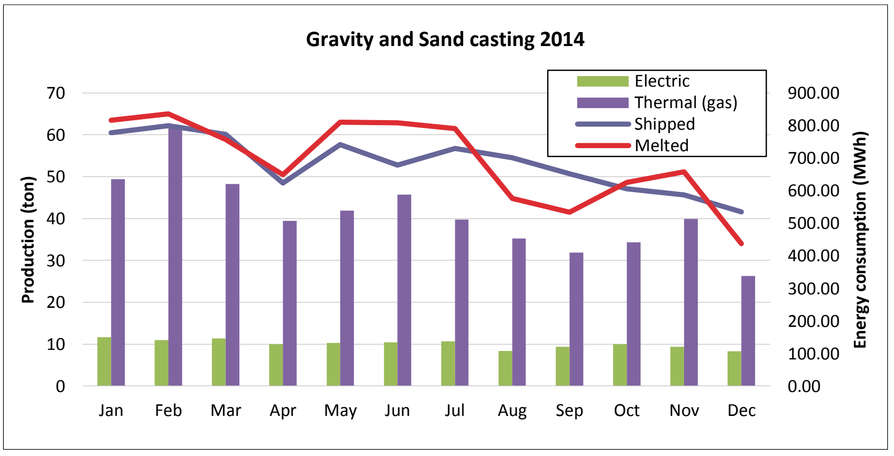

Figure 2: Example of energy data information captured by a gravity and sand casting foundry in the UK

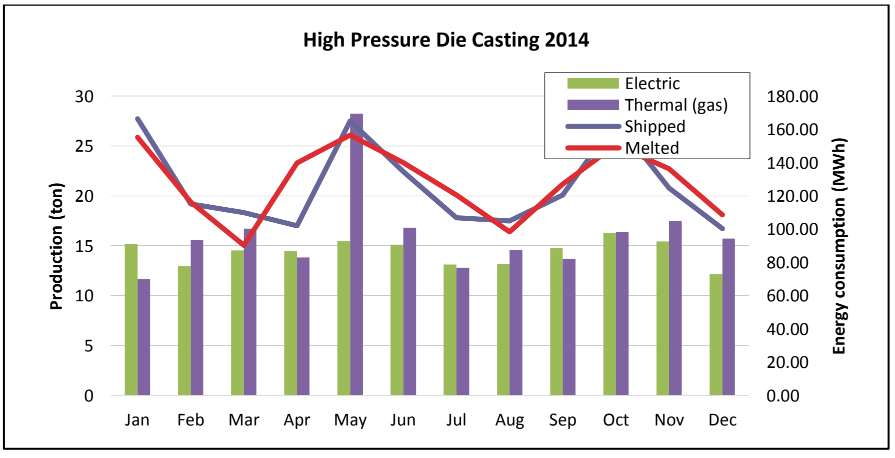

Figure 3: Example of energy data information captured by a high pressure die casting foundry in the UK

Frameworks have been developed for addressing this challenge. Indicatively, Dave et al. [8] developed a framework based on the concept of data granularity and validated it in a furniture manufacturing company. Using such a framework, can allow for the more efficient use of simulation models. Based on the realization that no energy measurement framework exist that is tailored to foundries, Salonitis et al. [9] developed one that will be described in detail in a following section.

Key decision making factors

As a follow up of the preceding finding, the interviews were focused in identifying the key decision making factors that foundries rely upon. Previous studies ([1], [10]) highlighted the need for updating the classical manufacturing decisions attributes (Cost, Quality, Flexibility and Time) by adding another one being the "sustainability" (figure 4). Within the "sustainability" decision attribute, the energy efficiency and the emissions can be considered as key performance indicators (KPIs). The interviews with the foundries, confirmed that UK foundries do not consider energy efficiency and emissions as key decision making factors, but there is a growing understanding of the need to control them.

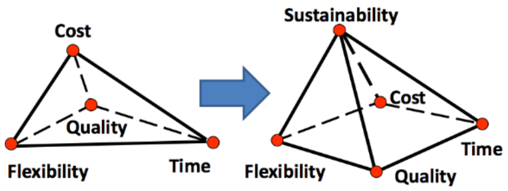

Figure 4: Manufacturing decision making attributes evolution [1], [10]

Different practices with regards energy efficiency

The review of scientific papers and discussions with representatives from international foundries in GIFFA 2015 indicated that major differences on practices between the foundries might exist. As a result, an agreement with four international foundries was set up for benchmarking their practices. The foundries were visited and additionally more than 100 companies and industry experts (including other foundries, suppliers, raw material suppliers etc.) were contacted.

A key difference identified was that the foundries visited closely monitor the energy consumption of a number of phases during casting (not all though) focusing mostly on the consumption of the melting and the holding phases. Considering that these two phases can account for up to 60% of the total consumption [11], this obviously is a good practice. Furthermore, the awareness of the importance of sustainability and energy efficiency was found to be higher, especially with the four big foundries interviewed.

Energy audit framework

Energy and resource measurement aids foundries to understand the quality and quantity of materials and energy used in each step of the process and deal with any inefficiencies and variations during the casting operation. Materials weight can be measured simply after each step of the process, so overall yield can be quantified by adding them up. However, energy consumption of each step of the process needs to be measured regularly on daily, monthly and annual basis. The information required for this stage can be estimated indirectly by calculation using nominal data specified by the manufacturer, operating hours and work load factors or directly by measuring data using meters or data logger systems to monitor the energy consumptions [12]. Energy and materials consumption patterns are the main part of the audit process. These patterns are used to understand the materials and energy flow in a foundry and help to control their cost by identifying areas where waste can occur and where scope for improvement may be possible [13]. This will help management make prompt and on time decisions to avoid losses due to inefficient operations by personnel or equipment.

To address the lack of knowledge on how to measure energy, a simplified framework has been developed that is composed of three major phases: the preparation, the measurement and the analysis phase [9]. Figure 5 shows the framework and the intermediate stages.

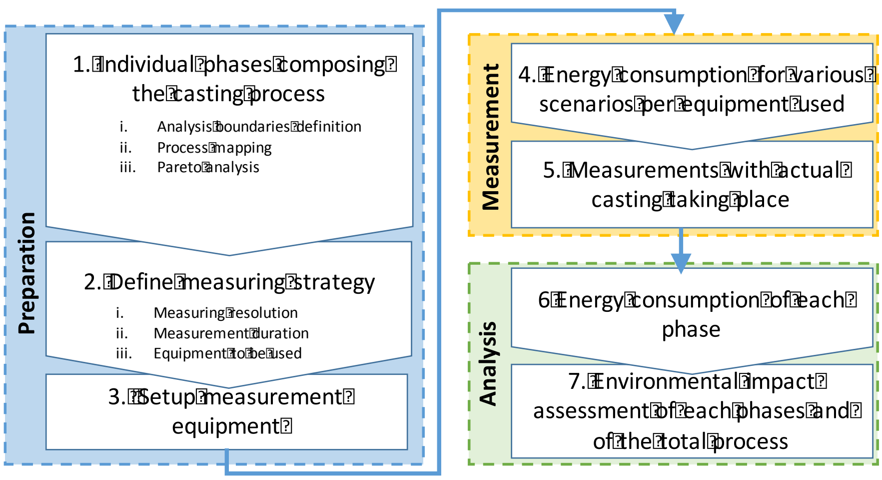

Figure 5. Proposed energy measurement framework

The first phase is about setting up the energy audit. Initially manufacturing process chain is analyzed and decomposed into specific processes such as melting, holding, casting etc. Each one of these phases is analyzed as per the specific needs that it might have in energy, source of energy (electricity, gas, etc.), the recycling streams etc. Based on this information, the measuring strategy can be decided, in terms of type of sensors to be used, resolution of data (data granularity), measuring period etc. These data can be represented in various forms, IDEF0 being one of this was found to be very practical. In figure 6, the IDEF0 modelling of an aluminum gravity die casting process in one of the visited foundries is shown.

Within the second phase (measurement phase) all the measurements are taking place (including energy usage and materials flows – yields, scrap, machining quantities etc.). Such measurements can be graphically represented in the form of Sankey diagrams. The final phase deals with the analysis of the results. The energy consumed from each phase can be estimated after direct measurement. Using a Pareto style analysis, the various subsystems are ranked with regard to the energy consumption, establishing in this way which subsystems are best to focus improvement efforts. Figure 7 shows as an example the outcome of such analysis for an aluminum gravity die casting process, highlighting where the analysis is consumed.

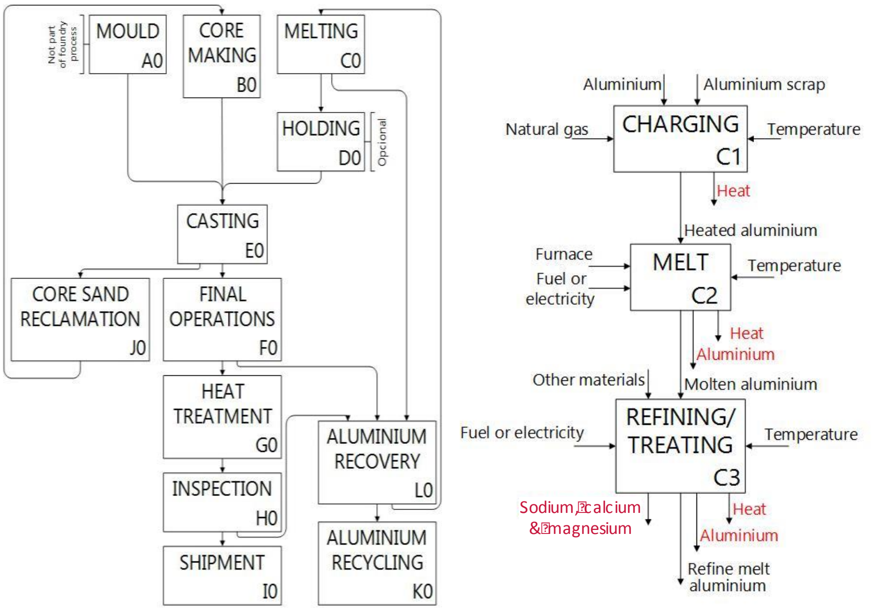

Figure 6. IDEF0 modelling of aluminum gravity die custing (left) and melting sub-process detailed IDEF0 diagram (right)

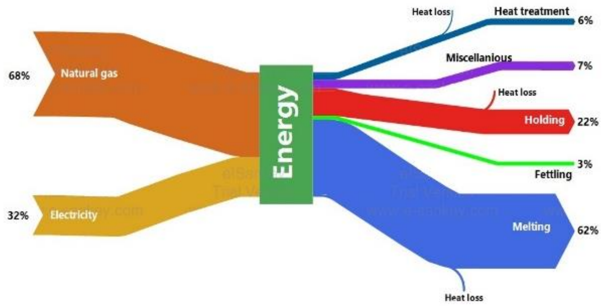

Figure 7. Energy consumption and losses for an aluminum gravity die casting foundry

Next steps

As a result of the survey, the need for a software that will be able to easily visualise the energy and material flows in a foundry plant was confirmed. A detailed analysis of the entire production chain from charge to waste will be enabled by the use of the computer program. This analysis will help decision makers to experiment scenarios where different improvements are implemented and the software will allow to quickly evaluate their impact in a visual manner (e.g. by means of process flow or Sankey diagrams). In particular, the identification of neglected or difficult to identify waste can uncover potential synergies. Another useful application of the computer program would be training the behavior of foundry personnel in showing clearly the impact of their actions on the overall performance. Finally, the thorough analysis previously described may benchmark the performance of the plant against similar ones. The first step to this approach was the development of a simple to use Excel tool (figure 8). This excel tool was validated during the benchmarking exercise with the four international foundries. The next version of the tool will be a stand-alone software to be used for the collection of energy and material flow, the comparison of these with the benchmarking data and the identification of areas of “quick-wins” for the foundries. This tool will be able to provide insight to the process chain to be selected, will cover the supply chain (for example the mould/die making suppliers, the manufacturers of the inserts, etc.) and be linked to the product design software.

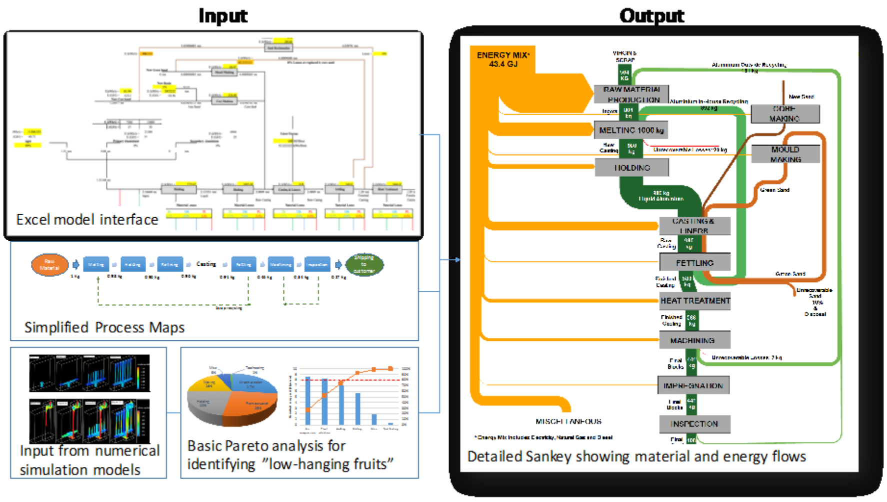

Figure 8: Outline of the software core idea

The work-flow of the program is designed to start from an input file describing the plant that is parsed and stored in the form of an internal data structure. A modular architecture interfaces the tool with other packages (e.g. graphviz) for the final graphical representation using the information contained in the mentioned internal data structure. The tool produces automatically Process Flow Diagrams (PFDs) – e.g. Figure 9 – with a user-specified set of colours and shapes to represent components and material or energy flows. The user can select the specific categories of flow to be represented (material or energy, although this could be extended) or all of them. In this last case, it is possible to specify that the flows describing the same physical process in two different categories will be hidden in the PFD to avoid double accounting. For example, in a melting furnace fossil fuels and air (material flows) describe the same physical process of thermal energy input and it is possible to request the visualisation of only one of them. Thus, besides a default behaviour, the program is designed to be largely customisable on a case to case basis. Another envisaged output module is a Sankey diagram generator. Particular attention has been devoted during the design of the computer program to make it easily extensible to introduce future additional flows (e.g. embedded energy) and new graphical output modules [14].

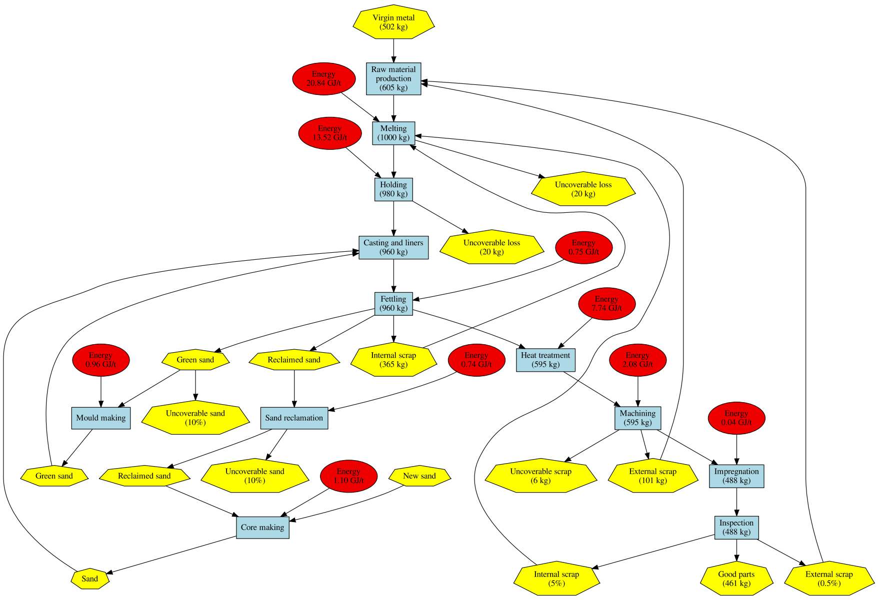

Figure 9: Example showing the overall material and energy flows in a foundry melting aluminium alloys with a low pressure sand casting process [14].

Conclusions

In the present study the outcome of the first phase of "Small is Beautiful" EPSRC funded project is presented. The project was based on an intensive survey of the current practices the UK foundries are employing with regards the energy and resource efficiency.

The key findings from this survey can be summarized into: foundries do not monitor the energy consumption in detail, but rather focus in energy bills, foundries do not know how to measure the energy consumption of their installed systems, subsequently energy consumption and emissions are not considered to be among the key decision making criteria, and finally there are indications of major differences on practices between the foundries.

The authors, for addressing these findings have developed a new energy measurement framework for the needs of the foundries. Furthermore, they are in the process of developing a software that will be able to effectively represent material and energy flows involved in the process and will be able to integrate with legacy systems.

Acknowledgements

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