RESOURCE EFFICIENT AND CLEANER PRODUCTION IN SELECTED FOUNDRIES THROUGH ENVIRONMENTAL PERFORMANCE EVALUATION

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RESOURCE EFFICIENT AND CLEANER PRODUCTION IN SELECTED FOUNDRIES THROUGH ENVIRONMENTAL PERFORMANCE EVALUATION

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ABSTRACT

RESOURCE EFFICIENT AND CLEANER PRODUCTION IN SELECTED FOUNDRIES THROUGH ENVIRONMENTAL PERFORMANCE EVALUATION

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The main objective of this study was to develop Resource Efficient and Cleaner Production (RECP) measures for the ferrous foundry sector. For this purpose, environmental performance evaluation and benchmarking studies were conducted in six ferrous foundries. The environmental performance was calculated by using environmental performance indicators of specific energy and water use, metal yield and sand regeneration ratio. The gap between the benchmarks and actual performances revealed the improvement potential.

The results indicated that specific energy consumption can be improved by 27% and 54% for iron and steel foundries respectively, which leads to decrease carbon emissions by 140,918 ton/ year. The water consumption was two times more than the benchmarks and 38,342 m^3 of water can be saved annually. The improvement potential for sand recovery ratio depends upon the moulding type and sand regeneration technique. The application of thermal sand regeneration will decrease the waste foundry sand by 38,018 ton. With regard to metal yield, the results showed that it can be increased by 21% (for iron) and 5% (for steel).

To improve the environmental performance, 21 options obtained from literature were discussed with the company representatives and 12 options were recommended: closing the furnace cover, using shredded scrap, preheating the charge, installing waste heat recovery systems, using more energy efficient lighting systems, installing automatic pouring systems, using casting simulation software, applying lost foam/ investment casting, using green sand, installing thermal sand regeneration system, using closed loop mechanical water chillers instead of cooling towers and reducing sand cooling requirements.

Keywords: Resource efficient and cleaner production (RECP), foundry, environmental performance evaluation

ÖZ

SEÇİLEN DÖKÜMHANELERDE ÇEVRESEL PERFORMANS DEĞERLENDİRMESİ ARACILIĞIYLA KAYNAK VERİMLİLİĞİ VE TEMİZ ÜRETİM

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Bu çalışmanın genel hedefi demir ve çelik döküm sektörü için kaynak verimliliğini artırmak ve temiz üretim uygulamaları geliştirmektir. Bu amaçla, altı dökümhane için çevresel performans değerlendirmesi ve karşılaştırma çalışmaları yapılmıştır. Firmaların çevresel performansları, birim üretim başına harcanan elektrik ve su miktarları, metal verimliliği ve kum geri kazanım oranlarını belirten göstergeler aracılığıyla belirlenmiştir. Hesaplanan çevresel performans değerleri ile bilimsel kaynaklarda bulunan en iyi performans değerlerinin karşılaştırılması sonucu elde edilen fark gelişme potansiyelini ortaya çıkarmıştır.

Sonuçlar enerji verimliliğinin demir ve çelik döküm üretimi için sırasıyla %27 ve %54 artırılabileceğini göstermiştir. Bu iyileşme ile CO_2 salınımı 140,918 ton/yıl azalacaktır. Su tüketimi en iyi performans değerlerine göre iki kat daha fazladır ve yılda 38,342 m^3 su tasarrufu sağlanabilir. Kum geri kazanım oranını artırma potensiyeli kalıplama türüne ve kum geri kazanım tekniğine göre değişmektedir. Isıl kum geri kazanım yönteminin kullanılması ile atık kum miktarı 38,018 ton azalacaktır. Çalışma sonucunda elde edilen sonuçlar metal verimliliğinin demir için %21 ve çelik için %5 artırılabileceğini göstermiştir.

Çevresel perfomansı artırmak için, literatür araştırması sonucu elde edilen 21 uygulama seçeneği firma temsilcileri ile tartışılmış ve bunlar arasından 12 seçenek uygulanmak üzere önerilmiştir. Bunlar, ocağın kapağını kapatmak, kırpılmış hurda kullanmak, eritilecek metali ısıtmak, atık ısı geri kazanım sistemi kurmak, enerji verimliliği daha yüksek olan aydınlatma sistemlerini kullanmak, otomatik döküm sistemleri kurmak, döküm similasyon yazılımları kullanmak, kaybolan köpük döküm işlemi uygulamak, yaş kum kullanmak, ısıl geri kazanım sistemi kurmak, kapalı sistem ocak soğutma sistemlerini kullanmak ve kumun soğutma ihtiyacını azaltmaktır.

Anahtar kelimeler: Kaynak verimliliği ve temiz üretim, dökümhaneler, çevresel performans değerlendirmesi

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ABBREVIATIONS

AFS	: American Foundry Society
BAT	: Best Available Techniques
BREF	: Reference document on best available techniques in the smitheries and foundries industry
CAD	: Computer Aided Design
CAM	: Computer Aided Manufacturing
CIPEC	: Canadian Industry Program for Energy Conservation
CNC	: Computer Numerical Controlled
CP	: Cleaner Production
EC	: European Commission
ECI	: Environmental Condition Indicator
EU	: European Union
EPE	: Environmental Performance Evaluation
EPI	: Environmental Performance Indicator
FIA	: Foundries Industrial Area
IED	: Industrial Emission Directive
IFC	: International Finance Corporation
IPPC	: Integrated Pollution Prevention Control
KPI	: Key Performance Indicator
KOSGEB	: Small and Medium Enterprises Development Organization
MoD	: Ministry of Development
MoEF	: Ministry of Environment and Urbanization (Forestry)
MoEU	: Ministry of Environment and Urbanization
MOSIT	: Ministry of Science, Industry and Trade
OIZ	: Organized industrial zone
OPI	: Operation performance indicator
PAH	: Polycyclic Aromatic Hydrocarbons
RECP	: Resource Efficient and Cleaner Production
SEC	: Specific Energy Consumption
SME	: Small and Medium sized Enterprise
SSR	: Secondary Sand Regeneration
SWC	: Specific Water Consumption

TFA	: Turkish Foundry Association
UN	: United Nations
UNEP	: *United Nations Environment Program*
USEPA	: United States Environmental Protection Agency
WFS	: Waste Foundry Sand
VOC	: Volatile Organic Compounds
VFD	: Variable Frequency Drive

CHAPTER 1

INTRODUCTION

The cleaner production (CP) approach is an integral part of the global sustainable development agenda. International efforts to promote the transition towards green industry and green economy that can meet society's needs while preserving the natural systems has required the broadening of the definition of CP by including the resource efficiency. Resource efficient and cleaner production (RECP) is defined by United Nations Environment Program (UNEP) as "the continuous application of an integrated preventive environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" (UNEP, 2010a). The only difference between the CP and RECP definitions is the addition of word "preventive" therefore RECP builds upon the CP in accelerating the application of preventive environmental strategies. RECP is a proactive approach which aims to improve the production efficiency by more vigorous use of natural resources. Improving resource efficiency not only reduces the material, water and energy consumption but also support competitiveness (EC, 2011a).

Sustainable consumption and production is a broader concept promoting both the RECP and sustainable consumption patterns. It is defined by Norwegian Ministry of Environment in Oslo Symposium (1994) as "The use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations" (UNEP, 2010b).

There is greater recognition that promoting sustainable consumption and production patterns and improving resource efficiency are essential for achieving global sustainable development (Akenji and Bengtsson, 2014). This ambition is reflected in policies at all level of governance. A number of countries not only within European Union (EU) but also Japan, Korea, the United States, China and others are implementing policies to endeavor the resource efficiency. The 10-year framework of programs on sustainable consumption and production patterns was adopted at the United Nations (UN) Conference on Sustainable Development (Rio +20) (UN, 2012).

Focusing on resource efficiency in policy making is considered as an opportunity for the EU. A priority objective of the EU's 7th Environment Action Program is to 'turn the EU into a resource-efficient, green and competitive low-carbon economy'. Resource efficiency is part of the EU's growth strategy for 2020 (EC, 2011a). The Roadmap to a Resource Efficient Europe outlines the structural and technological changes needed by 2050 and sets the milestones to be reached by 2020, one of which is determining the minimum environmental performance standards to remove the least resource efficient and most polluting products from the market. Policy incentives are obliged for the member states to boost the majority of the companies to measure and benchmark their lifecycle resource efficiency (EC, 2011b).

Environmental protection and sustainable use of resources are focused in the 10th Development Plan (2014- 2018) of Turkey. The plan promotes cleaner production technologies, green public procurement and sustainable consumption (MoD, 2013). The Turkish Industrial Strategy Document (2015-2018) defines the targets and policies based on the development plan. The transformation to resource efficient, greener and competitive industrial system is one of three main targets (MOSIT, 2015).

As presented above, the RECP issue was identified as being importance in many policy and strategy documents. However, sector based actions are required in order to put RECP policies into practice (Ulutaş et al., 2012). The top five high- priority industrial sectors of Turkey for RECP practices were determined as the basic metals industry, food products and beverages, chemicals and chemical products, other nonmetallic mineral products and textile products based on the project conducted for the Ministry of Environment and Urbanization (Forestry) (MoEF, 2010). In recent years, many studies have focused on the investigation of the RECP opportunities and applications in various industrial sectors. However, little work has been done for the RECP opportunity assessment of the foundry sector in Turkey which is a sub-sector of the basic metal industry.

Among the studies that demonstrated a wide range of RECP opportunities exist for the foundry operations which are implemented in some countries, most have focused on improving the energy efficiency. A process based case study was conducted in India in which an improved melting technology, i.e. divided blast cupola (DBC) was proposed to increase the energy efficiency, and consequently to reduce the greenhouse gas emissions to a large extent (Pal et al, 2008). Arasu and Jeffrey (2009) stated that it is possible to reduce the energy consumption and increasing productivity in foundry sector by using energy accounting approach. Fore and Mbohwa (2010) applied cleaner production method in a foundry company and they showed that there are many opportunities to improve energy efficiency and to reduce the wastes in foundry process. The guidelines for the application of best available techniques (BATs) in the following areas were developed in another study based on the literature research: pollution prevention and control, pollution reduction targets, treatment technologies, emission guidelines, monitoring and reporting (Fatta et al, 2004). The overall environmental impacts of foundry processes and products without and with the application of secondary sand regeneration (SSR) technique was assessed in a Master of Science thesis by using the life cycle approach. The study revealed that the application of SSR which is indicated as BAT in the literature does not reduce environmental impacts in the whole life cycle of foundry processes due to its energy demand. However, considering the reduction in the amount of waste foundry sand and fresh sand transported, it was recommended to consider the economic feasibility of SSR application while deciding its application (Yiğit, 2013).

In addition to these academic studies, there are some projects conducted for the foundry sector in order to identify RECP opportunities and to develop guidance for the use of the individual companies from the foundry industry. A detailed Manual and Self-Assessment Guide has been developed in the project called “Cleaner Production in the Queensland Foundry Industry” to provide a detailed list of opportunities that foundries may be able to apply to their own processes in Australia (UNEP, 1999). A cross sector benchmarking study was undertaken in Russia by the International Finance Corporation (IFC) comparing the Russian and European foundry sectors. It provided guidelines to individual foundries as well as to the broader sector to improve their resource efficiency potential. This study demonstrated that Russia’s ferrous foundry industry could save up to $3.3 billion annually, and improve individual foundry profitability by up to 15 percent, by matching EU standards with respect to more efficient use of natural resources (IFC, 2011). The Ministry of Environment and Urbanization of Turkey, prepared a guideline for the foundry industry including the cleaner production measures to prevent, reduce and reuse of the hazardous wastes (MoEU, 2012).

Foundries are energy intensive factories. In addition to the high energy consumption large amounts of sand is used within the process. Key environmental issues with regard to the foundry operations are mainly related to these two factors. Energy efficiency and management of heat are important environmental aspects. The Turkish Foundry Association reported that 3.179.000 MW electricity was used by foundries in 2012 in order to produce 1.445.000 ton of casting (TFA, 2013). The presence of thermal process and use of mineral additives causes the air emissions of mineral dust, acidifying compounds, products of incomplete combustion and volatile organic carbons (VOCs). Dust which may contain metal and metal oxides may be emitted in all process steps. Although most of the sand is recovered, large amount of sand is wasted which are usually disposed of. The Ministry of Environment and Urbanization reported that 450.000 ton of waste was generated and disposed of in 2007 for production of 1.294.500 ton of casting. The quantities of waste types were specified as: sand (65%), slag (10%), dust-sludge (15%) and others (refractories, oil, stone, paint, barrel etc.) (MoEU, 2012). In addition to these, the foundries may have high water consumption depending on the cooling and air control system. The water is mainly used for cooling systems of the furnaces, quenching and de-dusting operations. The waste water amount is less since the cooling water is internally recirculated or reused. However, it needs special attention in case wet de-dusting and (high) pressure die casting are applied.

The main objective of this study was to develop RECP measures for the ferrous foundry sector. To this purpose, environmental performance evaluation (EPE) and benchmarking studies were conducted for the selected companies. The EPE of the companies were determined in terms of the selected Environmental Performance Indicators (EPI) of specific energy consumption (kWh/ ton of good casting), metal yield (%), sand recovery ratio (%) and specific water consumption (m^3/ ton of good casting). The gap between the calculated EPI and benchmark values indicated the improvement potential. Considering the determined potential and best available practices in literature, the RECP measures were recommended.

The foundries investigated in this study produce multiple products depending on the customer needs. Total production amount of six foundries participated this study was 36,516.53 ton over the year 2014. This amount corresponds to around 3% of the total casting produced in Turkey in 2014.

The foundries are classified by the Turkish Foundry Association under three groups based on their annual production capacity and number of employees: large, small and medium sized and micro sized companies. Most of the foundries in Turkey are micro, small and medium sized companies producing ferrous castings. In this study, ferrous foundries with different sizes and annual production capacities were selected. Five of the studied companies had employee in the range of 44-250 and one company had 560 employees. Four companies had annual production capacity of 10,000-12,000 tons, one company had total capacity of 35,000 ton in two foundry shop, and one company had 5,500 ton capacity. Therefore, at least one foundry from each size in terms of annual capacity and number of employee was included in the study. The micro sized companies with capacities of 360 and 1,000 tons could not been included within the study since they could not provide the required data.

CHAPTER 2

BACKGROUND INFORMATION

2.1. Introduction to the Foundry Industry

A foundry is a factory that produces metal castings. Metals are cast into shapes by melting them into a liquid, pouring the metal in a mold, and removing the mold material or casting after the metal has solidified as it cools. Metal casting (NACE code: 27.5) is a sub-sector of the basic metal industry. The foundries have an important place in the manufacturing sector since the castings are required as an input in almost all industrial sectors. Foundry products are most often used in automobiles, plumbing fixtures, train locomotives, airplanes and as metal pieces in other kinds of equipment.

Metal casting is not only an energy intensive industry but also produces various types of wastes based on the applied techniques in the process. Some of the environmental issues related to foundry process are high energy consumption (Arasu and Jeffrey, 2009; EC 2005); air emissions in the form of mineral dusts, acidifying compounds, products of incomplete combustion and volatile organic carbons (EC, 2005; USEPA, 1998), solid waste production including sand, foundry dust, refractories, acid/ basic slags, broken molds (Miguel et al., 2012; Zanetti and Fiore, 2002; Ruiz et al., 2000) and wastewater production containing insoluble solids, phenol and oil (EC, 2005).

The foundries are classified according to type of metal input. Ferrous foundries process iron and steel, whereas the non-ferrous foundries use aluminum, magnesium, copper, zinc and lead. Depending on the type of melting furnace (induction furnace, cupola furnace, rotary etc.) and the type of mold (e.g. sand molding, die casting etc.), the applied techniques differ in foundries (EC, 2005).

2.1.1 Overview of the Foundry Process

The production process is divided into five major steps (Figure 1).

1. Pattern making
2. Mold and core making
3. Metal melting and treatment
4. Metal Casting
5. Finishing

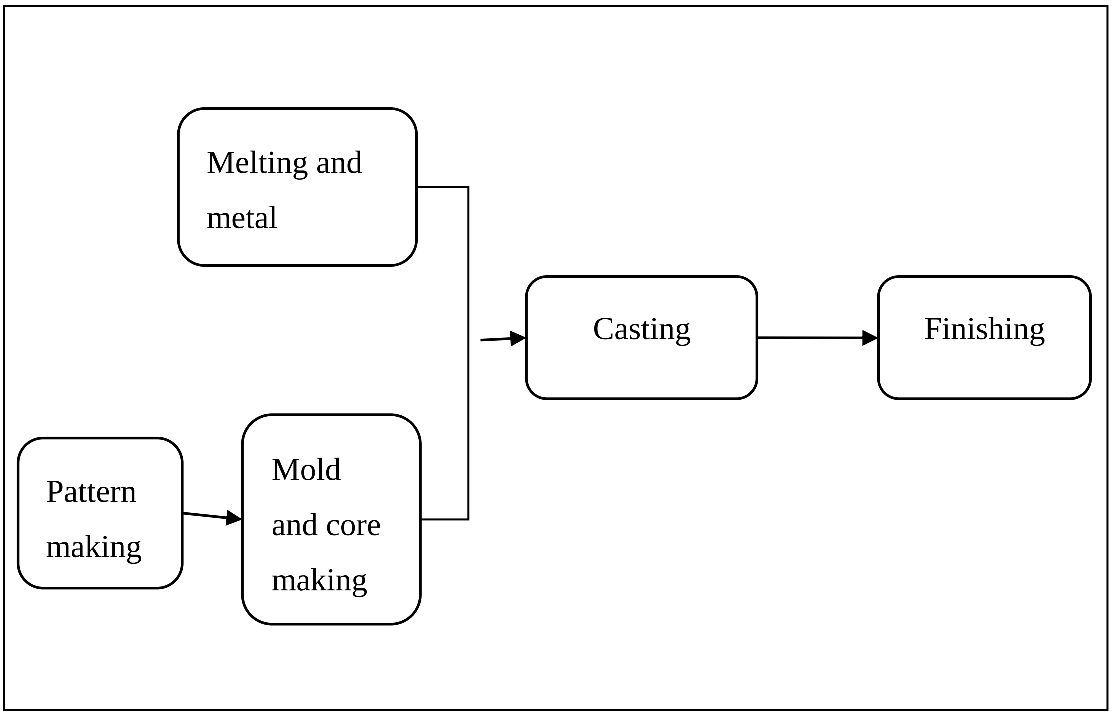

Figure 1 Foundry process flow chart (adopted from EC, 2005)

2.1.1.1. Pattern making

The first step in foundry production is the pattern making. Pattern is a physical copy of the desired end product. Hand tools, universal machines and computer aided design (CAD) / computer aided manufacturing (CAM) system on computer-numerical-controlled (CNC) machines are used in pattern making. The patterns are typically made of metal, plastic, wood or plaster (EC, 2005).

2.1.1.2. Mold and core making

The exterior shape of the product is given in mold. The type of material used for making the mold depends on the type of metal being casted and the desired shape of the final product. Compressed air, natural gas and electricity are also consumed during the process.

The molds used in foundry operations are classified as permanent or lost. Permanent molds are multi use molds which are typically metallic and are used for gravity and low pressure casting, pressure die-casting and centrifugal casting. On the other hand, the lost molds are single use and are generally made out of sand. Sand is mixed with various chemicals, clay and water in mold production process and gaseous or volatile reaction products and excess reagents are emitted. The refractory materials (silica sand, chromite sand, zircon sand or olivine sand) constitutes up to 95-99% of the raw materials used in mold making (EC, 2005).

Another classification of the foundry sands is done based on the type of binder system used in metal casting. There are two types in this classification: clay bonded sand (green sand) and chemically bonded sand (Siddique et al, 2010). Green sand is most widely used in the molding process (Basar and Aksoy, 2012; USEPA, 2014). The green sand is made of silica sand (85-95%) mixed with a binding material (a natural clay, bentonite) (5-10%), a coal dust (3-9%) and water (2-5%) (EPA, 2012). If chemical binders like resin are used as a binder in mold making, the sand is named as chemically bonded sand. Resins can be classified according to the hardening method: cold-setting, gas-hardened and hot curing resins.

The detailed interior shapes of the castings are created by using cores which are resistant to high temperature of the molten metal and easily dispersible from the metal after cooling. Sand mixtures are used for core production. Resins or other chemical binders are added in order to strengthen the properties of the core to withstand molten metal (Zannetti and Fiore, 2002).

When lost molds are used a significant amount of waste foundry sand is generated. After several reuses in the process the mold mixture made from sand loses the properties necessary for the fabrication of new molds, thus a portion of the sand is continuously removed and replaced with virgin sand (Mastella et al, 2014; EC, 2005). The spent foundry sand is either recycled in a non-foundry application or disposed to landfill. According to the MoEU, the production of a ton of cast metal generates approximately 0.6 to 0.8 ton of wastes, and 0.4 to 0.6 ton of these waste is sand (MoEU, 2012). Disposal of the solid wastes into landfill created greatest environmental impact of foundry operations due to their large volumes (Yılmaz et al, 2014).

Although disposal regulations for waste foundry sand (WFS) do vary among countries, the majority of molding sands is not considered to be hazardous in nature and can be sent to landfill (USEPA, 2002; Miguel et al., 2012). Waste foundry sand is typically used as landfill cover in Turkey and only a small amount is reused for engineering purposes because of the lack of information and research on the potential fields of WFS (Basar and Aksoy, 2012).

Regeneration of used sand is a standard process in foundries. Even in operations that undertake a high level of reclamation, some new sand is required to maintain the quality of the sand in the system. In regeneration process, the sand is classified in two: one is mono sand which consists only of bentonite or chemically bonded sand, and the other is mixed sand that consists of bentonite and chemically bonded sand(s) or several chemically bonded sand.

There are two methods for the regeneration of sand: primary and secondary regeneration. In primary regeneration, the mold and cores are processed to obtain the sand. The process includes screening the sand, removing tramp metal, and separating and removing fines and over-sized agglomerates. The main techniques are vibration, rotating drum or shot-blasting. The primary regenerated sand is used for mold only since its quality is not sufficient for core making.

Secondary regeneration consists of more aggressive mechanical processing, thermal treatment and wet processes to remove residual binder. The sand can be suitable for cores (EC, 2005). The main secondary regeneration techniques are: dry mechanical reclamation, wet mechanical reclamation and thermal reclamation (Zanetti and Fiore, 2002; Fiore and Zanetti, 2008). Thermal sand reclamation employs heat in a rotary kiln, multiple-hearth furnaces, or a fluidized bed to combust binders and contaminants. Dry mechanical sand reclamation is based on attrition and it removes lumps and binders from the sand. Mechanical scrubbing moves each sand grain through sand to metal or sand-to-sand interface to remove any impurities. Clay bonded sands are efficiently regenerated with the wet mechanical process as there is a wet mechanical attrition phase that is performed using water and hydrochloric or sulphuric acid (Zanetti and Fiore, 2002).

2.1.1. 3. Metal melting and treatment

Metal ignots and scrap are melted in furnaces. The slag waste results from the reaction of the impurities with the calcium carbonates and silicates. The slag is floated to the surface. Different alloys are added to satisfy the desired metallurgical properties of the castings based on the laboratory analysis of the melted metal.

Several types of furnaces are used in foundries depending on the type of metal being melted. Furnace types include cupolas, electric arc, induction and rotary. The mass stream differs for each furnace based on its properties. However, ferrous material (pigs, scrap, swarf, foundry returns), alloying metal (ferro alloys), energy and cooling water are the common inputs and metal alloy, dust, organic pollutants, slag and waste refractory are the common outputs for each type of the furnace (EC, 2005).

2.1.1.4. Metal casting

The metal casting process involves the pouring of the molten metal into mold and the removal of the mold after cooling (shake-out). Ladles are used to transfer the molten metal. The dust control equipment is used during the shake out. The main outputs released in this step are the used sand, castings, combustion products (from preheating of pouring ladles), organic pollutants (phenol, formaldehyde, amine, hydrogen cyanide, polycyclic aromatic hydrocarbons (PAH), benzene, volatile organic compounds (VOC), odor, waste from exhaust air cleaning (dry/sludge) and dust from shake out (EC, 2005).

2.1.1.5. Finishing and post casting operations

Finishing operations are applied in order to remove the residual sand, core, pouring burrs, and casting errors and to prepare the casting for further operations. The finished castings which do not satisfy the quality standards returned to process as internal scrap. Water and energy are used in this step. The emissions produced are dust, volatized metals, combustion products from thermal operations and wastewater.

The following finishing operations are often applied in foundries (EC, 2005).

- Shot or tumble blasting to remove residual sand, oxides and surface scale. It is labor intensive and non-value adding operation which requires electricity and produces internal scrap.
- Heat treatment, including annealing, tempering, normalizing and quenching (in water or oil), to enhance mechanical properties.
- Grinding, sawing or arc air (oxy-propane cutting) to remove excess metal.
- Welding to rectify the defects.
- Machining.
- Nondestructive testing to check for defects.
- Priming, painting or application of a rust preventative coating.

The general flow diagram is shown in Figure 2 for a typical foundry.

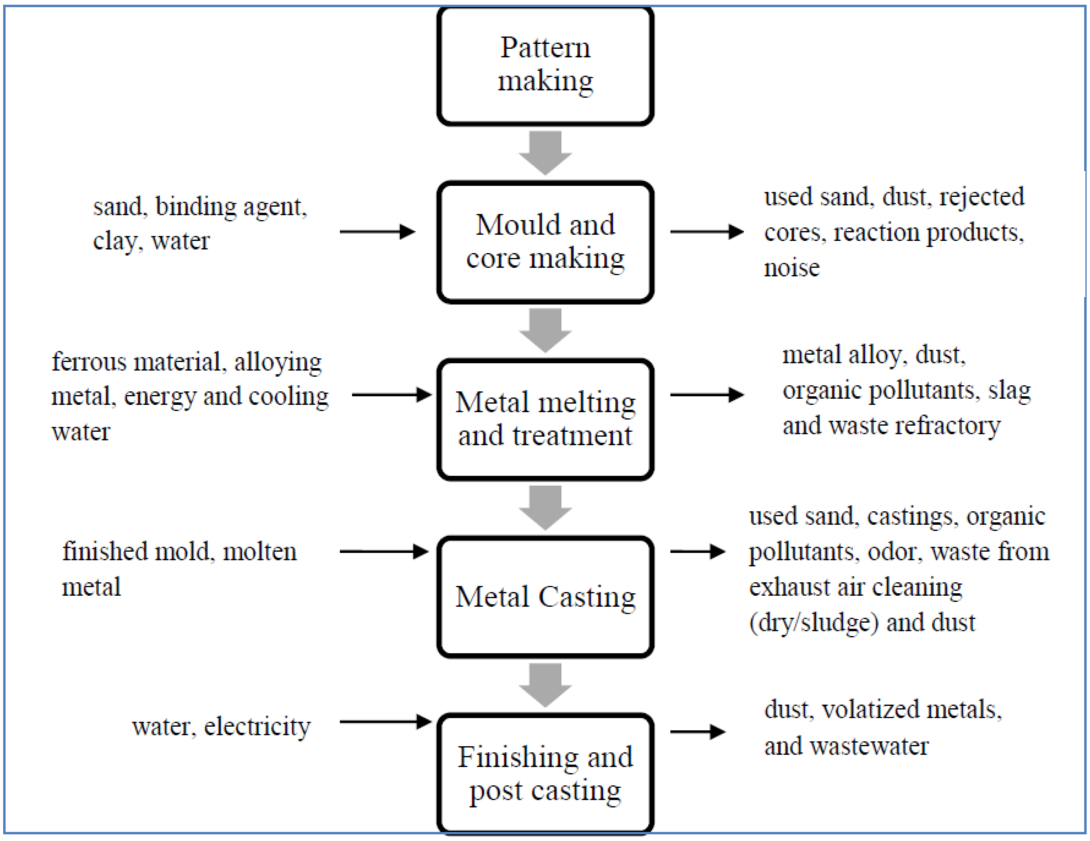

Figure 2 Inputs and outputs for a ferrous foundry (EC, 2005)

2.1.2. The Profile of the Metal Casting Industry in Turkey

The production in the Turkish foundry sector (about 1,450,000 ton of casting) was ranked as the 13th in the World in 2012. Turkey was among the top five countries in Europe with highest production along with Germany, France, Italy and Spain (AFS, 2013). It was reported that 61% (by weight) of the production was imported, 75% of which was sold to EU countries (TFA, 2013). The export and import of 5.2 and 4.95 billion dollars, respectively, were recorded in foundry industry in Turkey (MOSIT, 2012).

The Turkish metal casting industry, which was composed of approximately 1,400 facilities by the year 2012, provides employment to 33,000 people. The Turkish Foundry Association, classified the foundries in three groups based on their size: l) Large industrial facilities; 2) Small and medium enterprises (SMEs) and 3) Micro enterprises (family companies having 2-3 employee). Most of the foundries in

Turkey are micro, small and medium sized whereas the 58% of the production took place in 15 large industrial facilities having annual capacity of 30,000 tons and above. Although the industry is spread nationwide, five provinces namely İstanbul, Konya, İzmir, Ankara and Bursa account for 75 percent of the metal casting facilities.

On the basis of alloy type iron, steel and non-ferrous metals represents 60%, 9% and 31% respectively. The industry's end use market is led by machine, transport vehicles and defense industry. (TFA, 2013). The industry is under increasing pressures of low profit margin, rising prices of energy and raw materials and measures required to comply with the environmental regulations (TFA, 2013). Improving RECP applications reduces the energy and the raw material consumption through increasing the production efficiency. Therefore, the RECP measures not only provide the industry to save money but also to help complying with the environmental regulation by preventing the pollution at source.

2.1.3 Environmental Profile of Foundry Industry

Various types of wastes are produced by the foundries depending on the metal type, the furnace type and the used molding technology. The major environmental issues are disposal of solid wastes, electricity generation and melting of ferrous materials (Yılmaz et al, 2014). The general mass stream overview for the foundry process is given in Figure 3.

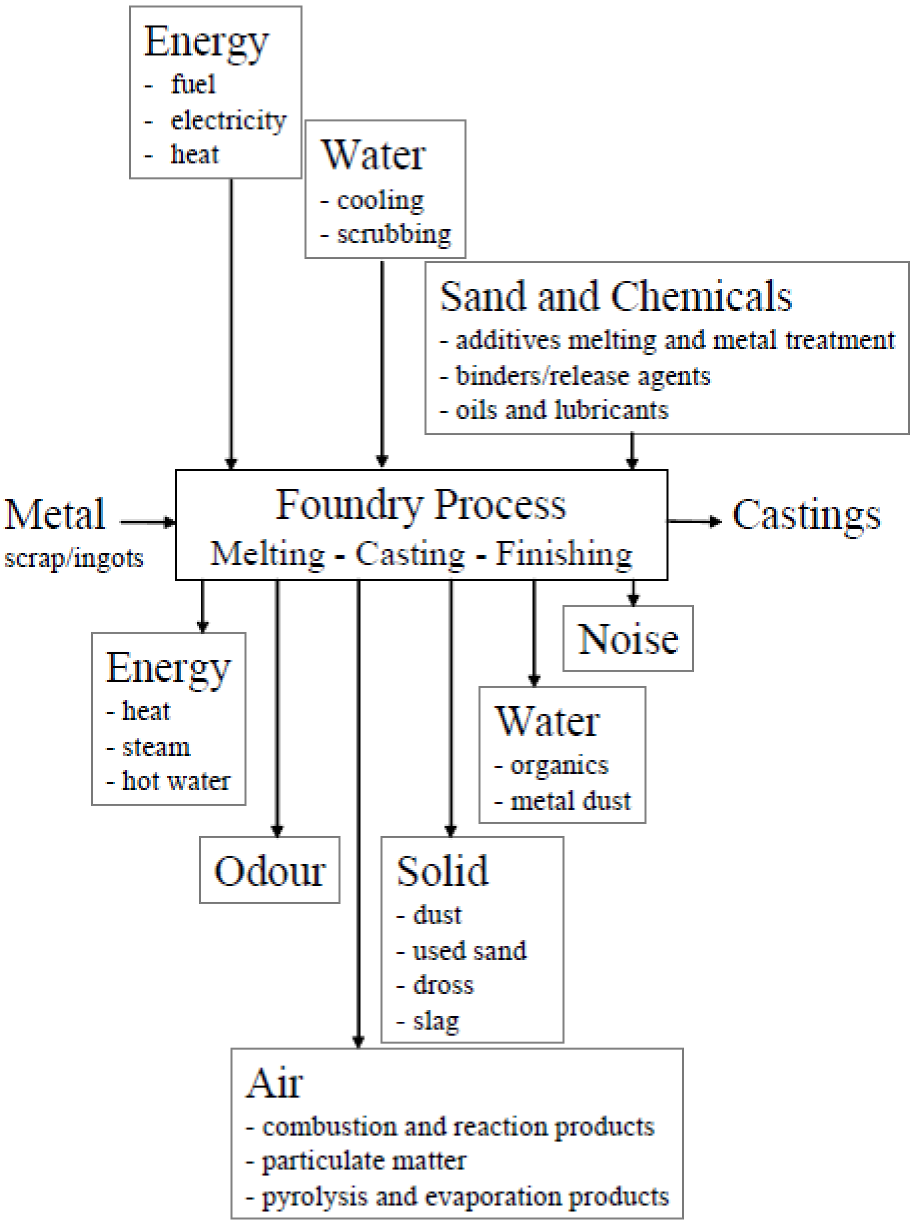

Figure 3 Mass stream overview for foundry process (EC, 2005)

2.1.3.1 Solid waste

Solid waste makes up a large portion of the pollution from foundries. Around 0.6 to 0.8 tons of waste per ton of casting is produced in foundries, and 0.4 to 0.6 tons of these wastes are the waste foundry sands. Other wastes include slag, collected dust, refractory lining etc (MoEU, 2012).

Sand waste from foundries using sand molds has been identified as the most pressing waste problem in foundries. Significant amount of sand waste is generated since the mold mixture losses its properties after several uses (Mastella et al, 2014). Although a high level of sand reclamation undertaken in foundries some new sand is required in order to maintain the desired mold quality and so sand is lost from the system. This waste sand may be sent to landfill, reclaimed off-site or put to beneficial reuse. The WFS from ferrous foundries can be sent to unlined landfill since they are not usually considered to be hazardous, typically passing TCLP (toxic characteristic leaching procedure) tests. The disposal regulations vary among countries however the majority of the WFSs are not regarded as hazardous (Miguel et al., 2012).

Slag is another waste which contains metal and metal oxides. It is formed within the furnace during the melting. It floats in the surface since it is lighter than melted metal. The electric induction furnaces produce less slag due to the fewer additives required. In general it is not a hazardous waste and can be sent to landfill.

The waste types generated in ferrous foundries are shown on Table 1.

Table 1 The waste types generated in ferrous foundries (MoEU, 2012)

Process	**Waste type**	**Quantity**
Melting	Slag	Depend on the furnace type and scrap
Melting	Discarded refractory lining	Depend on the furnace type
Mold making	Packing waste with/without dangerous contaminants	Unlikely
Mold making	Bonding material wastes	Little
Mold making (cold box)	Ammonium sulfate	Little, 0.1%
Mold making and	Core sand	0-5 %

Table 1 The waste types generated in ferrous foundries (MoEU, 2012) (continued)

Process	**Waste type**	**Quantity**
casting		
Mold making and casting	Molding sand	20-50%
Sand recovery (dry bag house)	Recovered dust	1-30%, depend on the recovery rate
Sand recovery (wet bag house)	Recovered dust sludge	Seldom, if any 1-20%
Finishing	Shot blasting sand	0.1-1%
Finishing	Dust with ferrous content	Average 0.1%

2.1.3.2 Emission to Air

The emission from the foundry operations is not limited to the direct emissions released due the processes. Significant amount of electricity is consumed since the foundries are energy intensive factories. Therefore, in addition to internal emission indirect carbon emissions are resulted from the power plants.

Air emissions from the foundry operations depend on the type of metal poured, the cleanliness of the charge, the types of binders used and the melting and pouring practices employed effects the emissions. Melting process, the binder system used in mold making, sand used in pouring and shakeout steps release mineral dust, acidifying compounds, incomplete combustion products and volatile organic carbons (EC, 2005).

The major source of air emissions is the melting operation. In addition to the furnace emissions during melting and refining, fugitive emissions released when the furnace lids and doors are open for charging, back-charging, alloying, slag removal, oxygen lancing (in steel melting) and tapping (Fore and Mbohwa, 2010). The major environmental issues related to these fugitive emissions are usually those of occupational health within the foundry and nuisance odors outside the foundry (USEPA, 1998). Additionally, the coke fired furnaces and gas or oil fired burner cause emission of combustion products like NO_x and SO_2. Incomplete combustion or recombination (PCDD/F) and dust can also be released if the scrap contains impurities such as oil and paint (EC, 2005).

Dust is generated in metal melting, sand molding, casting and finishing steps. Its composition varies depending on the scrap type and furnace additives. In general, it may contain metal (e.g. zinc, lead, chromium, nickel etc.) and metal oxides. In foundries, 10 kg of dust per ton of molten metal, with range of 5-30 kg/t, can be produced. Induction furnaces and flame ovens emit less air emissions (3 kg/t of molten metal) as compared to cupolas and electric arc furnaces (Fatta et. al., 2004)

Inorganic and organic (e.g. amines, volatile organic carbons (VOCs) compounds are produced in binding the sand and pouring the metal. Around 3% of the metal volatizes during the pouring process and various materials are added to bind the sand in making of mold and cores. The decomposition products (mainly VOCs) are continued to be generated during casting cooling and de-molding operations (EC, 2005). Hence about 16% of the total organic and semi-volatile wastes are released in pouring and cooling steps (USEPA, 1998).

The metal emissions are mainly produced in melting furnaces. The induction furnaces have less metal emissions than the cupola furnaces. The emission control systems are installed in furnaces, shakeout and cleaning areas in order to capture the metal emissions. The emissions from the pouring process increase with the metal temperature (EC, 2005).

The Table 2 presents the major air emissions from the foundry processes.

Table 2 The major air emissions from the foundry process (Petroesc et. al., 2011)

Process	**Emission characteristics**
Metal melting	Dust, SO_2, CO, VOC, NOx, metaloxides
Sand preparation	Dust
Mold and core production	Dust, VOC
Pouring, casting	Dust, CO, VOC
Finishing	Dust

2.1.3.3 Wastewater

The water is mainly used in cooling and dust removal processes of the foundries. Waste water in amount of 20 m^3/ton can be generated in a foundry without a proper water management. The characteristic of the waste water vary according to the type of metal and quality of the scrap. It may contain high levels of total suspended solids, copper (0.9 mg/l), lead (2.5 mg/l), total chromium (2.5 mg/l), hexavalent chromium, nickel (0.25 mg/l), and oil and grease (Fatta et al., 2004).

Up to 20 m^3/t of cooling water is recirculated in furnaces and so volume of the wastewater is very small. The pollutants that may exist in cooling water are oil and some chemicals added for the control of algae and corrosion (Petroesc et. al., 2011).

The dust removal and waste gas treatment systems are the major sources of the wastewater. These are applied in melting shop, moulding material preparation and reclamation and in the cleaning shop. Wet scrubbers and wet sand regeneration systems generate waste water. The waste water from the wet scrubbers contain heavy metals, solids such as oxides of silicon, iron and aluminium, calcium carbonates and cyanides, organic pollutants from the soiled scrap. The inorganic solids, specifically iron oxides and clays, are found in waste water if wet de-dusting is applied.

The scrap contains impurities which may cause soil and groundwater pollution when being washed off with raining. The impurities vary depending on scrap type. The scrap may contain cutting oils, emulsions (including chlorine), punching oils (with chlorine), hydraulic oils, gear oils, phosphates, zinc soaps, graphite, forming oils etc.

Hence the storage of the scrap is important in order to prevent the contamination of the water and soil with these hazardous impurities (EC, 2005).

2.2. Environmental Performance Evaluation (EPE) and RECP

ISO Standard 14031 defines the environmental performance evaluation (EPE) as “an internal process and management tool designed to provide management with reliable and verifiable information on an ongoing basis to determine whether an organization’s environmental performance meets the criteria set by the management of the organization”.

Indicators are used as a measurement tool in the EPE process. Two general categories of the indicators are defined in the standard depending on what they describe: 1. environmental performance indicators (EPIs); and 2.environmental condition indicators (ECIs). The EPIs measure a company’s environmental impact and ECIs describe the external condition of the company's environment. The operation performance indicators (OPI), which are a type of EPI, provide information about the environmental performance of the operations (Jash, 2000). The indicators must be selected carefully depending on the purpose of the usage. EPIs may be used not only for EPE but also for many other different purposes including regulatory, control, risk minimization, goal setting, reporting and benchmarking (Thoresen, 1999; UNEP, 2010a).

EPIs are useful tools for the companies in collecting data, and through EPE process the recorded data is translated into relevant knowledge that can be used to investigate the RECP opportunities. The organizational inefficiencies and cost reduction potentials can be detected by comparing the EPIs across different companies in the same sector (Rao et al., 2006). Thus, the RECP measures can be adopted to improve the efficiency of the process. These measures need to be integrated to environmental performance measurement system for the proper implementation (Hasibuan et al., 2013).

The RECP is a proactive approach which aims at preventing the pollution at source. It helps the companies to comply with environmental regulation by eliminating or reducing the pollution at source. Thus, the cost of expensive treatment methods is reduced. Moreover, RECP provides opportunities for the more efficient use of the resources (materials, energy, water, chemicals, etc.) which also reduces the cost of production. Considering the advantages, the RECP can be set as strategic environmental objective of an organization, and achievement of this objective may be controlled by the use of EPE process (Dias-Sardinha and Reijnders, 2001).

Implementing RECP in an organization may require investment for a new technology. Considering the financial consequences of this investment over the company budget, analyses shall be conducted to identify the advantages. The EPE being a regularly conducted process can be used as an efficient tool in identifying and monitoring of the RECP investments. Staniskis and Stasiskiene (2002) showed that EPE process and indicators were used as a communication tool in investment decisions by providing information about the environmental and economic advantages of RECP options.

ISO 14031:2013 provides guidance on the design and use of EPE within an organization. It is applicable to all organizations, regardless of type, size, location and complexity (ISO, 14031). EPE is a process shaped like a "plan-do-check-act" management model. First, the process is planned by defining the purpose and scope, and EPIs are selected. Then, data is collected based on the selected indicators. The data is analysed and converted to relevant information about the performance. The next steps are assessing information, reporting and communicating the results, and periodically reviewing and improving the EPE (check & act) (Jash, 2000).

Benchmarking should be considered as complementary or value adding to EPE process (Altham, 2007). It may help the companies to identify the potential for improvement of the environmental performance by comparing with the best practices. However, it is a useful tool for comparison of highly similar companies. While benchmarking not only the specific indicator values but also general characterization of the company (e.g. type of furnace, type of moulding etc) should be taken into account in order to obtain substantial results.

CHAPTER 3

METHODOLOGY

In this study, RECP opportunities were assessed for the selected foundries by using the EPE approach. The EPE, being also an ISO standard (ISO 14031), is a process and management tool which can be used by the enterprises for monitoring and benchmarking purposes.

The methodology applied in this study was developed by compiling different case studies (Thoresen,1999; Jasch, 2000; Rao et al,. 2006; Avşar and Demirer,. 2008) and UNIDO's Primer of Enterprise- Level Indicators for Resource Productivity and Pollution Intensity (UNIDO, 2010). In the scope of this study, only the ferrous foundries were considered. The study focused on six foundries in Ankara. The whole production steps of casting were considered in the study.

This work was carried out in two phases. In the first phase, EPE was conducted for six foundries. Then, the environmental performance of foundries was compared with the benchmarks obtained from a literature survey in order to identify potential areas for improvement. In the second phase, based on the results from the first phase, different RECP measures were determined, analyzed and proposed to improve the environmental performance of the companies. The results of the first phase indicated how much improvement was possible for KPIs based on the gap between the performance of the studied foundries and benchmarks. The RECP measures were identified considering these deviations as the potential areas for improvement.

In the following sections, the step by step approach used in this research is described.

3.1. Phase 1: Environmental Performance Evaluation

3.1.1. Step 1: Preliminary study

Initially, a literature review was carried out in order to identify commonly used technologies, operational practices and environmental aspects of the foundry industry. International benchmarks were investigated for the resource use and waste production in the sector. During the literature review, the reference document on best available techniques in the smitheries and foundries industry (BREF), theses, academic articles and technical reports were used. The BREF is the document that has been adopted by the European Commission under both the Integrated Pollution Prevention Control (IPPC) Directive (2008/1/EC) and the Industrial Emissions Directive (IED) (2010/75/EU). BREFs describe the applied techniques, present emissions and consumption levels, techniques considered for the determination of best available techniques (BATs) for defined activities.

In this step, the production processes and reported general environmental problems of foundries were investigated based on the literature survey.

3.1.2 Step 2: Identification of Environmental Performance Indicators

The EPIs were selected based on the obtained benchmark values and reported environmental issues of foundry process which were determined in Step 1. Availability of data in the companies was considered as a selection criteria. The most common indicators applicable to a wide range of enterprises in ferrous foundry sector were used in this study.

The selected Key Performance Indicators (KPIs) were listed below:

- Energy use (kWh/ ton of good casting)
- Metal yield (%) (mass ratio of metal melted to good casting)
- Sand regeneration ratio (%) (mass ratio of sand recovered to total used sand)
- Water use (m^3/ ton of good casting)

These indicators focus on three main environmental problems due to foundry operations: high energy consumption, waste foundry sand and water consumption. The metal yield, which is the ratio of the weight of metal melted to the net weight of the castings, not only measures the resource efficiency but also provides information about the efficiency in the operations.

3.1.3 Step 3- Data collection

A survey questionnaire was developed in order to collect the necessary data for the calculation of KPIs. The questionnaire was applied in Turkish; however the sample English version was given in Appendix A. The questionnaire asked information in the following nine areas:

1. General profile of the company including year of establishment, number of employee, alloy type, annual capacity
2. Production steps in the foundry
3. Type and number of melting furnace
4. Equipment/processes using energy and water
5. Molding technique
6. Gross and net weight of production by alloy type for each month
7. Energy source and consumption per month
8. Water consumption per month
9. Used and recovered sand per month

The study focused on the foundries in the First Organized Industrial Zone of Ankara (1stOIZ). Mr. Yusuf Ziya Kayır, who is a senior specialist and metallurgical engineer at Sincan Office of Small and Medium Enterprises Development Organization (KOSGEB) located in the Foundries Industrial Area (FIA) in the First Organized Industrial Zone of Ankara (1stOIZ), provided guidance in finding and selecting the foundries. There were many foundries with different sizes in the FIA. The micro enterprises having three-four employee do not keep regular records about the consumption and production data, and they could not fill the questionnaire. Ten companies located in Ankara were visited. Two companies did not provide data and two foundries did not have the records to fill the questionnaire.

The general information about eight visited companies was given in Table 3. One of the companies had two foundries which were indicated as A1 and A2. The questionnaires filled by the company representatives were provided in Appendix B. To assure the responding foundries confidentiality, “company code” was used instead of their company name.

Table 3 General information about the studied foundries

Foundry Code	**Alloy type**	**Annual capacity (ton/y)**	**Number of employee**	**Date of visit**
A1	Iron, steel	15.000	560	10.03.2015
A2	Iron, steel	20.000		
B	Iron, steel	12.000	135	18.02.2015
C	Iron, steel	10.000	50	24.02.2015
D	Iron, steel, non-ferrous	10.000	69	10.02.2015
E	Iron	10.000	100-250	10.03.2015
F	Iron	5.500	44	16.03.2015
G	Iron, steel and chromium	1.000	20	05.02.2015
H	Steel	300-360	15	09.03.2015

The general information about the companies was obtained by face to face interviews. After introducing the objective of the study and the contents of the questionnaire, the companies were asked to fill the questionnaire form. The questionnaires were filled up by the company representatives. The data collection was carried out on February-March 2015. The companies G and H could not provide the required data due to lack of regular records.

3.1.4 Step 4- Environmental Performance Evaluation and Benchmarking

In this step, the problem areas which need particular attention for potential RECP applications were determined based on EPE and benchmarking studies. First, the

EPE of the visited companies were evaluated in terms of the selected KPIs. Then, the calculated indicators were compared with the international and/or national benchmarks obtained from the literature in order to determine the major areas for improvement in terms of RECP. The results of the benchmarking indicated the efficiency improvement potential. The EPI values with value lower than the average benchmark values were used in identifying those areas that needs improvement.

The 2014 data was obtained from each company. Benchmarking study was based on the data from visited foundries returning a completed questionnaire (Table 3). The factual data collected from companies were analysed against the benchmark data retrieved from the literature research (Section 4.2).

The KPIs were calculated for each studied foundry. The relative performance indicators were calculated by dividing the absolute indicator to the net production amount. The information about the weight of casting produced was given as gross weight and net weight. The gross weight was the weight of metal melted including the mass of parts removed during finishing operations and melting losses and the net weight indicate the weight of good castings ready for shipment. In this study, the term "good casting" is used in order to indicate the net weight of castings.

The capacity utilization was the mass ratio of actual production in gross weight over installed capacity based on one year average. The net weight of castings was expressed as percentage of the gross weight to calculate the metal yield.

Specific Energy Consumption (SEC) (kWh/ ton of good casting) was calculated for each month by dividing the total energy consumption by net weight of castings, not tons melted, because many of the process steps have an effect on overall facility energy use, not just melt energy. The major energy sources used in the visited foundries were the electricity and the natural gas. The natural gas volume was converted to kWh by using the conversion factor 1 m^3 of natural gas= 10.69 kWh which was calculated based on the average heating value of natural gas, 38.5 MJ/m^3 (Fay and Golomb, 2002), and the equation of 1 kWh = 2.7778×10^{-4} kJ (Metcalf and Eddy, 2003). The overall energy consumption including the usage in the laboratory and offices was taken into consideration in all calculations.

For the calculation of the Specific Water Consumption (SWC) (m^3/ ton of good casting), the total water consumption was divided by the net weight of castings. The overall water consumption of companies included the water used for domestic purposes.

Sand regeneration ratio was calculated by dividing the amount of sand recovered to the amount of total sand used.

The monthly values for each indicator are given in Appendix C for each company.

3.2 Phase 2: Improvement of the Environmental Performance

After calculating the key performance indicators and determining the process areas or components of concern in the first phase, the RECP options to improve the existing environmental performance of the companies were identified and evaluated.

The results of the first phase revealed the gap between the existing operating performance of the companies and the achievable performance values obtained from literature. The gap was used to identify how much the performance could be improved for the selected KPIs. The benchmarks were accepted as reference values and deviations from these were considered as the areas of concern in terms of the RECP opportunities.

Considering the existing processes and techniques used in the companies, different RECP applications in literature (EC, 2005; CIPEC, 2003; IFC, 2011; UNEP, 1999) which can be used to improve the performance were listed. The general information about the equipment using electricity and water facilitated the understanding of potential process areas of concern for the energy and water use. A total of 21 RECP options were developed for the companies based on the literature research. After listing the measures for each KPIs, the options were discussed by the company representatives in order to identify the ones which can be adapted to their processes. Therefore, 12 RECP applications were recommended for the foundries in order to improve their resource efficiency in terms of the selected EPIs.

The financial and environmental benefits of improving EPIs were evaluated in Chapter 5. The CO_2 emissions was calculated by using the conversion factor 1 kWh electricity= 590.0 g CO_2 and 1 kWh natural gas= 181.40 g CO_2 (Alkaya, 2013).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Environmental Performance Evaluation of the Companies

4.1.1 Company A

The company was established in 1986. Ferrous castings including all type of steels, nodular and grey iron were produced. The company had two foundries (A1 and A2) which were located in the same organized industrial zone of Ankara. The annual capacity of two foundries was 35,000 ton/year. The company had 560 employees including managerial level staff, engineers and workers. The foundries were in operation as three shifts during the whole year.

4.1.1.1Techniques and technologies used in company A

Foundry A-1 and A-2 have the same production steps including 1. pattern making, 2.melting, 3. casting, 4. mould and core making, 5. heat treatment, 6. fettling and 7. Machining. The company did not provide the process flow diagram.

Melting unit had five induction furnaces with capacities of 4.000 kg/h (one double crucibles induction furnace), 8,250 kg/h (two induction furnaces) and 3,000 kg/h (two double crucibles induction furnaces). Ladle was used for pouring the liquid metal into the mould.

Moulding with resin bonded sand was the applied technique in mold making. The mould was composed of silica sand (%80 recovered sand and %20 fresh sand), resin %1.1:1.3, catalyser in the amount of 22:25 percent of the resin.

The energy sources used in the factory were the electricity and the natural gas. Induction furnaces, heat treatment furnace, heaters, cooling units, ventilation and illumination were the areas of energy consumption. Water was used for furnace cooling system, quenching tanks and domestic consumption. The wastes generated by the company were waste sand, dust, slag, wastewater, hazardous wastes, package wastes and medical wastes. On the basis of the legal framework, the wastes were either disposed or recycled after temporary storage. On average, 200,000 TL per year had been spent for the waste management.

4.1.1.2 The EPIs for Company A-1

8,569 ton (gross weight) of steel castings and 2,719 tons (gross weight) of iron castings were produced in 2014. Around 57% of the total energy was consumed as natural gas. 5% of the total energy and 5% of the total water were used for domestic purposes.

The data obtained from Company A-1 for 2014 is summarized in Table 4 The summary of EPE findings for Company A-1 are given in Table 5.

Table 4 Data obtained from Company A1

Company	**A-1**
Capacity (ton/y)	15,000
Metal type	Ferrous (steel, nodular and cast iron)
Type of melting furnace	Electric Induction Furnace
Molding type	Resin bonded sand molding
Total production (net weight) (ton/y)	7,932
Total production (gross weight) (ton/y)	11,288
Capacity utilization (%)	74
Total energy consumption (kWh/y)	32,769,842.18
Total water consumption (m^3)	22,947.00
Total sand consumption (ton)	79,032.08
Total recovered sand (ton)	48,080.92

Table 5 EPE of Company A1

Indicator	**Min**	**Max**	**Mean ± Standard Deviation**
SEC (kWh/ton of good casting)	3,704	4,738	4,156 ± 270
SWC (m^3/ton of good casting)	2.42	3.75	2.92 ± 0.40
Metal yield for iron (%)	74.31	86.41	79.77 ± 3.51
Metal yield for steel (%)	63.38	74.11	67.01 ± 2.93
Sand recovery (%)	60.33	61.31	60.82 ± 0.29

4.1.1.3 The EPIs for Company A-2

86 % of the overall production (13,690 ton gross weight) was steel casting in 2014. According to the energy consumption data given by the Company A2 for 2014, 58.93% of the energy was supplied from natural gas.

In mould and core making, 74,021 tons of total sand was used in 2014 including silica sand (39,053 tons), recovered sand (31,584 tons), chromite sand (2,868 tons) and olivine sand (515 tons).

The data obtained from Company A-2 for 2014 and EPE findings were summarized in Tables 6 and 7.

Table 6 Data obtained from Company A2

Company	**A-2**
Capacity (ton/y)	20,000
Metal type	Ferrous (steel, nodular and cast iron)
Type of melting furnace	Electric Induction Furnace
Molding type	Resin bonded sand moulding
Total production (net weight) (ton/y)	9,037
Total melted metal (gross weight) (ton/y)	13,690
Capacity utilization (%)	66
Total energy consumption (kWh/y)	34,224,500.08
Total water consumption (m^3)	15,756.00
Total sand consumption (ton)	74,021.36
Total recovered sand (ton)	31,584.03

Table 7 EPE of Company A2

Indicator	Min	Max	Mean ± Standard Deviation
SEC (kWh/ton of good casting)	2,868.94	5,183.16	3,793.99 ± 718.28
SWC (m^3/ton of good casting)	1.33	2.33	1.76 ± 0.29
Metal yield for iron (%)	73.79	86.01	81.37 ± 3.32
Metal yield for steel (%)	54.25	71.15	63.36 ± 4.42
Sand recovery (%)	29.78	58.30	41.72 ± 8.43

4.1.2 Company B

The company was established in 1984. With a total capacity of 12,000 tons per year, the factory was able to manufacture ductile iron and nodular cast iron. In addition, steel castings can also be produced depending on the customer needs. The company had 135 staffs working as two shifts during the whole year.

4.1.2.1 Techniques and technologies used in company B

The production process of the factory includes: 1. Pattern making, 2.Sand preparation (green sand making), 3. Mould making, 4. Machine and hand moulding, 5.Melting and casting, 6. Shake out, 7. Shot blasting, 8.Fettling, 9.Heat treatment, 10.Painting and 11.Packaging (Figure 4)

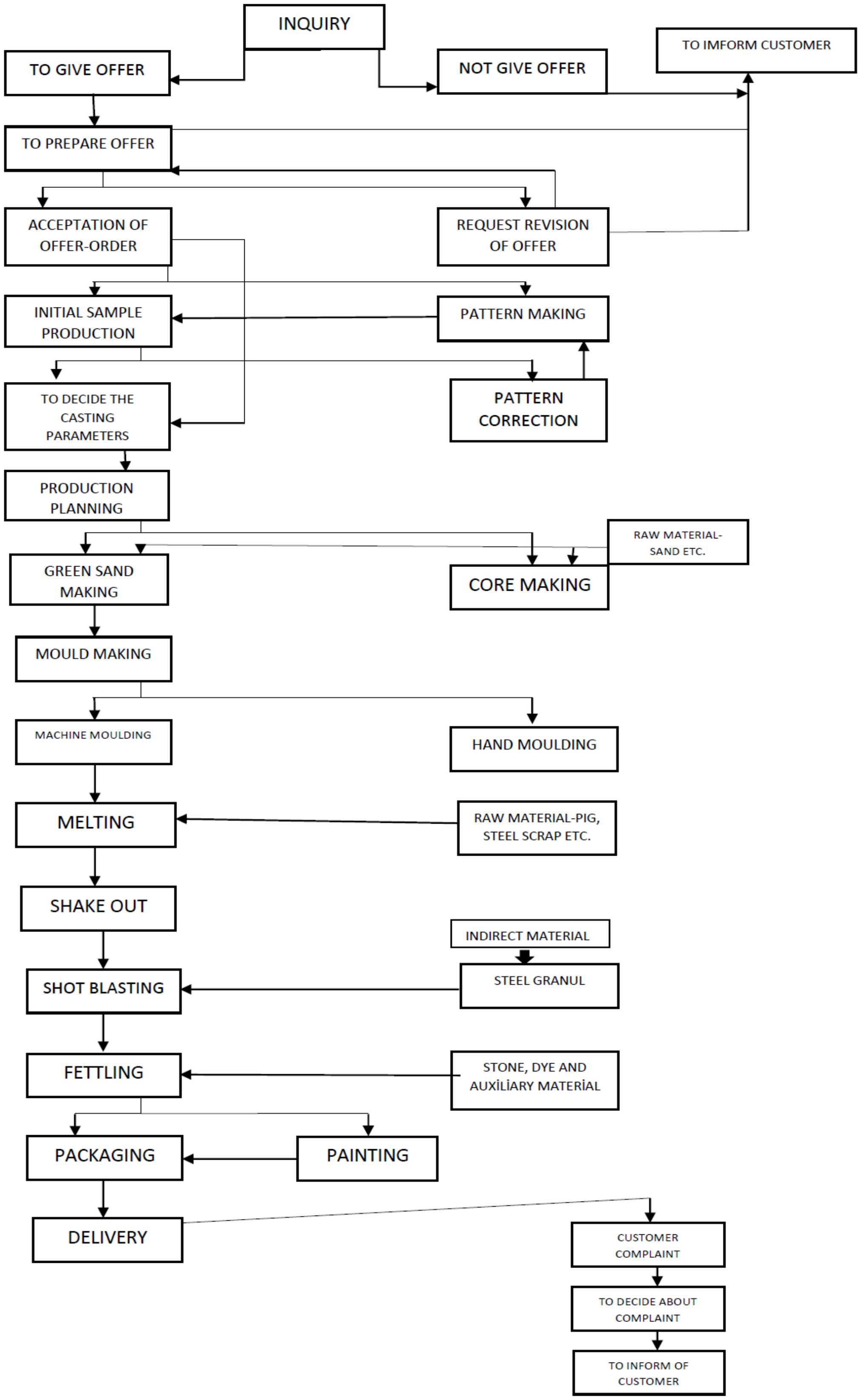

Figure 4 Process flow diagram of Company B

There were three induction furnaces in the factory with capacities of 4,000 kg/h (double crucibles), 1,000 kg/h and 750 kg/h (double crucibles). Each furnace had been working around 18 hours per day. The average energy consumption of the furnace was stated by the Company as 1.05 kWh/ kg of electricity.

Green sand moulding was the applied technique in moulding shop. In casting of some special products, resin bonded sand was also used. The mould mixture was composed of silica sand (fresh sand (%10) and recovered sand (90%)), bentonit (%2), coal dust (%1) and water (%2-2.5). The sand was reused internally after dry sand reclamation process with mechanical screening and magnetic separator.

The energy sources used in the factory were the electricity and the natural gas. The low amount of natural gas was being used only in core making process. Electricity was used in induction furnaces, heat treatment furnace, heaters, cooling units, ventilation and illumination.

Water was mainly used for cooling purposes. The application areas included furnace cooling system, cooling tank, cooling tower and domestic use. In addition, water was used in mold making. The water was re-circulated in furnace cooling system. In cooling (quench) tank the water was reused continuously with the addition of lost amount.

The wastes generated were: waste foundry sand (WFS), dust and slag. The WFS was transferred to a landfill site for a fee of 30 TL per ton. The company spent 8,000 – 10,000 TL per month for the transfer and disposal of WFS and slag.

4.1.2.2 The EPIs for Company B

The factory produced 9,547.70 tons of casting (gross weight) in 2014. Thus, the capacity utilization was 79.56%. In the questionnaire which was filled by the company representative, it was noted that the production was mainly iron casting. The net weight of steel casting was indicated as %2 of total production. 10,704,125 kWh electricity and 78,611 m^3 natural gas were consumed for the production of 6,626,746 kg of iron casting (net weight).

There was no record of the company for water consumption in each month of 2014. The data was available for the months of February, August, September, October, November and December. Within these months 6,094 m^3 of water was used which corresponded to 3,256,344 kg of iron casting manufacturing.

The data obtained from Company B for 2014 and EPE findings were given in Tables 8 and 9.

Table 8 Data obtained from Company B

Company	**B**
Total number of personnel	135
Capacity (ton/y)	12,000
Metal type	Ferrous (steel, nodular and cast iron)
Type of melting furnace	Electric Induction Furnace
Molding type	Green sand molding
Total production (net weight) (ton/y)	6,626.75
Total melted metal (kg/y)(gross weight) (ton/y)	9,547.70
Capacity utilization (%)	80
Total energy consumption (kWh/y)	11,544,477
Total water consumption for months of February, August, September October, November and December	6,094 m^3 (Total production in these months= 3,256.34 ton)
Total sand consumption (ton)	No data
Total recovered sand (ton)	No data

Table 9 EPE of Company B

Indicator	Min	Max	Mean± Standard Deviation
SEC (kWh/ton of good casting)	1,626	1,995	1,749± 109
SWC (m^3/ton of good casting)	1.48	2.59	1.87 ± 0.40
Metal yield (%)	68.01	71.00	69.37 ± 1.14
Sand recovery ratio (%)	N/A	N/A	80[1]

4.1.3. Company C

The company which was established in 1976 manufactured parts of gray cast iron, nodular cast iron and steel. There were 50 personnel working as one or two shifts whole year in the factory. The annual capacity was 10,000 ton.

4.1.3.1. Techniques and technologies used in factory

The production steps of the company included: 1. Pattern making, 2. Moulding, 3. Melting, 4. Casting, 5. Shake out, 6. Sand preparation, 7. Cleaning (shot blasting and fettling), 8. Heat treatment, 9.Painting and 10.Machining (Figure 5).

[1] No detailed record was given in the questionnaire about the quantities of monthly sand consumption and recovery. The average recovery ratio was indicated as 80%.

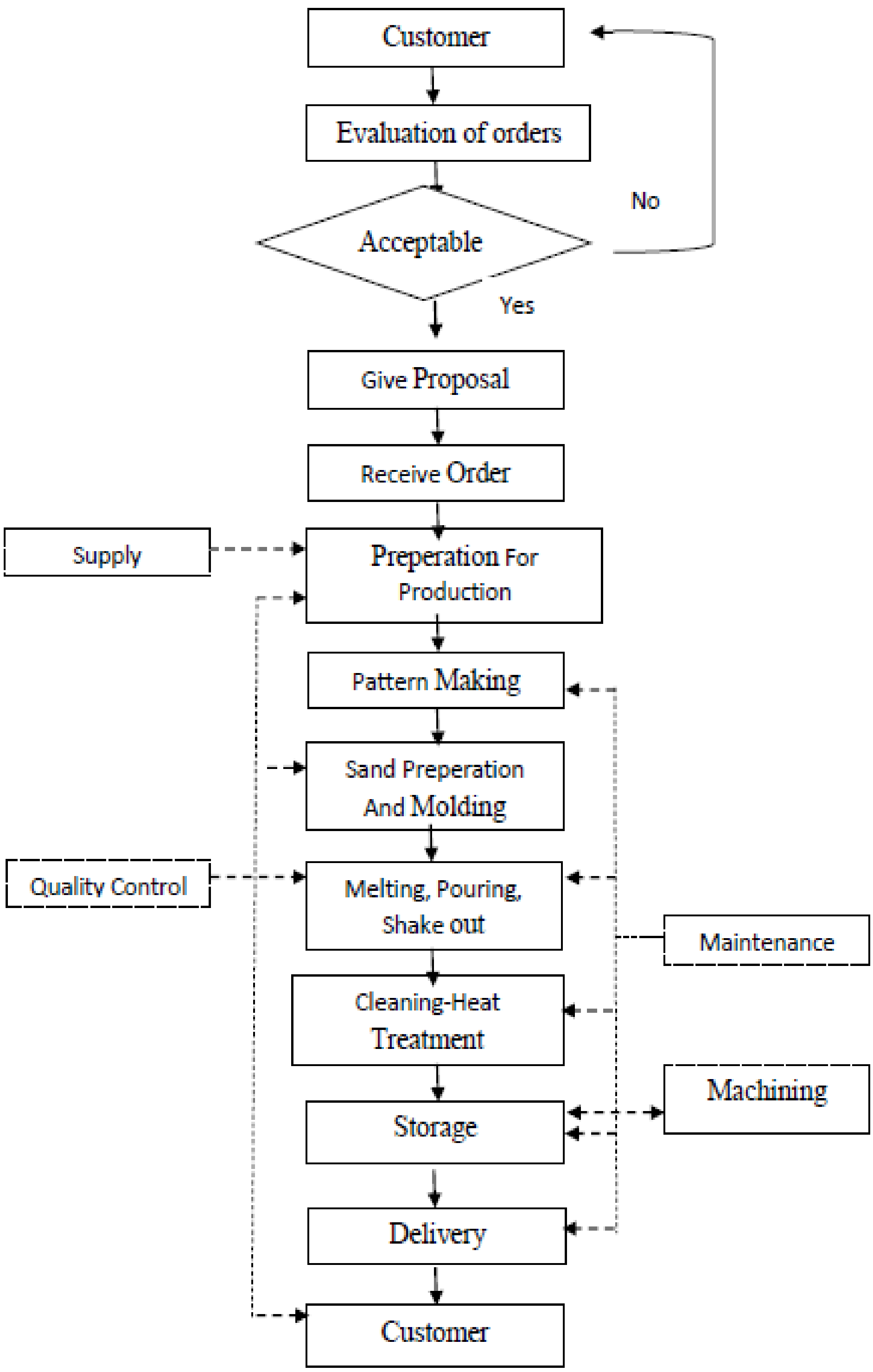

Figure 5 Process flow diagram of Company C

There were four induction furnaces with capacities of 5,000 kg (two furnaces), 4,000 kg and 2,000 kg (double crucibles furnace). The average energy consumption of the furnaces was provided by the Company as 0.8 kWh/kg.

The electricity was the only energy source used in the factory for melting, heat treatment, cooling, ventilation and illumination purposes. The melting was done by four induction furnaces during three days of week.

The moulding technique used in the factory was the chemically bonded sand. The phenol resin was used as binder. The mould was composed of silica sand (new sand %20) and reclaimed sand (%80)), phenol resin (%1-2) and ester (%0.2). The mechanical sand reclamation was applied.

The major areas of water usage were: furnace cooling system, cooling tower, quenching tank and domestic use. The wastes generated in the foundry were the WFS, dust and slug. These wastes were transferred to the landfill site for 120,000 TL/year.

4.1.3.2 The EPIs for Company C

3,393.55 ton of casting (gross weight) was produced in 2014. The steel production was 6.47% of the total production whereas the share of gray cast iron and nodular cast iron were 68.98% and 24.55% respectively. The capacity utilization was 33.94% in 2014.

The data obtained from Company C for 2014 was summarized in Table 10.

Table 10 Data used for Company C

Company	**C**
Total number of personnel	50
Capacity (ton/y)	10,000
Metal type	Ferrous (steel, nodular and cast iron)
Type of melting furnace	Electric Induction Furnace

Table 10 Data used for Company C (continued)

Company	**C**
Molding type	Resin bonded sand molding
Total production (net weight) (ton/y)	N/A
Total melted metal (kg/y)(gross weight) (ton/y)	3,393.55
Capacity utilization (%)	34
Total energy consumption (kWh/y)	4,298,286
Total water consumption for months of February, August, September October, November and December	4,088
Total sand consumption for months of February, March, September October and November (ton)	5,459.29
Total recovered sand (ton)	4,304.73

The net weight of castings was indicated as 12%, 18% and %30 for the gray iron, nodular cast iron and steel, respectively. The net weight of castings was calculated based on these ratios given by the Company. The findings for Company C were given in Table 11.

Table 11 EPE of Company C

Indicator	**Min**	**Max**	**Mean ± Standard Deviation**
SEC (kWh/ton of good casting)	1,265	1,754	1,540 ± 169
SWC (m^3/ton of good casting)	0.85	2.64	1.59 ± 0.57
Metal yield (%)	N/A	N/A	N/A
Sand recovery (%)	71.22	82.19	77.87 ± 4.10

4.1.4. Company D

The factory which was established in 1975 has a casting capacity of 10,000 tons and machining capacity of 4,000 tons per year. The total number of personnel who were working as one shift was 69. Gray cast iron, nodular cast iron and steel castings were produced.

4.1.4.1. Techniques and technologies used in factory

The production steps in the factory were: 1. Mould and core making, 2. Moulding, 3. Melting, 4. Casting, 5. Shake out, 6. Shot blasting, 7. Fettling, 8. Heat treatment, 9. Machining and 10. Sand regeneration. The patterns have not been produced within the factory (Figure 6).

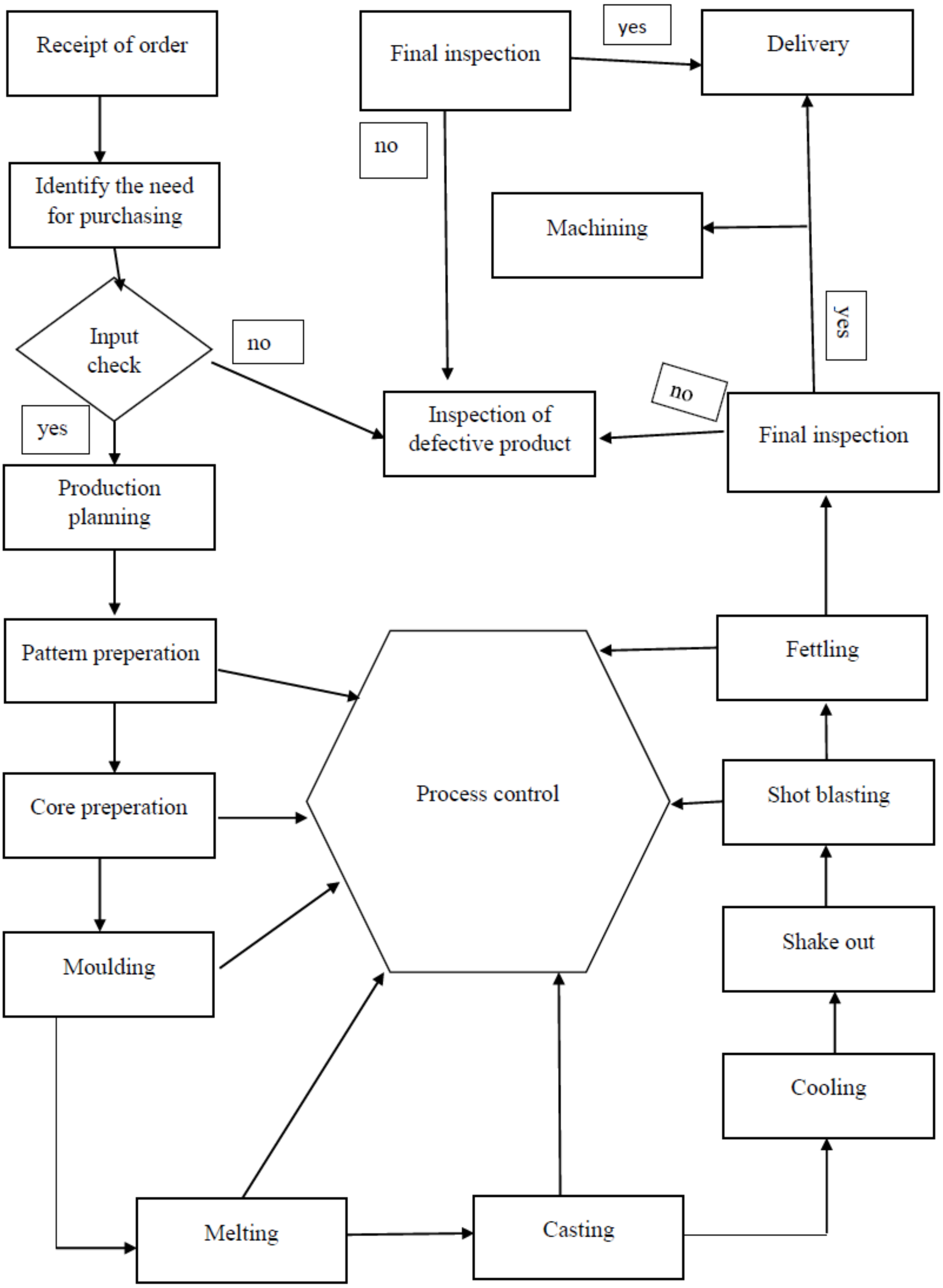

Figure 6 Process flow diagram of diagram for Company D

Electricity and natural gas were the energy sources used for melting, heat treatment, cooling, ventilation, illumination and domestic purposes. There were six induction furnaces two for each having capacities of 2,500 kg, 1,500 kg and 450 kg.

The applied technique in mold making was the chemically bonded sand. The mold mixture was composed of silica sand, resin (%8) and acid (%0,032).

The major areas of water usage were: furnace cooling system, cooling tower, quenching tank and domestic use.

The wastes generated were WFS, dust and slag. These were disposed by the authorized companies with a cost of 700 TL/truck. One truck received almost 20 tons of waste.

4.1.4.2 The EPIs for Company D

The company manufactured 2,738.87 tons (gross weight) of casting including iron, steel and non-ferrous products in amount of 2,001.42, 553.96 and 183.49 tons, respectively in 2014. Thus, the capacity utilization was 27%. The data obtained from Company D for 2014 is summarized in Table 12.

Table 12 Data obtained from Company D

Company	**D**
Total number of personnel	69
Capacity (ton/y)	10,000
Metal type	Ferrous (steel, nodular and cast iron) and non-ferrous
Type of melting furnace	Electric Induction Furnace
Molding type	Resin bonded sand molding
Total production (net weight) (ton/y)	1,388.39
Total melted metal (gross weight*) (ton/y)	2,738.87
Capacity utilization (%)	27
Total energy consumption (kWh/y)	3,514,116.42

Table 12 Data obtained from Company D (continued)

Company	D
Total water consumption (m^3)	2,491
Total sand consumption (ton)	345,000
Total recovered sand (ton)	319,000

The EPE findings for Company D were given in Table 13.

Table 13 EPE of Company D

Indicator	Min	Max	Mean ± Standard Deviation
SEC (kWh/ton of good casting)	1,704	3,280	2,570 ± 458
SWC (m^3/ton of good casting)	1.46	2.50	1.86 ± 0.38
Metal yield (%)	Iron: 35.21 Steel: 8.92	Iron: 85.98 Steel: 83.05	Iron: 54.12 ± 12.02 Steel: 44.46 ± 25.89
Sand recovery (%)	90.00	96.00	92.41 ± 1.53

4.1.5. Company E

The Company was established in 1987 and produces grey and nodular cast iron. It had a casting capacity of nearly 10,000 tons per year and a machining plant with a capacity up to 3,500 tons/year. The number of personnel changes between 100 and 250 working as two shifts whole year.

4.1.5.1. Techniques and technologies used in factory

The production steps in the factory were: 1. Mould and core making, 2. Moulding, 3. Melting, 4. Casting, 5. Shake out, 6.Shot blasting, 7. Fettling, 8. Heat Treatment, 9. Machining and 10. Painting (Figure 7).

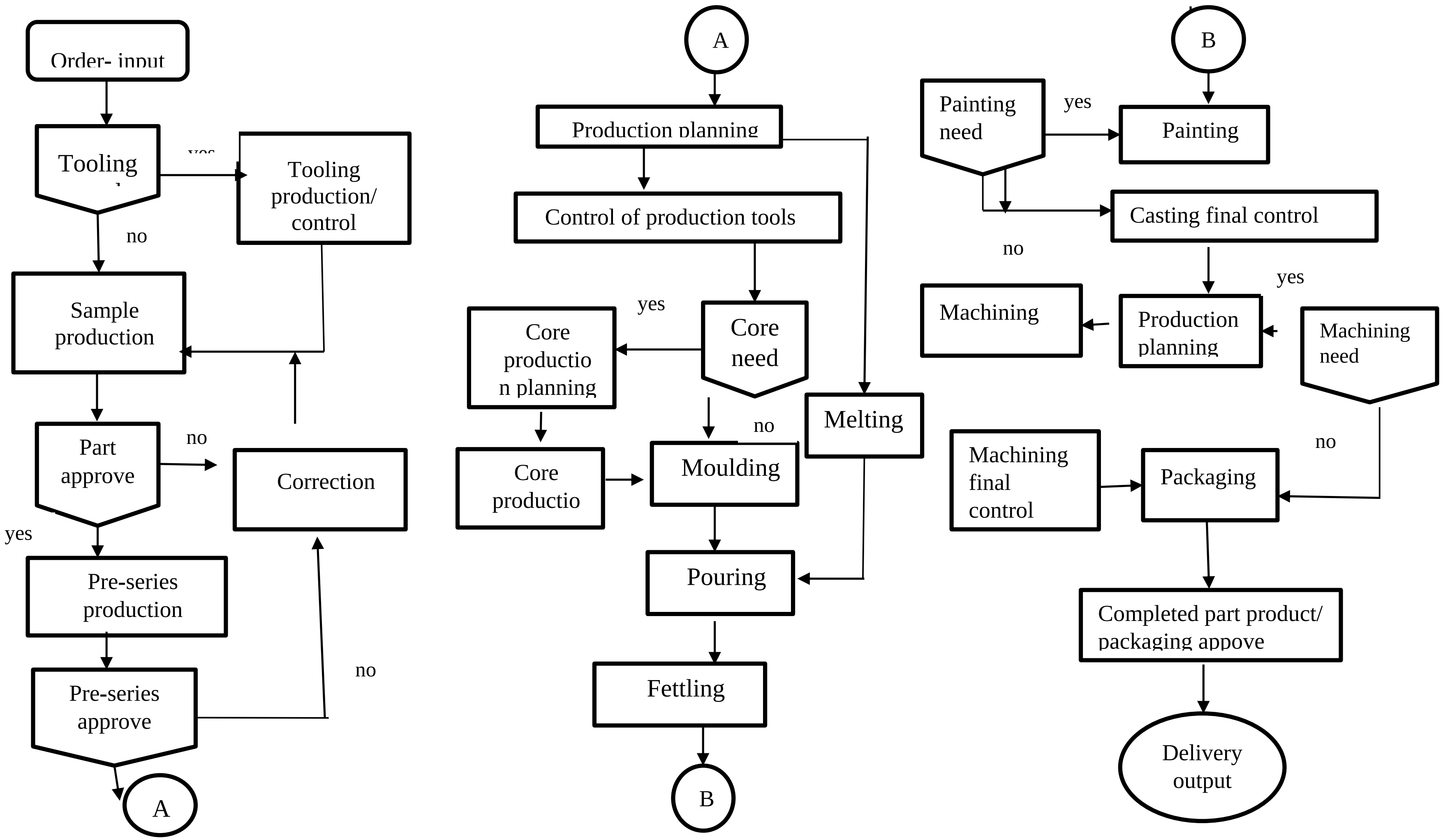

Figure 7 Process flow diagram of Company E

Electricity and natural gas were the energy sources used in the production steps. Energy was used in induction furnaces, heat treatment furnace, heaters, cooling units, ventilation and illumination. There were two induction furnaces in the factory with capacities of 3.000 kg and 1.500 kg. Each furnace had been working around 20 hours per day. The average energy consumption of the furnace was as 1.69 kWh/ ton.

Both the green sand and resin bonded sand were used in mould making. Green sand was more frequently used. The mould mixture was composed of silica sand (new sand 5% and recovered sand 95%), bentonit (%1) and coal dust (%0.05). The mechanical sand reclamation was applied in the factory.

Water was mainly used for cooling purposes. The application areas included furnace cooling system and domestic use. In addition, water was used in mold making, cooling tower and cooling tank. The waste generated in the company was indicated as WFS, dust and slag which were disposed to the landfill site with a cost of 4,000 TL/ month.

4.1.5.2. The EPIs for Company E

The factory produced 8,421.89 ton (gross weight) of iron casting in 2014. The capacity utilization was 84.22%. The data obtained from Company E for 2014 and findings were summarized in Tables 14 and 15.

Table 14 Data obtained from Company E

Company	**E**
Total number of personnel	100-250
Capacity (ton/y)	10,000
Metal type	Ferrous (cast iron)
Type of melting furnace	Electric Induction Furnace
Moulding type	Resin bonded and green sand moulding
Total production (net weight) (ton/y)	6,502.58
Total melted metal (gross weight*) (ton/y)	8,421.89
Capacity utilization (%)	84.22
Total energy consumption (kWh/y)	10,280,300.47
Total water consumption (m^3) (for first half of the year)	7,036
Total sand consumption (ton)	3,869.90
Total recovered sand (ton)	3,676.20

Table 15 EPE of Company E

Indicator	**Min**	**Max**	**Mean ± Standard Deviation**
SEC (kWh/ton of good casting)	811	3,778	1,690 ± 704
SWC (m^3/ton of good casting)	1.09	2.29	1.73 ± 0.44
Metal yield (%)	74.48	79.66	77.27 ± 1.56
Sand recovery (%)	94.98	95.01	94.99 ± 0.01

4.1.6. Company F

The Company F which was established in 1989 produces grey and nodular iron castings. The annual capacity was 5.500 ton/year, and total number of personnel working as one shift whole year was 44.

4.1.6.1. Techniques and technologies used in company F

The production steps of the company are: 1. Melting, 2. Casting, 3. Moulding, 4. Core making, 5. Finishing facilities, 6. Heat treatment and 7. Sand recovery. No flow diagram was provided by the company.

There were two induction furnaces with capacities of 2.500 kg (double crucibles) and 1.500 kg. The furnaces had been working for 9 h per day, and the average energy consumption was provided by the company as 1000 kWh. Energy was used in induction furnaces, heat treatment furnace, cooling units and illumination.

Sand moulding technique was used. The ingredients of the mould mixture were not indicated in the questionnaire. The wastes generated in the company were WFS and slug which were sent to landfill. The cost spent for waste management was not provided by the Company.

4.1.6.2. The EPIs for Company F

The factory produced 2,819.00 ton (gross weight) of iron casting in 2014. The capacity utilization was 51%. The data obtained from Company F for 2014 was summarized in Table 16.

Table 16 Data obtained from Company F

Company	**F**
Total number of personnel	44
Capacity (ton/y)	5,500
Metal type	Ferrous (grey and nodular iron)
Type of melting furnace	Electric Induction Furnace
Molding type	Resin bonded sand molding
Total production (net weight) (ton/y)	2,133.00
Total melted metal (gross weight*) (ton/y)	2,819.00
Capacity utilization (%)	51
Total energy consumption (kWh/y)	3,238,252.00
Total water consumption (m^3)	No data
Total sand consumption (ton)	3,899
Total recovered sand (ton)	2,775

The findings for Company F are given in Table 17.

Table 17 EPE of Company F

Indicator	**Min**	**Max**	**Mean ± Standard Dev.**
SEC (kWh/ton of good casting)	1,296	2,041	1,549 ± 211
SWC (m^3/ton of good casting)	N/A	N/A	N/A
Metal yield (%)	73.39	77.84	75.68 ± 1.42
Sand recovery (%)	47.75	96.77	72.62 ± 15.00

4.2. Analysis of Average Performance against Benchmarks

In this section, the environmental performance of the studied foundries was compared with the benchmarks obtained from literature. It was important to compare similar companies while benchmarking. Thus, key differentiating factors (alloy type and technology) were considered in analysis of the results.

Since the foundry industry was so highly segmented and specific KPIs differed for each product categories, this study focused on two major products: "iron" and "steel".

The foundries had similar technologies in moulding, melting and casting operations. All had induction furnaces in melting unit. After melting the metal, ladles were used for pouring the liquid metal. They used resin bonded and green sand in mould making. The poured moulds were left for cooling at ambient air temperature (solidification). All companies had finishing operations of fettling, shot blasting, heat treatment and machining. Hardening was the common applied heat treatment technique. In this process, the level of heat was raised above the transformation temperature and the work piece was subsequently rapidly cooled. Heat treatment furnaces working with electricity or natural gas were used for increasing the temperature and cooling tank (quenching tank) was used for sudden cooling. The water in the cooling tank was used continuously with the addition of the lost amount due to evaporation.

4.2.1. Specific Energy Consumption

The data obtained from the studied foundries include the overall energy consumption rather than energy used by each production steps. Therefore, the comparison was based on the total energy consumption. However, the types of alloy and melting furnace which had great influence on the energy consumption were taken into consideration while benchmarking the results. The type of the melting furnace was an important criterion to be considered since the melting stage was the most energy consuming process. Another criterion was type of alloy in energy benchmarking. Ferrous metals have a higher melting point. Cast iron has a lower melting point and better casting ability than steel (EC, 2005).

Electricity was the major source of energy. Natural gas was being used in a number of ways in the foundries. In ferrous operations, the primary uses were: heating of the workplace, heat treating furnaces, pre-heating of ladle and metallic charges, and core machines.

The studied foundries were identical in terms of the types of moulding and melting process. All companies had electrical induction furnace for melting which was a common practice in Turkey. The TFA reported that all the foundries have induction furnaces for melting steel, ductile and malleable iron in Turkey. Only %5 of the grey iron castings is being utilized in cupola furnaces using coke while %95 of the facilities uses induction and arc furnaces with electricity (TFA, 2013). The casting methods of studied companies were resin bonded sand and green sand.

Table 18 provides the SEC values for each foundry along with the annual average, best and worse practice in 2014. The SEC of the studied foundries was evaluated based on the data obtained through the completed questionnaire. It was indicated in the questionnaires that energy was used in all production steps by melting furnaces, heat treatment furnaces, heaters, moulding machines, cooling equipment, ventilation and illumination devices.

Table 18 Specific energy consumptions

Foundry	SEC (kWh/ton good casting)			Alloy type	Net weight (ton)	Total energy (kwh)
	Min	Max	Mean ± std dev.			
A1	3,704	4,738	4,156 ± 270	Steel(%72) Iron (%28)	7,932	32,769,842
A2	2,869	5,183	3,794 ± 718	Steel (%83) Iron (%17)	9,037	32,224,500
B	1,625	1,995	1,749 ± 109	Iron (%98), steel (%2)	6,627	11,544,477
C	1,265	1,754	1,540 ± 169	Iron (%93), steel (% 7)	2,897	4,298,286
D	1,704	3,280	2,570 ± 458	Iron (%75), steel (%17), chromium (%8)	1,388	3,514,116
E	811	3,778	1,690 ± 704	Iron (%100)	6,503	10,280,300
F	1,296	2,041	1,549 ±211	Iron (%100)	2,133	3,238,252

The SEC profiles showed that the foundries analysed in this study had an average energy consumption of 2,680 kwh/ ton of good casting. The seven ferrous foundries used 97,869,774.15 kWh of energy for the production of 36,516.53 ton of good castings. Among these total energy consumption 40,781,854.74 kWh (around 42%) was natural gas.

This result is compatible with the overall consumption data provided by the TFA. According to the TFA, on average 2.2 kWh electricity is being used in order to produce 1 kg of good casting. TFA reported that 3,179,000 MW of electricity was used in 2012 for production of 1,291,700 ton of total casting (TFA, 2013). The results also revealed that the steel foundries used much more energy than iron foundries. The companies A1 and A2 mainly produced steel castings and they consumed almost three times more energy than others. Moreover, although the company D mainly produces iron castings its steel production was higher than other iron foundries (B, C, E and F) and so its electricity consumption was higher as compared to others. The reason for this high consumption is that the cast iron has a lower melting point and better casting ability than steel (EC, 2005).

Due to the diverse nature of the foundry industry, there was no single benchmark that can be used to describe the entire energy use throughout the industry. Comparisons between foundries should be made with care since the foundries have very different number and range of activities (Svensson, 2011). The differences in the energy consumption between the foundry processes could not be determined due to the lack of process specific data. The studied foundries did not have a measurement unit in each production step. Thus, the conclusions were drawn based on the total energy consumption of the facilities.

To make relevant comparisons, the foundries were classified based on alloy type and the energy consumption values were compared on the basis of this classification. The foundries E and F produced only iron castings but others produced mixed castings and therefore, they were classified based on the majority of their overall production. Thus, the companies A1 and A2 were classified as steel foundries whereas the foundries B, C and D were considered as iron foundries.

Table 19 summarizes benchmark SEC values obtained from the literature research where total energy consumption was reported based on the alloy type of the foundries.

Table 19 Benchmark energy consumptions

Alloy type	Furnace type	Energy consumption		Reference
		For melting (kWh/ ton melted)	For casting (kWh/ ton casting)	
Iron	Induction	500-800	No data	UNEP, 1999
Steel	No data	620- 2,760	2,200- 6,600	CIPEC, 2003
Iron	No data	595-1,290	1,210-3,310	
Steel, Iron	Induction	520-800	No data	EC, 2005
Iron	Induction	620	No data	Arasu and Jefrey, 2009
Steel[2]	No data	EU: (500-525)[3]	EU: 1,503 -1,815	IFC, 2011
		Russia: (686-1,310)[3]	Russia: 3,604-5,359	
Iron[2]	No data	EU: 558-571	EU: 1,165-1,338	
		Russia: 807-1,118	Russia: 3,014-4,235	
Iron and steel[2]	No data	EU: (554-560)[3]	EU: 1,247-1,453	
		Russia: (779-1,164)[3]	Russia: 3,155-4,506	
Iron	Induction	565	No data	Gopal and Fellow, 2013

The energy consumption of Russian and European foundry industry was compared in the benchmarking study undertaken by IFC. The data which was collected from Russian foundries through a questionnaire over a period of three years, from 2007 to 2009, was analysed against data maintained by projects undertaken at various European ferrous foundries. The Russian foundries analysed in the study included both major and smaller foundries using a range of technological processes, for the production of both castings and mouldings. The survey focused on three major product categories: "grey iron," "ductile iron" and "steel castings," each of which differs in terms of the specific KPIs most relevant to it.

[2] The ranges indicate the best practice and average performance values
[3] Excludes post-tap refining

Most of the Russian foundries participating in the survey process more than one category of materials, and more than half of all foundries produce steel castings: 42% of the companies produce only iron and 13% only steel whereas 46% produce both iron and steel. Multiple technologies mainly induction and arc furnaces are used in melting shop. The majority of the foundries apply mechanized green sand moulding. The SEC values reported in the study are based on the total energy consumption (kWh) across various foundry departments, divided by the tonnage of net good castings produced. The energy was mainly used in melting and finishing operations (shot blasting, grinding, de-burring, thermal treatment, inspection/ testing) (IFC, 2011).

Canadian Foundry Association and Natural Resources Canada conducted a joint project named "Energy Efficiency Opportunities in Canadian Foundries" through the Canadian Industry Program for Energy Conservation (CIPEC). The energy benchmark per ton in good casting was reported in the project based on the alloy type in foundries (CIPEC, 2003).

Evaluation of SEC level was possible by type of alloy since the benchmark values could be obtained by alloy type. It is apparent in Table 19 that the best and average SEC values differ in each country depending on the alloy type in foundries. The European foundries have better performance than Russian and Canadian foundries (CIPEC, 2003; IFC, 2011).

According to the literature research, the best reported SEC value was 1,165 kWh/ton good casting for iron foundries and 1,503 kWh/ton good casting for steel foundries. The average SECs were 1,338 kWh and 1,815 kWh for iron and steel respectively (IFC, 2011). These average values were taken into consideration while comparing the actual performance of the foundries with the benchmark values. The average performance of the foundires was compared with the average benchmarks.

When SEC of the studied foundries was compared with the figures reported in literature, it was observed that a considerable energy saving potential was present. As shown in Table 19, the European foundries had the least energy consumption. Therefore, improving energy efficiency gains importance for the Turkish foundries since the 75% of the import have been done to European countries in 2012 (TFA, 2013). Considering that the energy cost comprises 15-25% overall production cost and any saving would provide advantage in terms of improving competitiveness (Hot Trends in Melting Efficiency, 2001).

The average of SEC was 1,820 (± 429) kWh/ ton good casting for the studied iron foundries (B, C, D, E and F), and 3,975 (± 256) kWh/ ton good casting for steel foundries (A1 and A2). As compared to average performance of European iron and steel foundries given in Table 19 (IFC, 2011), the studied iron and steel foundries used around 1.4 and 2.2 times more energy respectively (Figure 8).

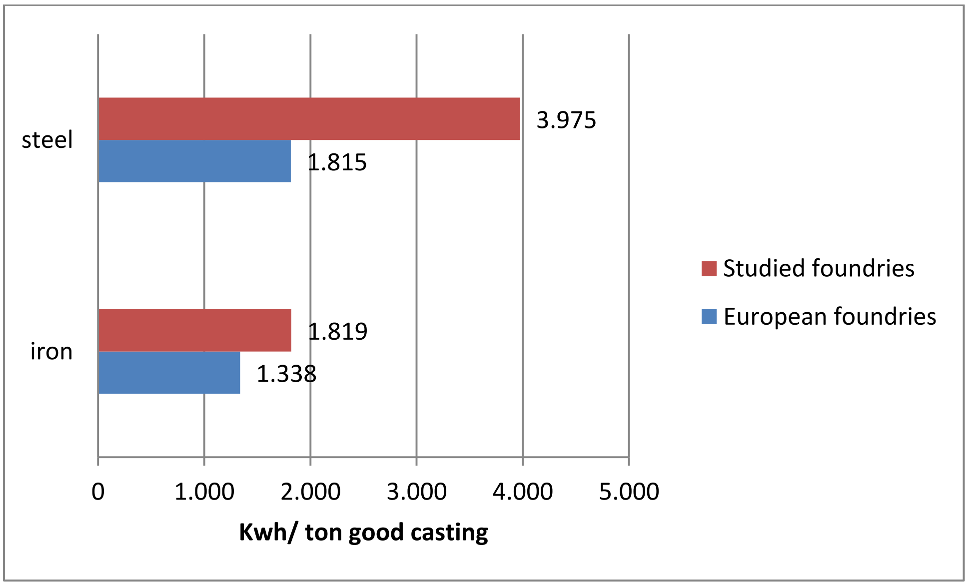

Figure 8 Comparison of energy consumption

The results for KPI of energy use indicated that there was a potential to improve the energy efficiency in foundries. Considering that the foundry industry was energy intensive, saving in energy consumption would contribute to decrease the production cost and so to improve the competitiveness. Moreover, less use of energy, mainly the electricity leads to reduce electricity demand and, consequently, reduction in greenhouse gas emissions by decreasing the emission of combustion gasses from power plants.

On the basis of the average SEC, there is an improvement potential of 27% for iron foundries. Average SEC can be as low as 1,338 kWh per ton of good casting according to the literature (IFC, 2011). Therefore, the studied iron foundries can reduce their average SEC by 481 kWh/ ton good casting. The total iron casting production was 22,817.36 ton in 2014 and so they could save on average 10,975,150 kWh per year. On the other hand, the improvement potential for steel foundries was 2,160 kWh per ton. Considering the weight of steel production in 2014 (13,605.66 ton), the steel foundries could save on average 29,388,225 kWh/year. Thus, the total annual energy saving would be around 40,386,193 kWh. Considering that 41% of the total energy consumption was natural gas, the electricity and natural gas saving were 23,827,854 kWh and 16,558,339 kWh respectively.

The decrease in the energy consumption would result in reduced average direct or indirect carbon emissions resulted from heat transfer systems by 140,918 ton per year.

The RECP applications which could be adopted by foundries in order to decrease energy consumption were discussed in Chapter 5.

4.2.2. Sand Regeneration

The high amount of the solid waste including sand, slag, emissions control dust and spent refractories, constitute the most significant impact of foundry operations (Yılmaz et al, 2014). The sand is used in great amount in moulding operation. Although it can be re-used by applying mechanical and thermal regeneration techniques, high amounts are wasted. The Ministry of Environment and Urbanization reported that around 0.6 to 0.8 tons of waste, of which 0.4 to 0.6 is used sand, is generated in order to produce one ton of good casting (MoEU, 2012)

The studied foundries transfer the solid wastes including sand, dust and slag to the landfill site for an amount of 4,000 TL to 16,000 TL per month depending on the ton of waste generated. While beneficial reuse is possible for the waste foundry sand, substantial savings can be made by reducing the waste at source. Thus, sand reclamation plays an important role in overall cleaner production strategy (UNEP, 1999; Yılmaz et. al., 2014).

The benchmark sand regeneration ratios obtained from literature research were given in Table 20. The indicator includes not only the amount of sand used in mould making but also the sand used in core making. Regeneration ratio was expressed as the percentage of the mass of regenerated to total mass of sand used. The rate of sand regeneration differs in accordance with: the type of sand system used (green sand or chemical bonded); the extent of core requirements and complexity and the molding process (IFC, 2011).

Table 20 Benchmark sand regeneration ratios

Sand type	**Regeneration Technique**	**Best Regeneration ratio (%)**	**Reference**
Green mono sand	Primary regeneration	98	EC, 2005
Green sand with compatible cores	Primary regeneration	94	
Cold setting mono sand	Simple mechanical regeneration	80	
Silicate mono sand	Heating and pneumatic treatment	85	
Mono sands of cold-box, SO2, hot-box, croning Mixed organic sands	Cold mechanical or thermal regeneration	100	
Mixed green and organic sand	Mechanical-thermal-mechanical treatment, grinding or pneumatic chafing	100	
No data	Manual reclamation	96	UNEP, 1999
No data	Thermal reclamation	98	
No data	No data	95.9	IFC, 2011
No data	No data	95	USEPA, 2002

As shown in Table 20, the sand regeneration ratio can be increased up to 100%. For the green sand high ratios can be achieved by primary regeneration. However, if chemically bonded sand is used the secondary regeneration is required in order to reach the same ratio.

All of the studied foundries used chemically (resin) bonded sand and all had a sand regeneration unit. Two of them (B and E) used a combination of green sand and chemically bonded sand. Silica sand was the refractory material used and the resin and/or the bentonite was the binder. Sand regeneration unit was present in all companies. In mold making, the ratio of the recycled sand to the fresh sand varied in the range of 15-30% based on the type of production. The Table 21 summarizes the sand regeneration ratios of studied foundries.

Table 21 Sand regeneration ratios of the studied companies

Foundry	Moulding type	Sand regeneration ratio (%)	
		Best	Average
A1	Resin bonded sand	61.31	60.82 ± 0.29
A2	Resin bonded sand	58.30	41.72 ± 8.43
B	Mainly green sand, and resin bonded sand if required	No data	No data
C	Resin bonded sand	82.19	77.87 ± 4.10
D	Resin bonded sand	96	92.41 ± 1.53
E	Combination of green sand and resin bonded sand, mainly green sand	95.01	94.99 ± 0.01
F	-	96.77	72.62 ± 15

The sand regeneration ratio of the Companies D and E were found higher than the other companies. After comparing the data of used sand amounts with the total production, it was observed that the sand usage of company D was extremely high (345,000 ton) for production of 1,727 ton casting whereas the sand usage of Company E (3,869.90 ton) was abnormally low for production of 6,500 ton of casting. Because of these inconsistencies the sand recovery ratio of Companies D and E were not taken into consideration in calculating the average performance of studied foundries.

Based on the results of the literature research given in Table 20, sand regeneration ratio of 98% can be achieved for green mono sand by primary regeneration. For mono and mixed sands 100% of regeneration is possible by thermal regeneration (EC, 2005).

The improvement potential was calculated for each foundry instead of comparing the average values since the benchmarks depended on the type of molding and applied sand regeneration technique which could differ for each foundry. All studied foundries used resin bonded sand and they had primary sand regeneration systems which might have different techniques. The foundry A1 had the average sand regeneration ratio of 60.82 ± 0.29 % which could be improved up to 85 % if heating and pneumatic treatment would be applied. The ratio could be inceased up to 100% if thermal regerenation would be used. The improvement potentials were given in Table 22 for foundries A1, A2 and C. The potential was not calculated for Foundry F since the moulding type which is the major factor affecting the sand regeneration ratio was not provided by the company.

Table 22 The improvement potential for sand regeneration ratio

	A1	**A2**	**C**
Sand regeneration ratio of the foundries	60.82 ± 0.29	41.72 ± 8.43	77.87 ± 4.10
Benchmarks (%)	85 (heating and pneumatic treatment) 100 (thermal sand regeneration)		
Improvement potential (%)	24 - 39	43 - 58	7 – 22
Total sand regenerated in 2014 (ton)	48,081	31,584	4,305
The mass reduction potential of WFS (ton)	11,539 – 18,752	13,581 – 18,319	301 - 947

The results indicated that more reclaimed sand can be reused internally. The foundries A1, A2 and C could decrease the WFS amount by 25,421 ton if they would apply heating and pneumatic treatment for sand recovery. The WFS amount would decrease 38,018 ton if thermal regeneration technique would be used.

Additional investment may be required in order to increase the sand recovery ratio. The reuse of the sand within the foundry results in the reduction of the sand cost and also reduction of solid wastes to be sent to landfill. According to the LCA study conducted by Yılmaz et al. (2014) on site recovery and external reuse of waste sand were capable of decreasing overall environmental impact of iron casting by 60-90%. The RECP applications to improve sand recovery ratio are discussed in Chapter 5.

4.2.3. Fresh Water Consumption

Foundries use, depending upon their production procedures, various quantities of water. Some have fairly dry operations resulting in small effluent streams, while others use large quantities of water in such operations as wet dust collecting, sand reclaiming, sand transporting, cooling, etc.

The water is mainly used for dust removal and waste gas treatment systems which are applied in melting and cleaning units, moulding material preparation and reclamation. It is also used in wet sand regeneration and core production, if wet scrubbers are used (depending on the core making technique and bonding agents used). Furthermore, the water is generally used in cooling systems of electric furnaces (induction) and in cooling baths (quenching ponds) which are used for heat treatment.

In general, the final volume of waste water is very small. Nevertheless, when wet de-dusting techniques are used, the generated waste water requires special attention. In (high) pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before its disposal (EC, 2005).

Because water consumption is often a relatively lower as compared to other resources, water efficiency may be overlooked in many foundries. Although it is not as important as other issues, there may be still some benefits in improving the water efficiency. The indicator of specific water consumption measures the volume of fresh water consumed per ton of good casting produced. The factors affecting SWC are the type of moulding medium (green sand, chemical bonded sand, etc.), cooling systems and heat treatment techniques that have a quench requirement (IFC, 2011). The benchmark water consumption data obtained from literature was presented in Table 23.

Table 23 Benchmark water consumption data obtained from literature

Alloy type	**Freshwater (m^3/ ton good casting)**	**Wastewater**	**Reference**
No data	No data	20 (max) (m^3/ ton melted metal)	Fatta et al, 2002
No data	No data	0,5 (average) m^3/ ton good casting)	EC, 2005
Iron and steel	0.76 (best practice in EU) 0.90 (average in EU)	No data	IFC, 2011

The average SWC of the studied foundries were given in Table 24. The water was used for sanitary purposes. The induction furnaces were also connected to the water system. Cooling (quench) tank used in heat treatment operations was also present in all foundries. Cooling tower was used for furnace and sand cooling systems. The Companies B and E use water in mould making.

Table 24 Specific water consumption of studied companies

Foundry	**Water consumption areas**	**SWC (m^3/ton good casting)**		
		Min	**Max**	**Mean ± std dev.**
A1 (steel)	Induction furnace cooling system, cooling tank, cooling tower and sanitary	2.42	3.75	2.92 ± 0.40
A2 (steel)	Induction furnace cooling system, cooling tank, cooling tower and sanitary	1.50	2.33	1.76 ± 0.29
B (iron)	Induction furnace cooling system, cooling tank, sanitary, cooling tower and mold making	1.48	2.59	1.87 ± 0.40
C (iron)	Induction furnace cooling system, cooling tank, cooling tower and sanitary	0.85	2.36	1.59 ± 0.57
D (iron)	Induction furnace cooling system, cooling tank, cooling tower and sanitary	1.46	2.50	1.86 ± 0.38
E (iron)	Induction furnace cooling system, cooling tower, sanitary and mold making	1.09	2.29	1.73 ± 0.44
Overall		0.85	3.75	1.95 ± 0.49

The monthly SWC of foundries were shown in Figure 9. The foundries B and E provided 6 months of water consumption data. As depicted in the Figure 9 the water consumption increased in summer period.

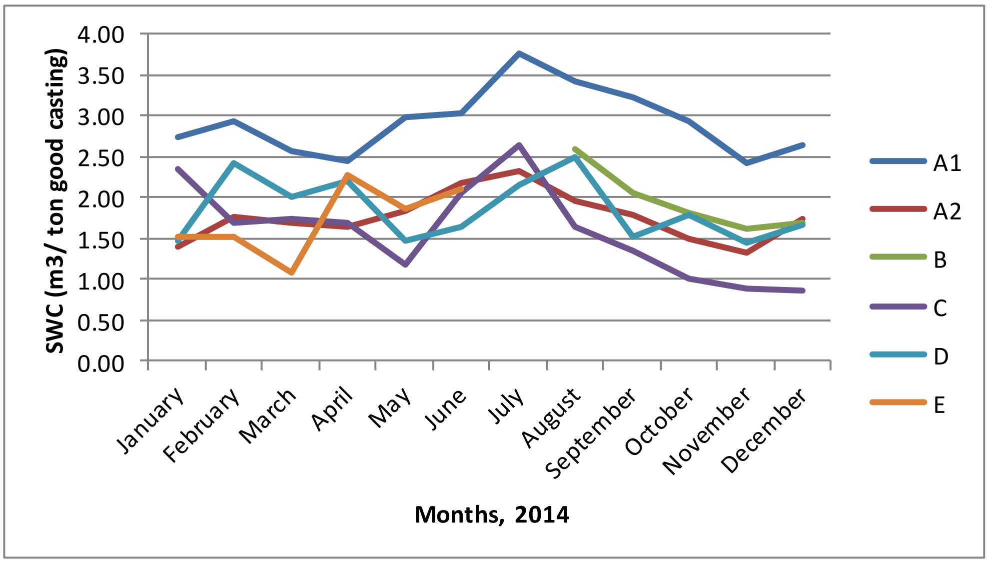

Figure 9 Monthly specific water consumption of companies

As shown in Table 24, the average SWC of the studied foundries was 1.95 (±0.49) m^3/ ton good castings. This amount was around two times higher than the average benchmark of 0.90 m^3/ton given in Table 23. Considering the total net weight of castings produced by foundries (36,516.53 ton) in 2014, they can save around 38,342 m^3 of water annually, which corresponds to around 323,993 TL based on the average unit cost of water indicated in the questionnaires which was calculated as 8.45 TL per m^3 of water.

The water was mainly used in cooling systems and quenching operations. Therefore, the wastewater amount is too little since the water reused internally within system. The cooling system generates no wastewater and the water losses due to evaporation are added to cooling tanks. The wastewater from quenching tank is very low since the water in the tank is used continuously. The wastewater only discharged while cleaning the tank when all the water is drained.

The RECP measures to achieve saving in SWC were discussed in Chapter 5.

4.2.4. Metal yield

The metal yield is the mass ratio of the metal melted to the finished good castings. It is an important parameter since it is a measure of the efficiency for the consumption of the raw materials. The main factors which affect metal yield are: quality requirement, choice of mold-box size, the extent of runner and feeder systems, metal shrinkage and scrap casting rate (EC, 2005). It does not have a direct effect on sand use and energy efficiency. However, improving the yield may result in less consumption of the sand and the energy (UNEP, 1999; CIPEC, 2003; EC, 2005).

The weight of metal melted always exceeds the weight of good castings due to metal losses (e.g. melting losses, spilt metal, grinding losses) and return metal (e.g. pigged metal, runners, scrap castings). Therefore, actual yield is always less than 100%. Good foundry practices shall be applied in order to achieve high yield (EC,2005; Envirowise, 2004). Although the bulk of this excess metal is collected and re-melted, it bears a significant cost to the foundry in the following ways: energy used in melting and holding the metal; capital costs for unnecessary metal handling capacity; increased fettling costs; unnecessary metal collection and sorting time; increased maintenance of equipment; lost time that could be used for value adding activities; and customer relations issues (UNEP, 1999).

The metal yield ratios obtained from literature were summarized in Table 25.

Table 25 Benchmark metal yield ratios obtained from literature

Casting type	**Metal yield (%)**	**Reference**
Heavy grey iron, simple shape	85-95	EC, 2005
Medium sized grey iron jobbing or small batch	65-75	
Mechanized repetition, general quality small to medium sized grey iron engineering and municipal castings	65-75	
Mechanized repetition, high quality small to medium sized grey iron engineering castings, relatively simple design	60-65	
Mechanized repetition, high quality small to medium sized grey iron engineering castings, complicated heavy cored design	55-60	
Medium sized nodular iron jobbing or small batch	50-60	
Small or very small grey iron repetition	45-55	
Mechanized repetition of malleable iron and small nodular iron castings	40-50	
Steel	45	
iron	54-84	CIPEC, 2003
steel	49-67	
Grey iron	65-90	Envirowise, 2004
Ductile iron	50-70	
Ductile iron pipe	90	Eppich, 2004
Iron	60-65	Arasu and Jefrey, 2009
Iron	52.5-69.1	IFC, 2011
Steel	45.3-71	
Simple shaped heavy grey iron	85-95	Thollander et al., 2005
Small ductile iron castings in mechanized volume production	40-50	

As shown above, yield differs significantly from one foundry to another depending on the type of casting produced and the type of metal concerned. A typical grey iron foundry can operate with a yield of 65% while foundries producing specialized grey iron castings may achieve a yield as high as 90%. For foundries producing malleable iron castings, yield may be only 35-45% whereas for those producing ductile iron a typical yield is 50-70% (Envirowise, 2004). In a facility producing ductile iron pipe, the metal yield will approach/exceed 90% because of the nature of the centrifugal casting process, which does not require a runner (gating) system or risers (Eppich, 2004).

The metal yields of the studied companies were given in Table 26. The studied foundries produce diverse range of products based on the customer needs. Thus, the size and complexity of castings varies a lot for each month. In the scope of this study, the weight of castings was collected by alloy type only and the detailed information about the size and complexity of castings were not obtained. The foundry C could not supply the yield data due to the lack of weight information for the good castings. The company representative estimated the metal yield as 88% for grey iron, 82% for nodular iron and 70% for steel castings. Thus, the company C was not included in analysis of metal yield indicator.

Table 26 Metal yield of companies

Foundry	**Alloy type**	**Metal yield (%)**		
		Minimum	**Maximum**	**Mean ± std dev.**
A1	iron (white, nodular and grey)	76.42	87.32	81.85 ± 2.92
	steel (plain carbon, low alloyed, manganese and high alloyed)	64.78	71.92	67.47 ± 2.14
A2	iron (grey and nodular)	76.00	87.86	83.30 ± 3.57
	steel (plain carbon, low alloyed and manganese)	58.20	71.85	65.62 ± 3.74
B	iron	67.18	71.00	69.37 ± 1.14
D	iron	35.21	85.98	54.12 ± 12.02
	steel	8.92	83.05	44.46 ± 25.89
E	iron	74.48	79.66	77.27 ± 1.56
F	iron	73.39	77.84	75.68 ± 1,42
Average	Iron (A1, A2, B, D, E, F)			73.59 ± 10.75
	Steel (A1, A2)			66.55 ± 1.31

The average metal yield was calculated as 73.59 (± 10.75) % for iron and 66.55 (± 1.31) % for steel foundries. The average results were compared against the benchmarks given in Table 25 since the studied foundries produced similar products. The benchmarks were provided as a range indicating the minimum and maximum performance achievements. The average benchmark could not be calculated since the achievable values differ based on the shape and complexity of the castings. According to the Table 25, the metal yield can be between 40 to 95% for iron and between 45 to 71 % for steel. Therefore, considering the maximum achievable benchmarks the metal yield of iron and steel foundries could be improved up to 21 % and 5 % respectively.

As shown above, the iron foundries had a better performance than the steel ones based on the comparison of average metal yields.

Considering the limited number of steel foundries which took part in this study, the individual performance of the companies was also checked against the average benchmark. Company A1 which produced 7,461 ton of good steel casting in 2014 had average metal yield of 67.47 (± 2.14) %, and company A2 made 7,461 ton of good steel casting with metal yield of 65.62 (± 3.74)%. Company D, which had very low amount of (236.96 ton) good steel production as compared to companies A1 and A2, had much lower average metal yield (44.46 ± 25.89 %). As a result, although the gap between the average performance of individual companies and the average benchmark differs, all companies had a potential to improve the metal yield considering the maximum achievable yield of 71% according to the literature (IFC, 2011).

The RECP measures which can be adopted to improve the performance of metal yield indicator were discussed in Chapter 5. The energy, sand and additives consumptions per unit of good castings could be reduced and thus the overall efficiency of the process would be improved by increasing the metal yield.

CHAPTER 5

RESOURCE EFFICIENT and CLEANER PRODUCTION OPPORTUNITIES

The main purpose of the study was to increase the resource efficiency and cleaner production applications in the foundry operations. The available RECP applications were investigated in order to improve the efficiency of energy, water and raw material consumptions. The improvement potential for each KPIs based on the results obtained from the EPE and benchmarking studies were presented in Table 27.

Table 27. Improvement potential for KPIs

KPI		Energy use (kWh/ ton good casting)		Metal yield (%)		Sand regeneration (%)	Fresh Water Consumption (m3/ ton of good casting)
		iron	steel	iron	steel		
Actual performance		1,820 (±429)	3,975 (±256)	74 (± 11)	66 (± 1)	Between 42 and 78	1.95 (±0.49)
Benchmark Performance	best	1,165	1,503	95	71	100	0.70
	avg.	1,338	1,815	N/A[4]	N/A[4]	85 and 100	0.90[5]
Improvement Potential (%)		27	54	Up to 21	Up to 5	Between 7 and 58	65

As shown in Table 27, the environmental performance of the companies could be improved in terms of the KPIs.

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[4] Not applicable

[5] Only one benchmark can be found for SWC. And the standard deviation was not indicated for average value in the reference document (IFC, 2011).

The RECP measures which could be adopted for this purpose were evaluated in this chapter. The measures were obtained from the literature research and then they were discussed with the company representatives who were engineers in order to decide whether they could be applied in the studied foundries. Therefore, the chapter includes both the literature review and recommended measures.

Some RECP applications could easily be adopted by the companies without any cost. The others may require process improvements or modifications which can be implemented at low or high cost. The adaptation of high cost measures may be difficult for the foundries. However, substantial benefits can also be gained through the application of no or low cost alternatives. Savings of up to 30% was reported due to the general housekeeping and process improvement practices (UNEP, 1999).

5.1 Improving energy efficiency

The energy is one of the most significant resources used in foundries and so RECP options for this industry include energy efficiency (Fore and Mbohwa, 2010; UNEP 1999). The benchmarking results showed that there is a potential to improve the SEC. While investigating the potential RECP measures, the focus was put on the equipment and processes using energy which are shown in Table 28. The area savings potential indicates how much the energy consumption can be improved for individual processes. The overall plant saving potential in the Table 28 reflects the multiplication of this amount with the potential energy consumption of that specific process. For example, the melting step consumes 59% of the total plant energy, and the energy consumed in melting can be reduced by 15% which will result 9% (59% x 15%= 9%) improvement in overall energy consumption.

Table 28. Energy usage areas and saving potential for foundries (CIPEC, 2003)

Equipment/ process	Consumption of total plant energy (%)	Area savings potential (%)	Overall plant saving (%)
Melting	59	15	9
Fans and pumps	6	35	2
Lighting	6	30	2
Motors	12	10	1
Air compressors	5	20	1
Miscellaneous	12	10	1
Total	97[6]	-	16

The inefficient use of equipment and processes (Table 28) cause the energy losses that can be overcome by better practices. The melting process consumes 40-60 % of the energy input (EC, 2005; CIPEC 2003). The melting and holding of the metal are the key areas to be considered in improving the energy efficiency since poor planning of these can double the energy cost (CIPEC, 2003).

Almost all of the foundries in Turkey use induction furnace for melting operation (TFA, 2013). The studied foundries used induction furnaces too. The energy loss occurs through radiation, conduction and slag skimming in induction furnaces. Keeping the furnace lid closed during the melting prevents the radiation losses which would be equivalent to 10-15 kWh per minute. Delays in melting and pouring operations also causes to heat losses. The molten metal is transferred from the furnace to mold by using ladles. Substantial heat losses occur during this transfer, and overheating of the charge is required in order to maintain the pouring at the right temperature. Therefore, rigorous use of ladle, furnace lids and the engineered ladle preheating systems are the activities which promote energy savings (Prucha, 2008).

In addition to melting, the foundry's other energy intensive systems, such as compressed air and transport systems for molten metal, sand, castings and scrap,

[6] Variation due to unaccounted influences

increase the energy usage too. Compressed air is the second largest source of energy loss (CIPEC, 2003). The compressed air is mainly used in finishing and moulding operations. For example, the hand tools in finishing operations, blowers which are used for mould and core making, pneumatic cylinders for transportation of the sand and moulding machines all work with compressed air (Eppich, 2004). One third of all compressed air is lost during the generation and delivery of the compressed air. Leak repairs, piping changes, air storage sizing and proper compressor sequencing are the typical energy saving measures which can be implemented at low cost (Gigante, 2010).

Energy consumption varies in accordance with the material, alloys, process involved in melting, variations in process yield, variations in heat treatment operations as well as the core content, use of different holding furnaces and different casting process (IFC, 2011; CIPEC, 2003; Schifo and Radia, 2004). All studied foundries used identical furnaces and processes. Moreover, the benchmarks obtained from the literature were compatible with the obtained results since they were classified according to the furnace and alloy types.

Another factor affecting the energy required to make a good casting is the size and complexity of the gating system which consist of the risers and runners. The gating system is used for feeding the molten metal to the casting and the system is removed before shipment of good castings. The removed gating metal is usually re-melt in the furnaces and again poured into the mould. Complex and heavy gating systems, especially in steel foundries, cause more energy requirements. Therefore, computer solidification models are used in foundries to design minimum weight gating systems (Schifo and Radia, 2004).

The energy consumption can be reduced in two ways. First, low energy technology can be used. Second, the efficiency of equipment or processes can be improved by minimizing the energy losses. RECP measures to reduce energy consumption in foundries were listed below. The foundries can save energy by implementing these methods.

1. Energy Auditing and Monitoring

The purpose of the energy audit is to identify opportunities for energy saving based on the assessment of the energy consumption data. The monitoring energy consumption of the most energy intensive equipment can help the company to identify the problem for the energy losses. The continuous monitoring through sub-metering the energy usage also provides the information about the impact of different improvement actions over time (Gigante, 2010).

The energy audit can either be done by external specialized companies or the company itself can conduct an energy audit if it has the qualified staff. Among the studied foundries, only Company A, which was the biggest in terms of annual capacity and employee, had recently conducted an energy audit. The energy audit report has recently been received by the Company at the date of interview and so the findings have not been put into practice yet. Although the other companies were aware of the benefits, they did not have an energy audit.

The SEC of the studied companies was calculated based on the overall energy consumption since the companies did not have the records for the energy consumption of the equipment. Only Company A had two meters measuring the energy consumption of the administrative building and foundry shop. The Company C and E had installed meters on the induction furnaces however regular records had not been kept for these meters. The Company B did not have any meter, but the sources for the energy losses were identified through the on-site inspection done by the Production Manager.

The investment cost for a monitoring system varies in accordance with the extent of installed metering, the desired coverage, and the methods for recording and analyzing energy use. The realized energy savings leads to recover the installment cost within months (CIPEC, 2003). Some case studies were presented below about the energy savings through establishment of energy monitoring system.

A foundry in the United Kingdom (UK), installed an energy monitoring meter on the electric induction furnace in order to analyse the power consumption on the minute by minute basis. The results revealed the inefficient practices of the operation such as failures to operate the furnace under high power; lengthy holding times while waiting for compositional checks and alloying additions; lengthy holding periods while waiting for transfer to the launder or transport ladle; raising of melt temperatures to unnecessarily high levels. The average melt SEC of the company was reduced by 57 kWh per tonne and so $17,500 was saved annually. The cost of the metering equipment was recovered in around 6 months.

Another company in the West Midlands, UK, used an integrated monitoring and scheduling system to observe the batch melting cost and to compare the furnace charging and scheduling methods. Thus, the charging procedures, slagging practices, cold start routines and relining procedures were optimized. The investment cost of the equipment ($75,000) was recovered in less than 6 months as a result of the energy savings. Among other savings, the company reduced energy consumption for one of the 10-tonne furnaces from 654 kWh per tonne to 553 kWh per tonne —a 15.4% improvement.

The measures implemented in a UK foundry based on the results of an energy audit improved the efficiency of the air compressor system. The operating pressure of the compressor was reduced from 7 bars to 6.5 bars. A control system with cost of $17,500 was installed in order to provide consistent supply. The system was also arranged to operate at 5 bars during scheduled breaks and to shut-off during the predetermined non-production times. These measures reduced the power consumption by around 26 kWh. Compressed air was also used to clean the mould cavities. The reprograming of the air guns per mould reduced the compressed air usage by 19.4% (UNEP, 1999).

2. Improve melting efficiency

The coreless induction furnace loses energy through radiation (furnace lid opening), conduction (furnace structure) and slag/dross skimming. These can be minimized by controlling the heat losses during the melting and holding operations. Some good practices which provide significant energy savings in induction furnaces were explained below.

For example, keeping the furnace cover closed reduces the radiation heat losses (EC, 2005; CIPEC, 2003; Lazzarin and Noro, 2015). The average radiation loss of medium sized induction furnace melting iron was reported as 10-15 kWh for every minute the cover was open (CIPEC, 2003). Thus, the lid of periods must be optimized in melting process. The lids are opened for charging, removing slag, temperature measuring, sampling and pouring. The necessary opening time for these operations varies between 50% and 25% of the shift time (EC, 2005). Some good practices are drilling a sampling port through the furnace lid to limit the opening of the lid (CIPEC, 2003); or reducing time for sample analysis & communication by using intercoms and alarms, pneumatic conveying and advanced logistical preparations (Patange and Khoud, 2013); etc.). In addition to these measures, ceramic insulation of furnace lids supports to control the furnace temperature. The power savings in the range of 6-26% could be achieved (CIPEC, 2003).

The furnace cover had not been closed by most of the studied foundries during the melting operations. The average melting period was indicated as 45-60 minutes for the induction furnaces. The capacity of the furnaces range between 450 and 5,000 kg, only Company A had one 8,250 kg furnace. The foundries melted 51,899 ton of scrap and ignot in 2014 in order to produce 36,516 tons of iron castings. Assuming that 4,000 kg induction furnace with melting time of 45 min was used for the melting and between 10 to 15 kWh/min radiation losses occurs for open furnace cover (CIPEC, 2003), the total radiation loss was between 5,838,637 and 8,757,956 kWh in 2014. The unit price of electricity was 0.20 TL/kWh, thus the companies lost around 1.2– 1.7 million TL because of the operation of induction furnace without closing the furnace cover. Moreover, the energy loss caused to release 3,445 – 5,167 ton CO_2 because of the redundant electricity consumption of the furnaces.

Another example is usage of clean scrap for melting and removal of sand from the return material. It was reported that energy saving of 10-15% could be achieved due to reduction in slag (EC, 2005). Since melting slag requires 1.7 to 2 times more energy than melting iron, using clean scrap is important to save energy. The amount of the non-metallic materials causes more slag formation. A good example of clean scrap is shredded scrap which has less non-metallic materials than sheared scrap. The energy consumption decreases by 15-20 % in the melting stage if shredded scrap is used instead of sheared scrap. Although the cost of shredded scrap is higher, considering economically more feasible to purchase (Gigante, 2010).

The studied foundries generally used shredded scrap instead of sheared scrap. The Company B used mainly metal ignots with small amounts of shredded scrap. If the foundries used sheared scrap, the energy consumption in melting stage would be reduced between 15 and 20%. The total energy consumption was 97,869,774.15 kWh in 2014. Assuming the melting energy was 59% of the total energy usage (CIPEC, 2003), the electricity used for melting was 57,743,167 kWh. If sheared scrap was used, the energy consumption in melting would decrease between 8,661,475 and 11,548,633 kWh corresponding to saving of 1.7 and 2.3 million TL. The CO_2 emissions resulted from the electricity use of the furnaces would reduce between 5,110 and 6,814 ton.

Slag is a type of waste produced during the melting and it negatively affects the melting efficiency. The slag formation decreases with the increase of melting temperature which leads to higher energy consumption. On the other hand, the accumulation of slag effects the melting efficiency and heat loss occurs during its removal though opening the furnace lid. Therefore, good balance between these two practices helps to reduce energy consumption (EC, 2005).

A good cooperation between the melting and moulding shop is also a good housekeeping practice which prevents unnecessary superheating of the metal. The holding time should be kept at minimum for the molten metal (EC, 2005; CIPEC, 2003)

The preheating of the charge is another good practice which reduces the energy consumption of the furnace by around 55-83 kWh per ton (Iyer et al., 2014). In addition to removing the moisture and residual oil of the charge, this practice shortens the melting time of the induction furnace (BCS, 2005).

The studied foundries did not preheat the charge. If so, considering the weight of total melted metal in 2014 (51,899.01 ton), their electricity saving would be between

2,854,445.55 and 4,307,617.83 kWh corresponding to saving of 570,889.11-861,523.57 TL. The reduction in the CO_2 emissions would be between 1,684.12 and 2,541.49 ton.

3. waste heat recovery

Net energy savings of 15% to 25% or more can be achieved by reuse of waste heat from many foundry processes. A heat recovery system may include the following major parts: waste heat source, heat exchanger, heat distribution system and heat recipient. The waste heat can be recovered to be used in heating the building, core drying, and/or shower heating. A range of conversion technologies are available in the market either transferring or converting the waste heat (Gigante, 2010; EC, 2005). Although the new technology is expensive to install, the captured waste heat can be used directly by transporting heat between different mediums. For example, the waste heat from the melting operation can be reused in many other operations like preheating the charge, core drying, shower water and building heating etc. (Iyer et al., 2014)

None of the studied companies had waste heat recovery systems. If so, considering the total energy consumption of 99,869,773.74 kWh and saving potential of 15-25%, they could save energy between 14,980,466.06 and 24,967,443.44 kWh.

For example, an energy audit was conducted in 2013 for a foundry which had 5 induction furnaces and a thermal heat recovery system. 432,000 kWh of thermal energy which was produced by the furnaces was used to heat offices and molding department. The yearly energy quantities were estimated based on the measurements of the furnaces electric power, the thermal recovered power and the thermal power dissipated by the cooling tower water circuit. It was determined that 31,055 MWh of electricity was used by the furnaces, 432 MWh of thermal energy was recovered for heating and 7,718 MWH of thermal energy was wasted in cooling tower (Lazzarin and Noro, 2015).

4. Install energy efficient lighting systems

Lighting systems can also be a source of significant energy saving. Modern lighting systems can reduce running costs by as much as 25% while achieving the same light output and extended lamp life (UNEP, 1999). For example, retrofitting of a facility HID lighting to T-5 high bay fluorescent was reported to save 1.1 million kWh of electricity per year (saving 74,000 $, investment 219,000 $). The deposition of dust and high heat can be a problem for the efficiency of lighting fixtures and sensors which can be overcome by tolerant specialized fixtures. Considering the high cost of replacing the existing lights with the more energy efficient ones, the activity can focus primarily to low dust areas such as offices, core rooms, pattern vaults, shipping warehouses, and maintenance shops (Gigante, 2010).

The type of correct lighting fixture differs in accordance with the requirements of the working environment. For example, the position of the fluorescents should be arranged in a way that there are no obstructions to lighting since it losses light from dust accumulation (CIPEC, 2003).

The Company B used halogen lamp ranging from 250 W to 400 W, average 325 W. There were 50 lamps in the factory. The Company preferred to use led lamp instead of fluorescent. They replace the broken lamps with led ones of 125 W. The factory works 2 shifts (18 hours per day) and 6 days per week. Hence, considering average power of lamps, the company can save 200 W per lamp which corresponds to 180 kWh (36 TL) saving per day. This leads to annual saving of 56,160 kWh (11,232 TL) and reduce CO_2 emissions by 33 ton.

The Company C used 500 Watt halogen lamp. There were around 20 lamps in the factory. The foundry was in operation as one shift (8 hours per day) and 6 days per week. The company can save 375 W per lamp by retrofitting the factory by led lamps. Thus, daily energy saving will be 60 kWh (12 TL) and annual saving will be 18,720 kWh (3,744 TL). The CO2 emissions will be reduced by 11 ton.

The Company E used 400 W mercury vapour lamp. Total number of the lamps was 66, and these were working 16 hours per day during 6 days of the week. The company plans to replace these with the 120 W led lamps. This retrofit will cause savings of 280 W per lamp and of 295.68 kWh (59 TL) per day. The annual saving will be 92,252.16 kWh (18,450.43 TL) and the CO_2 emissions will be reduced by 54 ton.

5. Improve the efficiency of the compressor

Compressed air system is the second largest energy consumer in a foundry. Average useful compressed air usage is 35% whereas energy is lost through leaks (25%), poor applications (20%), air lost in drainage systems (5%) and artificial demand (15%). The artificial demand is the excess compressed air which is wasted by operating the system at higher pressures than necessary. This average percentage of losses differs with the company. While investigating the energy saving opportunities, not only the individual components such as compressors, dryers, filters, coolers and auxiliary equipment should be considered but also an overall evaluation of the system should be done in terms of pressures versus volumes, rates of change in pressure, etc. (CIPEC, 2003).

There are many opportunities to improve the efficiency of the compressed air system. Preventive maintenance of motors, drives, compressed air, lighting and boiler plant is an important measure for energy improvement in foundries (Meffert, 1999; UNEP, 1999; Prucha, 2008; CIPEC, 2003). Regular simple maintenance of compressed air system can save up to 30% energy (Patange and Khoud, 2013). Preventive maintenance of equipment leads to increase the operation efficiency by minimizing leaks, spills and other potential losses of the resources. For example, 6 mm leak in a compressed air line is equivalent to left on 300 light bulbs of 60 watt. Ancillary services including motors, drives, compressed air, lighting and boiler plant, are the areas of particular importance for maintenance and inspection since they share almost half of the total energy consumption. (UNEP, 1999). All foundries made regular preventive maintenance for the compressors.

The location of the compressors is also important in terms of energy saving since lower inlet temperature can save more power. 1.4% power saving was reported at inlet temperature of 10^0C (Patange and Khoud, 2013). The energy consumption of the compressor was reduced by 1% for every 4^0C decrease in inlet air temperature (Prashanth et al., 2014).

Another measure is replacing screw compressor with VFD (Variable Frequency Drive) screw compressor. The VFD prevents the compressor to go to unload mode of operation. (Patange and Khoud, 2016). Gigante reported that the foundries in India can save minimum 20% of energy by installing VFDs for ID/FD (Induced draft/Forced draft) fans, oil circulation pumps and doubling machines; and by using mechanical damper for fans and valves. Moreover, majority of the doubling machines were operated at constant speed irrespective of the load on the machine (Gigante, 2010)

The Companies B and C had screw compressor, and the Company E one screw compressor and VFD. The potential savings by replacing the compressors could not be calculated since the capacities and power requirements of the processes were not known. The power draw of each compressor shall be measured in order to analyze potential energy savings.

Energy saving opportunities was investigated in a study conducted for a large iron foundry with capacity of 100,000 ton annual production. The foundry had six screw air compressors with the total load of 1,700 horsepower (hp) (two 450 hp compressors and four 200 hp compressors). The power draw of each compressor and system pressure were measured for 24 hours in order to identify the possible energy saving areas. It was observed that one of the 200 hp compressors had always been unloaded, and two compressors were used as a trim with varying load due to the variations in system pressure. One of 450 hp compressor which was used to trim could be used for base loading. It was expected to save more than 1,600 MWh annually by turning off two of the 200 hp compressor by isolating the supply and the demand sides of the system and installing an integrated microprocessor control system. (Meffert, 1999)

The annual energy and maintenance savings of 242,000 kWh and $24,000 were achieved in a foundry by implementing a retrofit project on foundry’s compressed air system. The engineers at Techni-Cast’s foundry in Southgate, California implemented the following actions in 2002: The compressed air system was retrofitted with more appropriately sized compressors, the compressor controls were upgraded and the existing condensate drains were replaced with more efficient, zero loss models. In addition to these, the optimum pressure levels for the use of compressed air were calculated, the leaks were repaired and the dryer's coalescing filter was cleaned. As a result the online compressor capacity was reduced by 50% without effecting the production. The total cost of the project was $38,000. It was reported that the system level evaluation is important for increasing the efficiency of the compressors (Energy matters, 2004).

After screening the RECP applications obtained from the literature, the applications presented in Table 29 are recommended to the foundries to improve their SEC.

Table 29. RECP measures to improve SEC

Proposed system	**Current system**	**Energy saving potential**
Install an integrated monitoring and scheduling system (Gigante, 2010; CIPEC, 2003; UNEP, 1999)	Although some companies had measurement devices, they did not keep regular records.	Provide the information about the potential energy saving areas by recording the continuous consumption data of equipment/ processes.
Keep the furnace cover closed and reduce lid-off periods (EC, 2005; CIPEC, 2003; Lazzarin and Noro, 2015)	The foundries did not close the furnace cover during melting.	Average radiation loss is 10-15 kWh for every minute the cover is open. The foundries can save between 5,838,637 and 8,757,956 kWh (1.2– 1.7 million TL) per year and CO_2 emission can be reduced by 3,445 – 5,167 ton.
Use shredded scrap instead of sheared scrap (Gigante, 2010)	The foundries usually use sheared scrap.	15-20% energy reduction in melting. The foundries can save between 8,661,475 and 11,548,633 kWh/year (1.7 and 2.3 million TL) and CO_2 emission can be reduced by 5,110 and 6,814 ton.
Preheat the charge (Iyer et al., 2014)	The foundries did not preheat the charge.	55-83 kWh saving per ton. The foundries can save energy of 2,822,380 to 4,259,229 kWh. CO_2 emission can be reduced

Table 29 con't.

		between 1,684 and 2,541 ton.
Waste heat recovery (Gigante, 2010; EC, 2005; Iyer et al., 2014)	The foundries did not have waste heat recovery systems.	15-25% of energy saving. The foundries could save energy between 14,680,466 and 24,467,443 kWh
Install energy efficient lighting systems (for example T-5 high bay fluorescent) (UNEP, 1999; Gigante, 2010; CIPEC, 2003)	The foundries B, C and E used 250-500 W halogen lamps and 400 W mercury vapor lamp.	25% reduction in running cost. The foundries B, C and E can save energy between 18,720 and 92,252 kWh per year by retrofitting the factory with led lamps. The CO_2 emission can be reduced between by 33, 11 and 54 ton respectively.
Preventive maintenance of compressed air system (Meffert, 1999; UNEP, 1999; Prucha, 2008; CIPEC, 2003)	All foundries did preventive maintenance.	30% energy saving.
Replace the screw compressor with VFD compressor (Patange and Khoud, 2013)	The foundries used both the screw and VFD compressors.	20% energy saving

As presented in Table 29 the foundries applied some of the recommended measures in their process. They did the preventive maintenance of the compressed air system and they used VFD in addition to screw compressors. On the other hand, they can save minimum 32 million kWh/year (around 32% of the overall energy consumption) by closing the furnace cover, using shredded scrap, preheating the charge, installing waste heat recovery systems and using more energy efficient lighting systems.

The improvement potentials for the SEC were given in Table 27. The application of the RECP measures in Table 29 will support the companies to move towards the more efficient use of the energy. The gap between the actual SEC of the foundries and best benchmark performance will be reduced. In addition to saving of energy and money, CO_2 emissions will be decreased between 10,200 and 14,500 ton per year.

5.2. Improving Metal Yield

The results of the first phase for average metal yield showed that the iron and steel foundries melt, cast and worked on 1.4 and 1.7 tons of metal, respectively, for every ton of casting sold. The improvement of the metal yield helps the foundries to increase their resource efficiency in terms of metallic raw material, energy and sand. An integrated approach is required while analysing the RECP measures in order to ensure the improvement in metal yield without compromising the quality of products.

The metal yield is the mass ratio of the metal melted to the net weight of finished castings. The weight difference results from metal losses and return metals (EC,2005). The Figure 10 presents the general metal mass balance for a typical foundry. Although the scrap castings, runners and pigged metal reused in the process, metal is lost through melting losses, split metal and grinding losses.

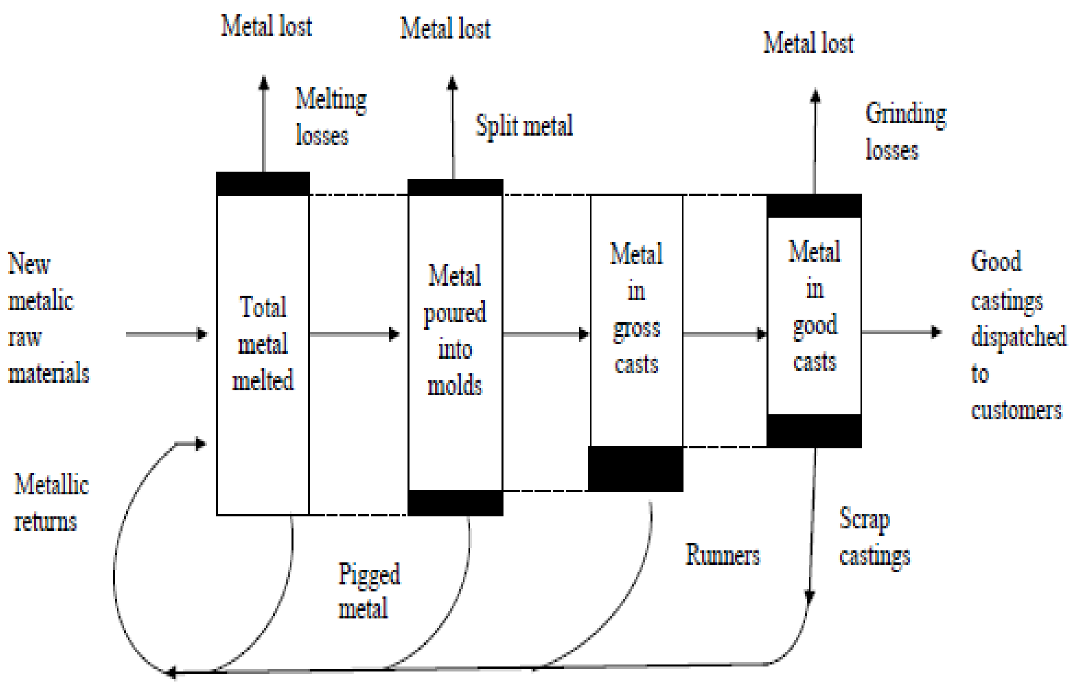

Figure 10 Metal Mass Balance of a Typical Foundry (UNEP, 1999)

In addition to loss of the raw material, the operation cost is increased due to the excess usage of energy and sand during re-processing the metallic returns. Energy is wasted in melting and holding the excess metal. Moreover, redundant volume of sand is used for moulding the scrap. Both the energy and labour force is spent in fettling which is a non-value adding operation.

Metal yield can be improved by decreasing the metal loss and amount of return metal (EC, 2005). As shown above there are three types of metal losses: melting losses, spilt and pigged metal losses. The oxidation, slag removal and sampling operations cause melting losses which were reported as 3% (UNEP, 1999). Some of the melting loss is unavoidable in order to achieve chemical composition for the desired quality of alloys. However, unnecessary loss from poor material qualities, inefficient process and technology can be minimized (IFC, 2011).

Metal split is the liquid metal tapped from the furnaces or ladles while transferring the molten metal. Pig is the excess molten metal remained after pouring into the moulds. 90-95% of the pig and split can be recycled. These losses vary in accordance with the applied melting process and moulding technology. For example, hand moulding requires excess metal melting since more split and pig would occur (IFC, 2011). Pigging up to %5 is acceptable in foundries considering the excess molten metal needed for the defective mould and casts (Envirowise, 2004).

The grinding losses can be minimized by reducing or eliminating the fettling stage. The need for fettling is reduced in lost foam or investment casting techniques since smoother castings are produced. Moreover, fettling process can be automated or combined into the machining process (UNEP, 1999).

Efficient design of casting and gating systems reduces the amount of return metal (UNEP, 1999). The gating system includes the runners and risers. Runner is a channel through which the molten metal is poured into the mould, and riser is the additional reservoir of feed metal during cooling. These parts are removed from the castings and reused in the process. Removing the gating system requires intensive energy and labour. Therefore, the weight of gating systems needs to be minimized as low as possible without compromising the quality of the castings (Schifo and Radia, 2004). Casting simulation software can be used in designing the gating system without jeopardizing the casting quality (UNEP, 1999).

The scrap which is the rejected casting can be minimized by preventing the metal from inclusions and porosity. The efficiency of the melting process affects these properties. Moreover, incorrect placement of risers and runners cause the casting defects.

The RECP measures:

1. Minimize melting losses

The melting losses can be minimized by using clean scrap, optimizing stirring practices to minimize slag formation, minimizing unnecessary superheating, selecting and maintaining appropriate refractory linings (UNEP, 1999; IFC, 2011).

2. Minimize split and pigged metal

Precision or automatic pouring systems minimize the spilt by improving the efficiency of the pouring process (Envirowise, 2004; UNEP, 1999). The amount of pigged metal is also reduced since the metal demand and supply is better matched with this system. The studied foundries did not have automatic pouring systems. The industrial case studies were presented below showing the savings achieved by the companies.

Chrysler Foundry, producing engine blocks, replaced teach-in pouring method with four Laser Pour systems by spending installation cost of $15,000-20,000. It was reported that the gross weight of the castings was reduced by around 3.2 kg per sprue cup poured and overall scrap rate was reduced by around 510 tons. The company saved approximately $1 million during the foundry' 1994-95 fiscal year.

Another foundry in the United States, Auburn Foundry, which has two plants and pours up to 1,600 tons of grey iron per day, installed a Laser Pour laser-controlled-molten-metal-pouring system. Cycle time was between 7 and 12 seconds based on the weight of the job. After using the Laser Pour system, it was reduced by between 0.5 and 1.7 seconds; and also the production rate was increased around 6-8% at one plant (UNEP, 1999).

3. Minimize weight of castings

Both the gross and net eight of castings are oversized in order to ensure the quality of the product. The uncertainties in the pouring and solidification processes also cause the foundries to melt more metal than necessary. Efficient design of casting and gating system help the foundries to increase metal yield by reducing the gross and net weights. Casting simulation software provides optimum design of the gating system without impairing the quality of the casting (UNEP, 1999; CIPEC, 2003; EC, 2005). The case studies demonstrated that the weight can be reduced by as much as 30% based on the current geometry and gating system used (UNEP, 1999). Using casting simulation software not only reduces the weight of castings but also helps to reduce the grinding losses and scrap by ensuring higher quality products.

For example, a foundry from UK, Fishercast Ltd., which produce steel valves and had been using standard engineering rules and formulas in determining the size of casting, installed casting simulation software. This helped the company to identify the opportunities for metal savings and production costs were reduced by 12%. The pour weight of one steel valve was reduced from 2,330 kg to 1,880 kg whereas the fettling time was reduced from 10.5 hours to 4.3 hours (UNEP, 1999).

The Companies A and E used casting simulation software and their average metal yield for iron were around 80% whereas that of other companies ranged between 54% and 76%.

4. Minimize grinding losses

Another significant source of metal loss is the fettling stage. The foundries investigate the ways to reduce or eliminate this non-value adding process. The use of lost foam or investment casting is one of the methods since the size of the castings obtained through this method is close to the size of the desired final product (IFC, 2011; UNEP, 1999). The studied foundries used neither lost foam nor investment castings.

Use the Foseco Kalpur direct pouring system which comprise feeder, pouring cup and filtration system. It was reported that the yield could be improved 10% on average since the system eliminates the conventional running system (Moffad, 2010). The studied foundries used the Foseco Kalpur direct poring system rarely.

Considering the RECP measures obtained from the literature, the measures presented in Table 30 are recommended to the foundries to improve their metal yield.

Table 30. RECP measures to improve metal yield

Proposed system	**Current system**	**Explanation**
Precision or automatic pouring systems (Envirowise, 2004; UNEP, 1999)	The ladles were used for pouring.	Reduction in gross weight of castings, scrap rate and cycle time
Casting simulation software (UNEP, 1999; CIPEC, 2003; EC, 2005)	The Companies A and E had casting simulation software.	30% decrease in cast weight
Lost foam or investment casting (IFC, 2011; UNEP, 1999)	The expandable pattern casting (chemically bonded or green sand) was used in the studied foundries.	Decrease the need for fettling

The improvement potentials for iron and steel foundries were calculated up to 21 and 5 % respectively (Table 27). The benchmark metal yield values differ significantly depending on the size and shape of castings. The yield ranges from 40 to 95 for iron and from 45 to 71 for steel. It decreases for the small and complex shapes castings (Table 24). Although the size and complexity of the castings were not known for the studied foundries, they can improve their metal yields by using casting simulation software, automatic pouring systems and lost foam or investment casting processes.

5.3. Improving sand regeneration

The sand regeneration is a common practice in foundries due to the large volume of sand used in the process. The results of the first phase revealed an improvement potential between 7 and 58 % for sand regeneration ratios.

There are many benefits to improve the sand regeneration ratio. The demand for the new sand is reduced since more sand is reused in the process. The amount of waste and accordingly the cost of waste disposal are also reduced by decreasing the amount of WFS.

The factors affecting the sand regeneration ratios are the type of sand (green sand or chemical bonded), the amount and complexity of cores, and the moulding technique (automatic, mechanized or manual) (IFC, 2011). Primary regeneration includes mechanical processing of the moulds and cores to transform them into their original grain size. The main techniques are vibration, rotating drum and shot blasting. The green sand can be regenerated by primary regeneration. However, this sand can only be used in mould making and further processing is required in order to use the primary regenerated sand in core making. Secondary regeneration techniques are cold mechanical treatment, thermal treatment and wet scrubbing (EC, 2005).

The whole of the six companies which provided data about the sand consumption have been using resin bonded sand in moulding. Only two of them (Company B and E) have used green sand in addition to the resin bonded sand.

The RECP measures:

1. Segregation of WFS (the excess metal fines, shot blast dust, chemical binders etc. negatively affect the sand regeneration).

Segregation is an important RCEP option which minimizes the contamination of the sand. Some options are: installing bag houses for the processes which generate dust (shot blast dust, furnace dust and sand dust); installing magnetic separators on bag houses, regeneration units and other transport systems for the removal of ferrous metals; providing separate bins and bays for different type of by-products etc.

The segregation of the waste foundry sand not only increases the potential for sand reuse but also reduce the cost of waste disposal by eliminating the hazardous waste from the others. For example, a Brisbane based foundry, RMC segregated the shot, sand, dust and gunmetal by replacing its shot blast units. After the instalment of new system, the shot was recirculated and the gunmetal was returned to the furnace. The sand reclamation ratio was increased to 100% since the shot contamination, which was classified as hazardous waste, was removed from the sand streams.

Another foundry from the Queensland, Toowoomba Foundry separated and reused easily recyclable material (e.g. paper, cardboard and metal drums) by separating the bins for different waste streams. The elimination of sand contamination enabled the company achieving one of the first examples of beneficial reuse in Queensland. The material was sent to a local compost operator. The company investigated other potential reuse options for the segregated materials. Moreover, an incentive program was implemented including gift voucher, dinners etc. for the production teams who achieve segregation targets for a given period. Although the cost of all these segregation activities, it was reported that the overall costs to the company have been significantly reduced (UNEP, 1999).

2. Apply primary sand regeneration (vibration, rotating drum or shot blasting).

Primary sand regeneration includes mechanical treatment processes to bring the sand into its original grain size, to remove the fines and to cool the sand. This technique provides significant regeneration ratios for the green sand. EC reported that 98% of regeneration may be achieved for green sand mono system. The ratio can be 90-94% if the system has high degree of incompatible cores (EC, 2005).

Most of the studied foundries use chemically bonded sand which requires further treatment processes to remove the residual binder. If green sand is used instead of the resin bonded sands, the companies can achieve higher regeneration ratios by using primary sand regeneration techniques.

A foundry in UK reduced new sand purchase by 75% after the instalment of mechanical reclamation system. Using reclaimed sand reduced the binder and acid consumption by around 35% (UNEP, 1999).

Another foundry J Youle & Co Ltd. having a mechanical sand reclamation plant, gradually increased the level of sand reclamation by working in close cooperation with its binder supplier. The sand quality and optimum resin/hardener rates were investigated. Initially, the sand reclamation ratio of 70% was achieved and the resin addition rates were reduced from 1.65% to 1.5%. The alkaline phenolic binder system was upgraded and type of virgin silica sand was changed in the end of the planned program to obtain high reclamation levels. As a result, the reclamation ratio was increased up to level of 80% without damaging the mould quality. The additional costs (new binder system, equipment operation and instalment) were recovered within around 18 months due to the reduced new sand and disposal costs (ETBPP, 1998).

3. Apply cold mechanical regeneration using an impact drum.

Additional processes which remove the residual binder are needed in order to use the primary reclaimed sand for core making. Secondary regeneration bring the sand quality similar to, or better than, that of new sand. Mechanical regeneration systems like fluidized bed systems may be used in order to regenerate the sands with cold setting resins. On the other hand more intensive cold mechanical treatment methods are needed for regeneration of sands bonded with gas-hardened and thermosetting resins (EC, 2005).

The "cold mechanical regeneration using an impact drum" can be used both for the regeneration of the mixed sands and mono sands. A drum with rotating internal axis is used in this method for grinding of the sand. This method is more effective for chemically bonded mono sand; however it can also be applied for the mixed bentonite organic sand with addition of a magnetic separator. The green sand is removed by magnetic separator based on its weak magnetic characteristic due to un-reacted bentonite. The regenerated sand can be used in core making after use of this method. It was reported that a company from Turkey, Döktaş used the method with 5 magnetic separator and 2 grinders (EC, 2005).

4. Apply thermal sand regeneration

If the share of the chemically bonded sand or core is high, thermal reclamation is an alternative regeneration method. The organic materials are removed by thermal treatment. The heat is used in this technique to combust binders and contaminants. Mechanical step is required prior to the thermal process to obtain the sand in correct grain size and also to eliminate any metallic contaminants. Although regeneration ratio of 98% was reported, the use of this method is not popular due to the high investment cost (UNEP, 1999).

It was reported that a foundry using sand type of cold box core units achieved sand regeneration ratio of 95% with the application of thermal regeneration by multiple hearth furnace (500 ^{0}C) with sieving and classification (EC, 2005).

Rising waste disposal costs drive the Foundry in Staffordshire to install a 3 tons/hour thermal reclamation unit with a cost of £ 215,000 in 1996. The payback period was recorded as 1.6 years (ETBPP, 1998).

A foundry from USA installed in 1988 a thermal sand reclamation system to recover its 2,200 ton/y WFS (green sand). The investment cost was $428,500. Another foundry producing aluminum casting of 1,500 ton/year installed a thermal reclamation system with capital cost of $120,000 and operating cost of $34,250 per year. The company saved $172,000 year from the disposal and new sand purchase. Hence, the cost of the system was recovered in 9 months (UNEP, 1999)

Considering the above RECP measures obtained from the literature, the measures presented in Table 31 are recommended to the foundries to improve their sand regeneration ratio.

Table 31. RECP measures to improve sand regeneration

Proposed system	**Current system**	**Explanation**
Segregation of WFS (UNEP, 1999)	The slag did not mix with the dust and WFS. Moreover, the other domestic and package wastes were collected separately.	Increases the potential for sand reuse and reduce the cost of waste disposal by eliminating the hazardous waste from the others
Use green sand and apply primary regeneration (EC, 2005)	All foundries applied the primary regeneration however, only the Companies B and E used green sand.	98% of regeneration may be achieved for green sand mono system. The ratio can be 90-94% if the system has high degree of incompatible cores
Apply cold mechanical regeneration using an impact drum (EC, 2005)	Only the Company C used this method.	This method is more effective for chemically bonded monosand. The regenerated sand can be used in core making after use of this method.
Apply thermal sand regeneration (EC, 2005; UNEP, 1999; ETBPP, 1998)	None of the foundries had a thermal regeneration unit.	Regeneration ratio of 98% can be achieved

The EPE and benchmarking studies showed that the actual sand recovery ratio of the studied foundries could be improved between 7-58 % (Table 27). The higher benchmark sand recovery ratios are achieved by the foundries using either the green sand moulding or thermal sand regeneration ratios.

The EPI of sand regeneration ratio could be calculated for the Companies A, C and F due to lack of sand consumption information of other foundries. These companies used resin bonded sand. Therefore, there are two options to increase their sand recovery ratio up to the average benchmark value. First option is the use of green sand instead of chemically bonded sand. This will require a modification in moulding process. The second option is to install a thermal sand regeneration system which has a significant investment cost.

The investment cost of thermal reclamation plant depends on the size and type of equipment. The system includes a mechanical pre- or post-treatment step and a mechanical regeneration (e.g. grinding units). EC reported the investment cost between EUR 500,000 and 6,000,000 (EC, 2005). On the basis of the current TL/EUR rate of 3.84, the investment cost is between 1,920,000 and 23,040,000 TL.

The Companies A1, A2 and C recovered 83,970 ton of sand in 2014. Their sand recovery ratio can be improved between 22 and 58% by installing a thermal reclamation system. Hence, additional 38,018 ton sand would be recovered by thermal sand regeneration. In addition to reduction in the total volume of the waste, the companies would save money. They spent 30TL/ton for the disposal of their WFS by authorized companies. Moreover, they pay 132 TL/ton for the new sand. Hence, the companies would save 1.2 million TL from waste management cost and 5 million TL from the new sand cost.

5.4. Improving Water Efficiency

Water consumption is relatively low in foundries as compared to other resources. However, there may be options to reduce water loss and consequently to provide cost advantage. The water consumption can be reduced by 65% based on the results of the first phase. The typical rates of water loss are shown in Table 32.

Table 32. Typical rates of water loss (UNEP, 1999)

Potential source	**Rate of loss (litres/hour)**	**Annual loss (kL)**
Dripping union or flange (1 drop/second)	0,5	4.7
Leaking valve	6	53
Leaking pump shaft seal	0-240	0-2,100
Open ball valve (12,5 mm)	420-480	3.680-7.360
Running hose (25 mm)	1,800-4,000	15,770-34,690
Broken pipe (50 mm)	4,200	367,920

The water consumption varies in foundries based on the several factors. The water is mainly used in cooling systems. The inefficiency of these systems together with the evaporation losses leads to high levels for water consumption. Use of quench tank or pool in heat treatment operation increases the water use. Water is also used in the preparation of the green sand and excessive green sand temperatures require high cooling rates by evaporation. Moreover, the use of water based dust collection or cleaning systems contributes to high water consumption.

The water used in quenching cannot be changed in order to achieve the desired casting quality. Moreover, the water consumption increases with the increase in ambient air temperature since more water is required for evaporative cooling (IFC, 2011). The SWC results of the studied foundries increased during summer (Figure 7).

The water management practices in a foundry have two main principles: conservation of the use and utilization of the heat the water carries (CIPEC, 2003). As shown in Table 28, leaking pumps and valves causes significant water losses which can be minimized by preventive maintenance.

The water was mainly used for cooling system, quenching and sanitary purposes in the studied companies. The water was re-circulated in the cooling systems after cooling down with the help of cooling towers. The water is added in these open systems to compensate the evaporation losses. Moreover, the water treatment is required in order to prevent scale and slime formation and corrosion (CIPEC, 2003).

The closed loop mechanical water chillers can be used instead of open systems. The refrigerant coil is used for heat transfer. They have many advantages: water conservation, very cold water production and elimination the need for water treatment. However, the installation and operation cost is higher than the open systems (CIPEC, 2003).

Many opportunities exist for increasing the water efficiency of the foundry operations which are implemented in some countries. Preventive maintenance of pumps and valves eliminates the water leaks (CIPEC, 2003). Use closed loop mechanical water chillers instead of cooling towers decreases the loss in cooling systems (CIPEC, 2003). Cooling towers are open systems which need additional energy to drive the fans and water addition to compensate for evaporation. Moreover, the water has to be treated to prevent scale and slime formation and corrosion. On the other hand, the closed loop mechanical water chillers use the refrigerant condensing coil to extract the heat. Although they have higher investment and operation costs, their efficiency is higher in terms of water use. The water conditioning chemicals are not needed in this system and very cold water is produced. They can be used in induction furnace coil cooling.

The industrial case studies showed the efficiency of water chillers. A foundry from Hanover, Pennsylvania saved 13 ML of water per year and improved the grinding processes after installment of a 60 kL closed loop cooling system with temperature and bacteria controls. Considering the reduced coolant disposal costs and other savings in water cost, the investment had two to three year payback period. A valve manufacturer in the UK, reduced its water consumption from 500 kL per week to 220 kL per week. The major changes implemented by the company were to use closed circuit cooling systems and electronic sensors for flushing urinals, to control evaporative cooling systems and to have staff awareness campaigns (UNEP, 1999).

Replacing the water based dust collection systems with dry bag filters is another option to reduce SWC (IFC, 2011).

Considering the RECP measures obtained from the literature, the measures presented in Table 33 are recommended to the foundries to improve their specific water consumption.

Table 33. RECP measures to improve specific water consumption

Proposed system	**Current system**	**Benefit of proposed system**
Preventive maintenance of pumps and valves (CIPEC, 2003)	All foundries made preventive maintenance of pumps and valves.	Prevent the water loss through leaks
Use closed loop mechanical water chillers instead of cooling towers (CIPEC, 2003)	All foundries had cooling towers for cooling of the induction furnaces.	Save water and eliminate the need for water treatment
Replace water based dust collection systems with dry bag filters (IFC, 2011)	All foundries had dry bag filters.	Water consumption is reduced

The improvement potential for SWC was 65% as compared to the average benchmark values. The companies had already applied the measures of preventive maintenance and using dry bag filters. However, none of them had closed cooling systems. They can replace the cooling towers with closed loop mechanical water chillers. This retrofit will require an investment cost.

On the other hand, they can also save water by process improvements. For example, the sand temperature can be decreased to reduce the cooling requirements. The increase in the storage volume of the sand in the sand system cause decreasing the sand cooling requirement by increasing the dwell time for the reuse of the sand. Moreover, the reduction in the sand-metal ratios leads to reduce sand temperature and cooling requirement.

Another good practice is maintaining correct sand properties (i.e. moisture and clay relationship) to avoid the excess use of water in mould making (IFC, 2011). The foundries using green sand moulding (Company B and E) can evaluate the optimum water content of the mould mixture.

As a result, the companies can increase their water efficiency by using closed loop mechanical chillers instead of cooling towers and by reducing the sand cooling requirements. By this way, they can decrease the SWC and close the gap between their performance and average benchmark which was found as 38,342 m^3 of water.

5.5 Recommended RECP measures

The evaluation of RECP measures obtained from the literature were summarized in Table 34. There were total 21 RECP measures obtained from the literature, and among these 12 measures were recommended for the studied foundries in order to increase their environmental performance in terms of the selected KPIs.

Table 34 Evaluation of RECP measures

No	**RECP Measure**	**Target**	**Status**
1	Install an integrated monitoring and scheduling system	Improve SEC	Already applied in some fundries
2	Keep the furnace cover closed and reduce lid-off periods	Energy saving of 10-15 kWh for every minute the cover is closed	Recommended

Table 34 con't.

3	Use shredded scrap instead of sheared scrap	15-20% energy reduction in melting	Recommended
4	Preheat the charge	55-83 kWh saving per ton	Recommended
5	Waste heat recovery	15-25% of energy saving	Recommended
6	Install energy efficient lighting systems	25% reduction in running cost	Recommended
7	Preventive maintenance of compressed air system	30% energy saving	Already applied
8	Replace the screw compressor with VFD compressor	20% energy saving	Already applied
9	Precision or automatic pouring systems	Improve metal yield	Recommended
10	Casting simulation software	30% decrease in cast weight	Recommended
11	Lost foam or investment casting	Improve metal yield	Recommended
12	Segregation of WFS	Improve sand regeneration ratio	Already applied
13	Use green sand and apply primary regeneration	up to 98% of regeneration ratio is possible	Recommended
14	Apply cold mechanical regeneration using an impact drum	Improve sand regeneration ratio	Already applied by some foundries
15	Apply thermal sand regeneration	Sand regeneration ratio of 100% can be achieved	Recommended
16	Preventive maintenance of pumps and valves	Improve SWC	Already applied

Table 34 con’t.

17	Use closed loop mechanical water chillers instead of cooling towers	Improve SWC	Recommended
18	Replace water based dust collection systems with dry bag filters	Improve SWC	Already applied
19	Decrease the sand cooling requirement	Improve SWC	Recommended
20	Reduce sand-metal ratio	Improve SWC	Already implemented
21	Maintain correct sand properties (moisture and clay relation)	Improve SWC	Already implemented

CHAPTER 6

CONCLUSION

Resource efficient and cleaner production approach gained importance in global sustainable development agenda since it reduces the material, water and energy consumption and promotes competitiveness. The governments provide incentives to promote RECP applications through putting it into the policy and strategy documents. However, sector specific studies are required in order to increase awareness in industries and widespread its application by providing guidance about available applications and technologies.

The RECP opportunities in foundries were investigated in this study. To this purpose, environmental performance evaluation and benchmarking studies were conducted in the first phase. The investigation focused on six foundries in Ankara producing iron and steel castings. The production and consumption data of 2014 were collected from the companies through questionnaire. The environmental performance of the companies was evaluated based on the selected KPIs of specific energy consumption (kWh/ ton of good casting), sand recovery ratio (%), metal yield (%) and specific water consumption (m3/ ton of good casting).

The comparison of average performance against the benchmark values obtained from the literature revealed the improvement potential for each KPI. After screening the RECP applications which were obtained from the literature with the company representatives, the measures were recommended to the foundries in order to improve their performance up to the best achievable benchmarks.

The study proved that the environmental performance of the selected foundries can be improved in terms of the KPIs. The improvement potential of SEC was calculated as 27% and 54% for iron and steel foundries respectively. The companies did not have regular records on the energy consumption of equipment and processes. Therefore, the EPE and benchmarking studies were conducted based on the overall energy consumption. The distinction was made between the iron and steel productions since the indicator varied significantly for different types of alloys. The energy consumption was higher in production of steel castings. The results revealed that foundries can save minimum 32 millions kWh/year of energy by closing the furnace cover, using shredded scrap, preheating the charge, installing waste heat recovery systems and using more energy efficient lighting systems. In addition to saving of energy and money, CO_2 emissions will be decreased between 10,200 and 14,500 ton per year.

The sand regeneration ratio of the foundries can be improved within the range of 7 to 58 percents depending on the type of moulding (green sand and chemically bonded sand) and regeneration system. High ratios can be achieved by primary regeneration when green sand is used. If chemically bonded sand is used secondary regeneration is required. All studied foundries could not provide the sand consumption data since they did not have records. The data of three foundries (A1, A2 and C) could be used due to missing or inconsistent sand data. These companies used resin bonded sand and they recovered 83,970 ton of sand in 2014. It was shown that the foundries would save 38,018 ton of WFS if thermal regeneration was applied. Therefore, the waste management and new sand costs would be reduced by 1.2 and 5 millions TL respectively. The recommended RECP applications were using green sand or installing thermal sand regeneration system. Although the second option requires high investment cost, the savings from the material and disposal costs will reduce the payback period.

With regard to metal yield indicator, the weight of castings was collected by alloy type only and the detailed information about the size and complexity of castings were not obtained. One of the six companies could not provide net weight of castings so it was not included in the metal yield analysis. The wide range of metal yield ratios was available in literature based on the type, size and shape of castings. The results indicated that the metal yield could be improved for iron and steel foundries. The improvement potential was estimated up to 21% for iron castings and up to 5% for steel castings. RECP options recommended for the companies in order to reach highest available benchmarks were using casting simulation software, automatic pouring systems and lost foam or investment casting processes. Increase in the metal yield does not have a direct environmental effect; however it reduces the energy, water and resource consumption by improving the process efficiency.

The water consumption was not as important as other indicators, since it is relatively lower as compared to other resources. On the basis of the average performances, the foundries had an improvement potential of 65% for the specific water consumption. The foundries were recommended to reduce their SWC by using closed loop mechanical chillers instead of cooling towers and by reducing the sand cooling requirements. Therefore, 38,342 m^3 of water could be saved annually.

To sum up, the foundries have the potential to improve their efficiency in consumption of energy, water and material (sand). The available RECP applications which were listed in Table 35 will provide them not only to improve their environmental performance but also to improve competiveness through more efficient use of resources.

Table 35 Recommended RECP applications

EPI	**Improvement Potential (%)**	**RECP options**	**Environmental benefit**
SEC	Iron: 27; steel: 54	Closing the furnace cover, Using shredded scrap, Preheating the charge, Installing waste heat recovery systems Using more energy efficient lighting systems	Minimum 32 million kWh/year energy saving CO_2 emissions will be decreased in the range of 10,200 and 14,500 ton per year.

Table 35 con’t

Sand regeneration ratio	31	Using green sand or, Installing thermal sand regeneration system.	The amount of WFS will be reduced by 38,018 ton per year
Metal yield	Iron: -2 Steel: 2	Using casting simulation software, Automatic pouring systems Lost foam or investment casting processes	No direct effect, but it reduce the energy, water and material consumption
SWC	65	Using closed loop mechanical chillers instead of cooling towers, Reducing the sand cooling requirements.	The water consumption will be reduced by 38,342 m^3 per year.

Although the EPE and benchmarking studies were conducted for six foundries, the other companies can use the results to improve their own performances.

The economic analysis could not be performed since the study focused on environmental effects of foundry operations. A detailed economic analysis should be performed for the recommended RECP applications in order to support the study.

The governmental organizations should provide incentives in order to support the applications which require additional investments. In addition to providing incentives, a network that would be used by foundries to share their experience and lessons learnt, will also support to widen the RECP applications.

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APPENDIX A

SAMPLE QUESTIONAIRE

QUESTIONARIRE FORM	
1. Company information	
Company name, adress	
Contact person Contact details	
Year of establishment	
NACE code	
2. Production data	
Main and secondary products	
Annual working duration Daily working time	( ) seasonal ( ) all year ( ) one shift ( ) two shift ( ) three shift
Number of employee	
Annual production capacity of the foundry (ton)	
Maximum unit weight of castings	
Indicate the energy using equipment in the foundry	( ) Ergitme ocağı ( ) Soğutma üniteleri ( ) Isıl işlem fırını ( ) Havalandırma ( ) Isıtıcılar ( ) Aydınlatma ( ) Diğer ....
Indicate the water using equipment in the foundry	( ) Ocak soğutma sistemi ( ) Soğutma kulesi ( ) Soğutma tankı ( ) Evsel ( ) Diğer ....
Indicate the processes applied in the foundry	( ) Pattern making ( ) Moulding ( ) Pattern painting ( ) Sand preperation ( ) Melting ( ) Core making ( ) Pouring ( ) Shake out

	( ) Heat treatment ( ) Sand regeneration ( ) Cleaning ( ) Other ....
Indicate the wastes generated in the foundry	( ) Sand ( ) dust ( ) slag ( ) wastewater ( ) other (...........)
What is your waste management strategy? (eg. Dispose to landfill, sell, etc.)	
How much money you spent for waste management?	
3. Moulding	
Indicate the mold type used	
If green sand or chemically bonded sand is used, please indicate the ingredients of the mold mixture	
Indcate the new sand/recovered sand ratio of your mould mixture	
4. Melting	
Indicate the furnace type (induction, cupola etc.) in the foundry	see table below
Average daily working duration of the furnace	
Indicate the unit energy consumption of the furnace(s) per ton of good casting	

Type	**Quantity**	**Brand/model**	**Melting capacity**

QUESTIONAIRE FORM

Production and consumption data for last one year

Months (2014)	Electricity *Tariff type		Natural gas		Fuel oil		Coal		Water	
	kWh	**TL**	**Sm3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

*Specify the tariff type:

Months (2014)	**Good castings**			**Raw material**				
	Iron (ton)	**Steel (ton)**	**Other (......) (ton)**	**Melted iron (ignot+ scrap) (ton)**	**Melted steel (ignot+ scrap) (ton)**	**Diğer (.......) (ton)**	**Used sand (ton)**	**Recovered sand (ton)**
January								
February								
March								
April								
May								
June								
July								
August								
September								
October								
November								
December								

Name Surname, position of the person who filled the questionnaire

Date

APPENDIX B

THE QUESTIONAIRES FILLED BY THE COMPANIES

ANKET FORMU	
5. FİRMA BİLGİLERİ	
Firma Adı, Adresi;	A1, A2 1. Organize Sanayi Bölgesi, Ankara
İrtibata geçilecek yetkili iki kişinin Adı Soyadı, Unvanı, e-mail, telefon no	
İşletmenin kuruluş yılı	1986
İşletmenin dahil olduğu sektörel grup ve NACE Kodu (3. sayfada verilen listeden yararlanabilirsiniz)	27.51-27.52
6. FİRMANIN ÜRETİM BİLGİLERİ	
İşletmede üretilen ana/ ikincil ürünler nelerdir?	Pik, Sfero, Çelik Döküm
Yıl içinde çalışma süresi nedir? Kaç vardiya çalışılmaktadır?	( ) Mevsimlik (*) Tüm Yıl ( ) Tek vardiya ( ) İki vardiya (*) Üç vardiya
İşletmenizde kaç kişi çalışmaktadır?	560
İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)	15.000 ton (A1) 20.000 ton (A2)
Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?	170 ton
İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.	(*) Ergitme ocağı (*) Soğutma üniteleri (*) Isıl işlem fırını (*) Havalandırma (*) Isıtıcılar (*) Aydınlatma ( ) Diğer ....
İşletmenizde mevcut su kullananım alanlarını işaretleyiniz	(*) Ocak soğutma sistemi (*) Soğutma kulesi (*) Soğutma tankı (*) Evsel ( ) Diğer ....
İşletmenizde yer alan üretim aşamalarını işaretleyeniz.	(*) Model yapımı (*) Kalıplama (*) Model boyama (*) Kum hazırlama (*) Ergitme (*) Maça yapımı (*) Dökme (*) Kalıp bozma (*) Isıl işlem (*) Kum geri kazanım (*) İş temizleme (*) Diğer .İşleme.............
İşletmenizde üretilen atıkları işaretleyiniz.	(*) Kalıp kumu (*) Toz (*) Ocak cürufu (*) Atık su (*) Diğer (Tehlikeli atıklar, ambalaj atıkları, tıbbi atık)
İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına gönderme, satma vb.)	Mevzuat kapsamında; geçici depolama ve sonrasında bertaraf yada geri dönüşüm

<table>
<tr><td>Atık yönetimi için ne kadar para harcıyorsunuz? (TL-yıllık veya aylık miktar)</td><td colspan="4">200.000.-TL/yıl</td></tr>
<tr><td colspan="5">7. KALIPLAMA</td></tr>
<tr><td>İşletmenizde kullanılan kalıp tipini işaretleyiniz.</td><td colspan="4">( ) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm
(*) Kuru kum kalıba döküm ( ) Basınçlı döküm
( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm
( ) Alçı kalıba döküm ( ) Sürekli döküm
( ) Diğer ....</td></tr>
<tr><td>Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.</td><td colspan="4">%80 Reklamasyon yapılmış (eski kum), %20 yeni kum, %1.1:1.3 reçine, reçinenin %22:25 oranında katalizör (serter)</td></tr>
<tr><td>Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.</td><td colspan="4">-</td></tr>
<tr><td colspan="5">8. ERGİTME</td></tr>
<tr><td rowspan="5">İşletmenizde bulunan ocak tipini (örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.</td><td>Ocak tipi</td><td>Adet</td><td>Marka/model</td><td>Ergitme kapasitesi</td></tr>
<tr><td colspan="4">1 adet İNDÜKSIYON OCAĞI - 2 POTALI (4000 KG/H) TRAFO PANOSU , KUMANDA PANOSU, SOĞUTMA KULESI, POTA HIDROLIK SISTEMI</td></tr>
<tr><td colspan="4">2 adet EGES İNDÜKSIYON OCAĞI (8250 KG/H) TRAFO PANOSU , KUMANDA PANOSU, SOĞUTMA KULESI, POTA HIDROLIK SISTEMI</td></tr>
<tr><td colspan="4">1 adet İNDÜKSİYON OCAĞI – ÇİFT POTALI (3000 KG/H'LİK) TRAFOSU, KUMANDA PANOSU, POTA HİDROLİK SİSTEMİ</td></tr>
<tr><td colspan="4">1 adet İNDÜKSİYON OCAĞI – ÇİFT POTALI (3000 KG/H'LİK) TRAFOSU, KUMANDA PANOSU, POTA HİDROLİK SİSTEMİ</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.</td><td colspan="4">---</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.</td><td colspan="4">---</td></tr>
</table>

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI (Anket Formunun devamı) (A1)

Aylar (2014)	ELEKTRIK				DOĞAL GAZ				SU			
	Sayaç 1		Sayaç 2 (idari)		Sayaç 1		Sayaç 2 (idari)					
	kWh	**TL**	**kWh**	**TL**	**m^3**	**TL**	**m^3**	**TL**	**m^3**	**TL**	**m^3**	**TL**
Ocak	1,247,547.60	234,126.60	65.660,40	12,322.45	1.664.887,75	118,356.00	87.625,67	6,229.26	2.006,40	14,497.68	105,60	786.72
Şubat	1.088.786,00	205,315.30	57.304,00	10,806.07	1.524.955,30	108,543.60	80.260,80	5,712.82	1.875,30	14,402.31	98,70	758.01
Mart	1.240.468,20	233,467.50	65.287,80	12,287.76	1.570.443,18	111,884.20	82.654,90	5,888.64	1.741,35	13,599.94	91,65	715.79
Nisan	1.186.979,40	221,517.40	62.472,60	11,658.81	1.466.582,21	104,453.30	77.188,54	5,476.54	1.754,65	13,809.09	92,35	726.79
Mayıs	1.175.508,00	219,404.76	61.868,00	11,547.62	1.461.657,00	104,049.00	76.929,35	5,476.30	1.995,95	16,785.94	105,05	883.47
Haziran	1.197.336,30	223,314.38	63.017,70	11,753.39	1.447.133,95	102,958.69	76.164,95	5,418.88	1.980,75	16,658.11	104,25	876.47
Temmuz	1.019.892,45	192,397.77	53.678,55	10,126.20	1.351.328,58	96,137.78	71.122,56	5,059.88	1.968,40	16,554.24	103,60	871.28
Ağustos	954.539,10	180,290.41	50.238,90	9,488.97	1.471.363,54	104,704.80	77.440,19	5,510.78	1.747,05	14,797.51	91,95	778.82
Eylül	1.035.100,05	195,202.10	54.478,95	10,273.79	1.341.164,63	95,445.68	70.587,62	5,023.45	1.882,90	16,042.31	99,10	844.33
Ekim	1.010.518,80	202,911.25	53.185,20	10,679.53	1.317.196,33	101,779.92	69.326,12	5,356.84	1.606,45	15,036.37	84,55	79.391
Kasım	1.015.369,50	203,832.06	53.440,50	10,728.00	1.418.889,87	109,723.41	74.678,41	5,774.91	1.374,65	12,990.45	72,35	683.70
Aralık	1.255.348,05	251,103.53	66.070,95	13,215.97	1.668.355,54	128,986.80	87.808,19	6,788.77	1.865,80	17,631.81	98,20	927.99

Aylar (2014)	**Ürünler**		**Hammadde**		Silis kumu (kg)	Geri kazanılan kum (kg)	Kromit kum (kg)	Olivine kumu (kg)	Toplam kullanılan kum (kg)
	Demir döküm (ton)	**Çelik döküm (ton)**	**Ergitilen demir (külçe+ hurda) (ton)**	**Ergitilen çelik (külçe+hurda) (ton)**					
Ocak	146	624	184	899	2,674,584	4,479,889	134,574	18,330	7,307,377
Şubat	190	483	239	705	2,469,393	4,049,708	126,456	5,250	6,650,807
Mart	81	634	109	955	2,612,634	4,310,312	127,329	13,950	7,064,225
Nisan	227	527	287	767	3,060,546	4,980,856	122,400	15,540	8,179,342
Mayıs	167	536	201	822	2,497,257	4,183,708	129,975	22,080	6,833,020
Haziran	129	561	163	757	2,352,588	3,866,016	121,221	18,240	6,358,065
Temmuz	53	499	70	773	1,843,833	3,099,864	159,399	20,880	5,123,976
Ağustos	219	320	265	501	2,134,779	3,633,726	196,941	8,940	5,974,386
Eylül	173	443	217	699	2,227,059	3,807,252	180,996	32,850	6,248,157
Ekim	209	369	253	555	1,927,326	3,299,012	198,117	9,180	5,433,635
Kasım	336	263	444	393	2,259,705	3,795,215	229,251	6,930	6,291,101
Aralık	248	495	287	743	2,648,508	4,575,359	267,387	76,737	7,567,91

A2:

Aylar (2014)	ELEKTRIK		DOĞAL GAZ		SU			
	Sayaç 1		Sayaç 1		Sayaç 1		Sayaç 2 (idari)	
	kWh	**TL**	**kWh**	**TL**	**m^3**	**TL**	**m^3**	**TL**
Ocak	1,440,582.00		965,281.36		1,126.00		-	
Şubat	1,231,788.00		1,509,806.66		1,069.00		-	
Mart	1,122,768.00		2,266,958.04		1,259.00		-	
Nisan	1,036,794.00		1,951,711.60		1,264.00		-	
Mayıs	1,012,506.00		1,505,574.72		1,284.00		-	
Haziran	948,060.00		1,510,230.29		1,601.00		-	
Temmuz	914,940.00		1,137,559.21		1,572.00		-	
Ağustos	927,636.00		1,674,296.09		1,279.65		67.35	
Eylül	1,103,448.00		1,708,053.27		1,357.55		71.45	
Ekim	1,091,718.00		1,306,717.45		1,194.15		62.85	
Kasım	1,635,990.00		2,127,384.61		1,120.05		58.95	
Aralık	1,588,656.00		2,506,040.78		1,300.55		68.45	

Aylar (2014)	**Ürünler**		**Hammadde**		Silis kumu	Geri kazanılan kum (kg)	Kromit kum (kg)	Olivine kumu (kg)	Toplam kullanılan kum (kg)
	Demir döküm (ton)	**Çelik döküm (ton)**	**Ergitilen demir (külçe+ hurda) (ton)**	**Ergitilen çelik (külçe+hurda) (ton)**					
Ocak	216	595	267	976	2,722,329	1,294,388	143,907		4,160,624
Şubat	126	479	155	883	3,415,263	1,501,570	125,127		5,041,960
Mart	145	602	174	983	3,066,417	1,682,434	301,515		5,050,366
Nisan	76	689	97	1,095	2,625,744	1,504,507	231,954	17,850	4,380,055
Mayıs	76	623	103	1,035	2,155,992	3,420,322	277,962	12,900	5,867,176
Haziran	170	565	206	864	3,182,172	3,484,190	222,951	109,500	6,998,813
Temmuz	48	626	59	1,012	3,168,807	2,582,862	119,961	75,570	5,947,200
Ağustos	204	483	253	764	3,145,999	2,884,814	302,429	76,801	6,410,043
Eylül	78	725	94	1,019	3,368,172	2,990,057	271,535	70,035	6,699,799
Ekim	131	705	165	1,028	3,807,729	3,488,389	220,689	46,470	7,563,277
Kasım	183	702	213	1,114	4,401,012	3,098,621	333,123	38,625	7,871,381
Aralık	123	667	143	988	3,994,257	3,651,872	317,111	67,425	8,030,665

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

TARİH:12.03.2015

<table>
<tr><th colspan="2">ANKET FORMU</th></tr>
<tr><th colspan="2">1. FİRMA BİLGİLERİ</th></tr>
<tr><td>Firma Adı, Adresi</td><td>B, 1. OSB, Sincan</td></tr>
<tr><td>İrtibata geçilecek yetkili iki kişinin</td><td>Üretim Müdürü</td></tr>
<tr><td>İşletmenin kuruluş yılı</td><td>1984</td></tr>
<tr><td>İşletmenin dahil olduğu sektörel grup ve NACE Kodu</td><td>27.51</td></tr>
<tr><th colspan="2">2. FİRMANIN ÜRETİM BİLGİLERİ</th></tr>
<tr><td>İşletmede üretilen ana/ ikincil ürünler nelerdir?</td><td>Sfero ve dökme demir, çelik</td></tr>
<tr><td>Yıl içinde çalışma süresi nedir?
Kaç vardiya çalışılmaktadır?</td><td>( ) Mevsimlik (x) Tüm Yıl
( ) Tek vardiya (x) İki vardiya ( ) Üçvardiya</td></tr>
<tr><td>İşletmenizde kaç kişi çalışmaktadır?</td><td>135</td></tr>
<tr><td>İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)</td><td>12.000 ton</td></tr>
<tr><td>Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?</td><td>10.000 ton sıvı metal kapasitesi; maksimum 1 ton döküm yapılıyor. Genelde küçük parçalar, otomasyon, makine döküm</td></tr>
<tr><td>İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.</td><td>(x) Ergitme ocağı (x) Soğutma üniteleri
(x) Isıl işlem fırını (x) Havalandırma
( ) Isıtıcılar (x) Aydınlatma
( ) Diğer ....</td></tr>
<tr><td>İşletmenizde mevcut su kullananım alanlarını işaretleyiniz</td><td>(x) Ocak soğutma sistemi (x) Soğutma kulesi
(x) Soğutma tankı (x) Evsel
(x) Diğer: Kalıp yapımında- 1-2% civarı</td></tr>
<tr><td>İşletmenizde yer alan üretim aşamalarını işaretleyeniz.</td><td>(x) Model yapımı (x) Kalıplama
( ) Model boyama (x) Kum hazırlama
(x) Ergitme (x) Maça yapımı
(x) Dökme (x) Kalıp bozma
(x) Isıl işlem (x) İş temizleme
- Kum geri kazanım (rejenerasyon): Eleme ve manyetik separatör
- Diğer: galvaniz kaplama</td></tr>
<tr><td>İşletmenizde üretilen atıkları işaretleyiniz.</td><td>(x) Kalıp kumu (x) Toz (x) Ocak cürufu
( ) Atık su ( ) Diğer(...........)</td></tr>
<tr><td>İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına gönderme, satma vb.)</td><td>ITS aracılığıyla depolama sahasına gönderiyor.</td></tr>
<tr><td>Atık yönetimi için ne kadar para harcıyorsunuz? (TL-yıllık veya aylık miktar)</td><td>ITS'ye 30 TL/ton veriliyor. Aylık ortalama 8.000-10.000 TL harcanıyor.</td></tr>
</table>

3. KALIPLAMA	
İşletmenizde kullanılan kalıp tipini işaretleyiniz.	(x) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm ( ) Kuru kum kalıba döküm ( ) Basınçlı döküm ( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm ( ) Alçı kalıba döküm ( ) Sürekli döküm (x) Diğer: az miktarda reçineli kalıp da kullanılıyor.
Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.	- Yeni kum (%10) - Bentonit (%2) - Kömür tozu (%1) - Su (%2-2,5) - Geri kazanılan kum
Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.	10% - 90%

4. ERGİTME				
İşletmenizde bulunan ocak tipini (*örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.*), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.	**Ocak tipi**	**Adet**	**Marka/model**	**Ergitme kapasitesi**
	Endüksiyon	1	Inductotherm (çift pota)	4 ton/saat
	Endüksiyon	1	Inductotherm	1000 kg
	Endüksiyon	1	Inductotherm (çift pota)	750 kg
Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.	18 saat			
Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.	Ortalama 1,05 kWh/ kg			

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI

Aylar (2014)	ELEKTRIK		DOĞAL GAZ*		FUEL OIL		KÖMÜR		SU	
	kWh	**TL**	**m3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
Ocak	1,015,875		6,709							
Şubat	912,500		6,148						878	
Mart	870,125		7,046							
Nisan	842,750		5,709							
Mayıs	873,625		7,141							
Haziran	930,625		8,100							
Temmuz	874,875		5,934							
Ağustos	861,000		5,984						1,378	
Eylül	923,750		5,632						1,193	
Ekim	789,750		6,302						936	
Kasım	859,375		7,372						757	
Aralık	949,875		6,534						952	

* Doğalgaz maça yapımında kullanılıyor.

Aylar (2014)	Ürünler			Hammadde				
	Demir döküm ** (kg)	**Çelik döküm (ton)**	**Diğer (.......) (ton)**	**Ergitilen demir (külçe+ hurda) (kg)**	**Ergitilen çelik (külçe+ hurda) (ton)**	**Diğer (.......) (ton)**	**Kullanılan kum (ton)**	**Geri kazanılan kum (ton)**
Ocak	660,907			935,100				
Şubat	592,040			847,100				
Mart	509,837			734,000				
Nisan	488,033			726,500				
Mayıs	545,827			784,300				
Haziran	588,572			861,300				
Temmuz	577,226			825,200				
Ağustos	532,993			750,650				
Eylül	581,315			831,700				
Ekim	514,346			734,600				
Kasım	470,143			691,300				
Aralık	565,507			825,950				

** 2014 yılı için toplam döküm miktarı olup ağırlıklı olarak demir döküm ve yaklaşık %2 civarı çelik döküm miktarını içermektedir.

*** Kullanılan ve geri kazanılan kum tonajları net olarak bilinmemekle beraber kum geri kazanım oranı yaklaşık 80%' dir.

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

Üretim Müdürü

TARİH: 18.02.2015

ANKET FORMU	
9. FİRMA BİLGİLERİ	
Firma Adı, Adresi;	C 1. OSB, Avrupa Hun Cad. No: 12, Sincan
İrtibata geçilecek yetkili iki kişinin Adı Soyadı, Unvanı, e-mail, telefon no	
İşletmenin kuruluş yılı	1976
İşletmenin dahil olduğu sektörel grup ve NACE Kodu	27.51, 27.52
10. FİRMANIN ÜRETİM BİLGİLERİ	
İşletmede üretilen ana/ ikincil ürünler nelerdir?	Pik, sfero ve çelik
Yıl içinde çalışma süresi nedir? Kaç vardiya çalışılmaktadır?	( ) Mevsimlik (x) Tüm Yıl (x) Tek vardiya (x) İki vardiya ( ) Üç vardiya
İşletmenizde kaç kişi çalışmaktadır?	50
İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)	10.000 ton/yıl (iki vardiya) 5.000 ton/yıl (tek vardiya)
Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?	Kalıplama maksimum 22 tona kadar Döküm: Tek parça pik dökümlerde 22 ton; sfero dökümlerde 15 ton, çelik dökümlerde 10 ton
İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.	(x) Ergitme ocağı (x) Soğutma üniteleri (x) Isıl işlem fırını (x) Havalandırma ( ) Isıtıcılar (x) Aydınlatma ( ) Diğer ....
İşletmenizde mevcut su kullananım alanlarını işaretleyiniz	(x) Ocak soğutma sistemi (x) Soğutma kulesi (x) Soğutma tankı (x) Evsel ( ) Diğer ....
İşletmenizde yer alan üretim aşamalarını işaretleyeniz.	(x) Model yapımı (x) Kalıplama (x) Model boyama (x) Kum hazırlama (x) Ergitme (x) Maça yapımı (x) Dökme (x) Kalıp bozma (x) Isıl işlem (1100 ^{0}C) (x) Kum geri kazanım(rejenerasyon) (mekanik) (x) İş temizleme: Çapak temizleme ve kumlama (x) Diğer: Talaşlı imalat (CNC Portal Freze tezgahı
İşletmenizde üretilen atıkları işaretleyiniz.	(x) Kalıp kumu (x) Toz (x) Ocak cürufu ( ) Atık su ( ) Diğer(...........)

<table>
<tr><td>İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına gönderme, satma vb.)</td><td colspan="4">Belediyenin gösterdiği çöp alanına dökülüyor.</td></tr>
<tr><td>Atık yönetimi için ne kadar para harcıyorsunuz? (TL-yıllık veya aylık miktar)</td><td colspan="4">400 ton*3.2-0.2= 250 ton/ay kum atılıyor.
25 kamyon*300 TL= 7,500 TL/ay= 120,000 TL/yıl (30,000 TL/yıl cüruf için)</td></tr>
<tr><td colspan="5">11. KALIPLAMA</td></tr>
<tr><td>İşletmenizde kullanılan kalıp tipini işaretleyiniz.</td><td colspan="4">( ) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm
( ) Kuru kum kalıba döküm ( ) Basınçlı döküm
( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm
( ) Alçı kalıba döküm ( ) Sürekli döküm
(x) Diğer: Reçineli kum kalıba döküm</td></tr>
<tr><td>Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.</td><td colspan="4">- Silis kumu
- Fenolik reçine (%1-2): bunun %20 si ester</td></tr>
<tr><td>Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.</td><td colspan="4">80% eski kum- 20% yeni kum</td></tr>
<tr><td colspan="5">12. ERGİTME</td></tr>
<tr><td rowspan="4">İşletmenizde bulunan ocak tipini (örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.</td><td>Ocak tipi</td><td>Adet</td><td>Marka/model</td><td>Ergitme kapasitesi</td></tr>
<tr><td>İndiksiyon</td><td>2</td><td>JUNKER</td><td>5,000 kg</td></tr>
<tr><td>İndiksiyon</td><td>1</td><td>BBC</td><td>4,000 kg</td></tr>
<tr><td>İndiksiyon</td><td>1</td><td>JUNKER- Çift potalı</td><td>1,000 kg</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.</td><td colspan="4">3 gün/hafta, 16*3= 48-50 saat/ hafta</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.</td><td colspan="4">0.8 kw/kg
Toplam ortalama elektrik tüketimi: 1.1 kw/kg (0.3=tezgahlar, kompresör vb)</td></tr>
</table>

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI

Aylar (2014)	ELEKTRIK *TARIFE TİPİ		DOĞAL GAZ		FUEL OIL		KÖMÜR		SU	
	kWh	**TL**	**Sm3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
Ocak	276,276	53,991.14							371	2,763.95
Şubat	240,258	47,773.42							233	1,789.44
Mart	226,320	45,294.06							229	1,788.49
Nisan	199,893	40,073.09							204	1,605.48
Mayıs	377,775	72,628.22							353	2,968.73
Haziran	271,032	53,014.94							365	3,069.65
Temmuz	239,775	47,699.65							379	3,187.39
Ağustos	443,877	85,327.96							510	4,319.70
Eylül	502,527	96,330.38							444	3,782.88
Ekim	477,066	97,269.92							352	3,294.72
Kasım	496,110	100,986.94							327	3,090.15
Aralık	547,377	111,131.22							321	3,033.45

Aylar (2014)	**Ürünler***			**Hammadde**				
				Ergitilen demir (külçe+ hurda) (ton)	**Ergitilen çelik (külçe+ hurda) (ton)**	**Diğer (..........) (ton)**	**yeni kum (kg)**	**Geri kazanılan kum (ton)**
Ocak				151,755	25,274	4,610	151,300	
Şubat				118,759	31,274	10,353	178,440	441,560
Mart				78,262	73,975	2,266	140,000	487,000
Nisan				101,430	34,739	4,792	113,690	
Mayıs				242,426	87,695	19,199	221,870	
Haziran				123,086	68,992	18,079	137,360	
Temmuz				97,150	64,205	7,623	139,020	
Ağustos				254,970	67,775	43,480	249,640	
Eylül				243,781	95,679	48,729	279,770	1,107,516
Ekim				288,862	101,440	17,377	249,410	1,150,590
Kasım				304,565	97,338	26,981	306,933	1,118,067
Aralık				335,729	84,819	16,082	304,620	

***** Ürünlerin net ağırlığı bilinmemekle beraber çelik için 30%, sfero için 18% ve pik döküm için 12% kayıp olduğu düşünülmektedir.

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

Kalite Müdürü

TARİH: 24.02.2015

ANKET FORMU	
1. FİRMA BİLGİLERİ	
Firma Adı, Adresi;	D ASO 2.OSB 2011 CD. NO:21 TEMELLİ-ANK.
İrtibata geçilecek yetkili iki kişinin Adı Soyadı, Unvanı, e-mail, telefon no	
İşletmenin kuruluş yılı	**1975**
İşletmenin dahil olduğu sektörel grup ve NACE Kodu	27.51
2. FİRMANIN ÜRETİM BİLGİLERİ	
İşletmede üretilen ana/ ikincil ürünler nelerdir?	PiK VE SFERO DÖKÜM PARÇALAR
Yıl içinde çalışma süresi nedir? Kaç vardiya çalışılmaktadır?	( ) Mevsimlik ( ) Tüm Yıl (X) Tek vardiya ( ) İki vardiya ( ) Üç vardiya
İşletmenizde kaç kişi çalışmaktadır?	69
İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)	10,000 ton döküm ve 4,000 ton işleme
Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?	450 kg
İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.	(X) Ergitme ocağı (X) Soğutma üniteleri (X) Isıl işlem fırını (X) Havalandırma (X) Isıtıcılar (X) Aydınlatma ( ) Diğer ....
İşletmenizde mevcut su kullananım alanlarını işaretleyiniz	(X) Ocak soğutma sistemi (X) Soğutma kulesi (X) Soğutma tankı (X) Evsel ( ) Diğer ....
İşletmenizde yer alan üretim aşamalarını işaretleyeniz.	( ) Model yapımı (X) Kalıplama ( ) Model boyama (X) Kum hazırlama (X) Ergitme (X) Maça yapımı (X) Dökme (X) Kalıp bozma (X) Isıl işlem (X) Kum geri kazanım ( ) İş temizleme ( ) Diğer ....
İşletmenizde üretilen atıkları işaretleyiniz.	(X) Kalıp kumu (X) Toz (X) Ocak cürufu (X) Atık su ( ) Diğer(...........)
İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına	Anlaşılan firma aracılığıyla depolama sahasına gönderiliyor.

<table>
<tr><td>gönderme, satma vb.)</td><td colspan="4"></td></tr>
<tr><td>Atık yönetimi için ne kadar para harcıyorsunuz? (TL-yıllık veya aylık miktar)</td><td colspan="4">700 TL/kamyon
1 kamyon yaklaşık 20 ton atık alıyor.</td></tr>
<tr><td colspan="5">3. KALIPLAMA</td></tr>
<tr><td>İşletmenizde kullanılan kalıp tipini işaretleyiniz.</td><td colspan="4">( ) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm
( ) Kuru kum kalıba döküm ( ) Basınçlı döküm
( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm
( ) Alçı kalıba döküm ( ) Sürekli döküm
(x) Diğer: Reçineli kum kalıp</td></tr>
<tr><td>Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.</td><td colspan="4">Silis kumu, resin (%8), asit (%0,032)</td></tr>
<tr><td>Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.</td><td colspan="4">Karışımda 15%-30% arası yeni kum kullanılmaktadır.</td></tr>
<tr><td colspan="5">4. ERGİTME</td></tr>
<tr><td rowspan="4">İşletmenizde bulunan ocak tipini (örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.</td><td>Ocak tipi</td><td>Adet</td><td>Marka/model</td><td>Ergitme kapasitesi</td></tr>
<tr><td>İndüksiyon Ocağı</td><td>2</td><td>İnductotherm/ (Steel Shell)</td><td>2,500 kg</td></tr>
<tr><td>İndüksiyon Ocağı</td><td>2</td><td>İnductotherm/ (Dura Line)</td><td>1,500 kg</td></tr>
<tr><td>İndüksiyon Ocağı</td><td>2</td><td>İnductotherm/ (Dura Line)</td><td>450 kg</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.</td><td colspan="4">Ortalama en az 9 Saat</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.</td><td colspan="4">--</td></tr>
</table>

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI

Aylar (2014)	ELEKTRIK		DOĞAL GAZ		FUEL OIL		KÖMÜR		SU	
	kWh	**TL**	**Sm3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
Ocak	273,322	61,923	3,581	6,414					199	
Şubat	227,203	53,608	5,284	4,722					210	
Mart	210,643	49,180	6,036	4,505					204	
Nisan	252,415	58,361	4,297	3,843					200	
Mayıs	257,632	58,250	4,406	3,937					197	
Haziran	258,377	58,493	3,629	3,241					213	
Temmuz	151,027	34,430	2,140	1,912					220	
Ağustos	215,321	49,027	3,111	2,922					223	
Eylül	264,214	59,609	3,902	3,558					211	
Ekim	249,931	59,229	4,342	4,214					203	
Kasım	277,421	65,401	6,654	5,519					201	
Aralık	293,813	69,265	7,136	5,918					210	

Aylar (2014)	**Ürünler**			**Hammadde**				
	Demir döküm (ton)	**Çelik döküm (ton)**	**Diğer (.......) (ton)**	**Ergitilen demir (külçe+ hurda) (ton)**	**Ergitilen çelik (külçe+ hurda) (ton)**	**Diğer (..........) (ton)**	**Kullanılan kum (ton)**	**Geri kazanılan kum (ton)**
Ocak	100.66	25.46	9.80	182	55.33	13.96	35,000	32,000
Şubat	70.66	4.04	11.8	167	45.33	29.32	25,000	23,000
Mart	90.66	1.75	9.80	162.11	40.33	12.31	25,000	23,000
Nisan	60.66	20.72	9.80	172.29	45.33	21.66	25,000	23,000
Mayıs	100.66	26.48	7.80	183.22	55.33	10.84	35,000	33,000
Haziran	90.66	28.73	9.80	166.31	40.33	12.93	25,000	23,000
Temmuz	80.66	15.59	5.80	93.81	25.33	6.61	20,000	18,000
Ağustos	70.66	13.71	4.99	148.05	35.33	9.80	25,000	23,000
Eylül	100.66	35.09	2.78	180.53	45.33	7.80	35,000	32,000
Ekim	90.66	13.42	9.80	166,16	45.33	18.39	30,000	28,000
Kasım	90.66	37.648	9.8	157.93	45.33	26.07	25,000	24,000
Aralık	110.66	14.33	1.54	222.02	75.33	13.80	40,000	37,000

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

Kalite Sistemi ve İş Güvenliği Yöneticisi

Kalite Yönetim Temsilcisi

TARİH: 17.02.2015

ANKET FORMU	
1. FİRMA BİLGİLERİ	
Firma Adı, Adresi;	E Ankara 1. OSB Karamanlılar Cad. No:1 Sincan
İrtibata geçilecek yetkili iki kişinin Adı Soyadı, Unvanı, e-mail, telefon no	
İşletmenin kuruluş yılı	1987
İşletmenin dahil olduğu sektörel grup ve NACE Kodu	27.51
2. FİRMANIN ÜRETİM BİLGİLERİ	
İşletmede üretilen ana/ ikincil ürünler nelerdir?	Gri ve Sfero Döküm Parça - Talaşlı İmalat
Yıl içinde çalışma süresi nedir? Kaç vardiya çalışılmaktadır?	( ) Mevsimlik (x) Tüm Yıl ( ) Tek vardiya (x) İki vardiya ( ) Üç vardiya
İşletmenizde kaç kişi çalışmaktadır?	100-250
İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)	10,000 ton
Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?	Yaş kum : 110 kg Furan : 500 kg.
İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.	(x) Ergitme ocağı (x) Soğutma üniteleri (x) Isıl işlem fırını (x) Havalandırma (x) Isıtıcılar (x) Aydınlatma ( ) Diğer ....
İşletmenizde mevcut su kullananım alanlarını işaretleyiniz	(x) Ocak soğutma sistemi (x) Soğutma kulesi (x) Soğutma tankı (x) Evsel (x) Diğer: maça yapımı
İşletmenizde yer alan üretim aşamalarını işaretleyeniz.	(x) Model yapımı (x) Kalıplama ( ) Model boyama (x) Kum hazırlama (x) Ergitme (x) Maça yapımı (x) Dökme (x) Kalıp bozma (x) Isıl işlem (x) Kum geri kazanım (mechanical) (x) İş temizleme (x) Diğer .Talaşlı İmalat.
İşletmenizde üretilen atıkları işaretleyiniz.	(x) Kalıp kumu (x) Toz (x) Ocak cürufu ( ) Atık su ( ) Diğer(...........)
İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına gönderme, satma vb.)	Atık sahasına gönderme
Atık yönetimi için ne kadar para	4,000 tl/ay

<table>
<tr><td>harcıyorsunuz? (TL-yıllık veya aylık miktar)</td><td></td></tr>
<tr><td colspan="2">3. KALIPLAMA</td></tr>
<tr><td>İşletmenizde kullanılan kalıp tipini işaretleyiniz.</td><td>(x) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm
(x) Kuru kum kalıba döküm ( ) Basınçlı döküm
( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm
( ) Alçı kalıba döküm ( ) Sürekli döküm
( ) Diğer ..Reçineli kalıba döküm</td></tr>
<tr><td>Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.</td><td><table><tr><td>KÖMÜR TOZU</td><td>0.005</td></tr><tr><td>BENTONİT</td><td>0.01</td></tr><tr><td>SİLİS KUMU</td><td>0.05</td></tr></table></td></tr>
<tr><td>Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.</td><td>% 95</td></tr>
<tr><td colspan="2">4. ERGİTME</td></tr>
<tr><td>İşletmenizde bulunan ocak tipini (örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.</td><td><table><tr><th>Ocak tipi</th><th>Adet</th><th>Marka/model</th><th>Ergitme kapasitesi</th></tr><tr><td>İndüksiyon ocağı</td><td>1</td><td>EGES (2,000 kwh)</td><td>1*3,000 kg</td></tr><tr><td>İndüksiyon ocağı</td><td>1</td><td>EGES (1,000 kwh)</td><td>2*1,500 kg</td></tr><tr><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.</td><td>20 saat / gün</td></tr>
<tr><td>Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.</td><td>1.69 kwh/ton</td></tr>
</table>

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI

Aylar (2014)	ELEKTRIK		DOĞAL GAZ		FUEL OIL		KÖMÜR		SU	
	kWh	**TL**	**Sm3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
Ocak	786,992	152,858	4,687	3,544					864	6,951.74
Şubat	766,277	152,696	12,063	9,122					865	7,174.66
Mart	860,792	166,576	10,336	7,818					675	5,693.49
Nisan	847,495	164,502	8,487	4,913					1,493	12,689.90
Mayıs	896,724	173,491	5,230	3,965					1,232	11,190.01
Haziran	943,670	181,458	2,713	2,054					1,185	10,763.12
Temmuz	949,452	181,715	1,663	1,259						
Ağustos	889,933	170,885	1,474	1,120						
Eylül	752,938	141,506	1,173	891						
Ekim	432,762	87,086	7,12	522						
Kasım	817,927	158,961	981	746						
Aralık	781,992	161,272	2244	1,845						

Aylar (2014)	**Ürünler**			**Hammadde**				
	Demir döküm (kg)	**Çelik döküm (kg)**	**Diğer (.......) (ton)**	**Ergitilen demir (külçe+ hurda) (kg)**	**Ergitilen çelik (külçe+ hurda) (kg)**	**Diğer (...........) (ton)**	**Kullanılan kum (ton)**	**Geri kazanılan kum (ton)**
Ocak	569,592			746,212			335.4	318.6
Şubat	564,799			758,299			283.2	269.0
Mart	620,014			805,571			339.3	322.3
Nisan	652,579			865,403			337.3	320.4
Mayıs	658,499			844,788			398.2	378.3
Haziran	594,516			753,181			306.5	291.1
Temmuz	504,411			638,461			310.6	295.1
Ağustos	239,747			309,764			171.8	163.2
Eylül	507,726			669,870			375.3	356.5
Ekim	542,949			681,622			280.8	266.8
Kasım	525,022			675,857			395.8	376.0
Aralık	522,726			672,870			335.7	318.9

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

Yönetim Temsilcisi,

Planlama Müdürü

Proje ve Sistemler Müdürü

TARİH: 10.03.2015

ANKET FORMU	
1. FİRMA BİLGİLERİ	
Firma Adı, Adresi;	F
İrtibata geçilecek yetkili iki kişinin Adı Soyadı, Unvanı, e-mail, telefon no	
İşletmenin kuruluş yılı	1989
İşletmenin dahil olduğu sektörel grup ve NACE Kodu	27.51
2. FİRMANIN ÜRETİM BİLGİLERİ	
İşletmede üretilen ana/ ikincil ürünler nelerdir?	Dökme demir
Yıl içinde çalışma süresi nedir? Kaç vardiya çalışılmaktadır?	( ) Mevsimlik (x) Tüm Yıl (x) Tek vardiya ( ) İki vardiya ( ) Üç vardiya
İşletmenizde kaç kişi çalışmaktadır?	44
İşletmenizin yıllık toplam döküm kapasitesi nedir? (ton)	5,500 ton /yıl
Tek parçada kaç kg' a kadar döküm yapabiliyorsunuz?	5,000 kg/adet
İşletmenizde mevcut enerji kullanan ekipman(ları) işaretleyiniz.	(x) Ergitme ocağı (x) Soğutma üniteleri (x) Isıl işlem fırını ( ) Havalandırma ( ) Isıtıcılar (x) Aydınlatma ( ) Diğer ....
İşletmenizde mevcut su kullananım alanlarını işaretleyiniz	(x) Ocak soğutma sistemi (x) Soğutma kulesi ( ) Soğutma tankı (x) Evsel ( ) Diğer: ….
İşletmenizde yer alan üretim aşamalarını işaretleyeniz.	( ) Model yapımı (x) Kalıplama ( ) Model boyama (x) Kum hazırlama (x) Ergitme (x) Maça yapımı (x) Dökme (x) Kalıp bozma (x) Isıl işlem (x) Kum geri kazanım (x) İş temizleme ( ) Diğer …..
İşletmenizde üretilen atıkları işaretleyiniz.	(x) Kalıp kumu (x) Toz (x) Ocak cürufu ( ) Atık su ( ) Diğer(...........)
İşletmenizin atık yönetim stratejisi nedir? (örn: çöp sahasına gönderme, satma vb.)	Çöp sahasına gönderme
Atık yönetimi için ne kadar para harcıyorsunuz? (TL-yıllık veya aylık miktar)	-

3. KALIPLAMA				
İşletmenizde kullanılan kalıp tipini işaretleyiniz.	(x) Yaş kum kalıba döküm ( ) Metal (kokil) kalıba döküm (x) Kuru kum kalıba döküm ( ) Basınçlı döküm ( ) Seramik kalıba döküm ( ) Savurma (santrifüj) döküm ( ) Alçı kalıba döküm ( ) Sürekli döküm ( ) Diğer ..Reçineli kalıba döküm			
Cevabınız kuru veya yaş kuma döküm ise, kalıp yapımında kullanılan malzemeleri ve karışım oranlarını listeleyiniz.	-			
Karışımdaki yeni kum / eski (geri kazanılan) kum oranını belirtiniz.	% 50- 55			
4. ERGİTME				
İşletmenizde bulunan ocak tipini (*örn: endüksiyon ocağı, kupol ocağı, döner fırın vb.*), sayısını, marka-modelini ve her bir ocağın toplam ergitme kapasitesini belirtiniz.	**Ocak tipi**	**Adet**	**Marka/model**	**Ergitme kapasitesi**
	Endüksiyon	1	inductotherm	2,500 kg çift pota
	Endüksiyon	1	inductotherm	1,500 kg
Ergitme ocağının/ ocaklarının günlük ortalama çalışma süresini belirtiniz.	9 saat			
Ergitme ocağının/ ocaklarının birim üretim başına tükettiği enerji miktarını (kWh/ton) belirtiniz.	1,000 kWh			

SON BIR YILDAKI ÜRETIM VE TÜKETIM BILGILERI

Aylar (2014)	ELEKTRIK		DOĞAL GAZ		FUEL OIL		KÖMÜR		SU	
	kWh	**TL**	**Sm3**	**TL**	**Ton**	**TL**	**ton**	**TL**	**m3**	**TL**
Ocak	280,168	54,270								
Şubat	265,463	52,050								
Mart	296,327	57,901								
Nisan	335,157	64,588								
Mayıs	316,976	60,618								
Haziran	252,989	48,838								
Temmuz	254,975	39,452								
Ağustos	227,487	44,510								
Eylül	239,314	46,724								
Ekim	235,828	48,939								
Kasım	238,761	49,497								
Aralık	294,807	60,576								

Aylar (2014)	Ürünler			Hammadde				
	Demir döküm (kg)	Çelik döküm (kg)	Diğer (.......) (ton)	Ergitilen demir (külçe+ hurda) (kg)	Ergitilen çelik (külçe+ hurda) (kg)	Diğer (...........) (ton)	Kullanılan kum (ton)	Geri kazanılan kum (ton)
Ocak	199			265			377	180
Şubat	161			210			256	195
Mart	170			220			347	210
Nisan	256			335			358	245
Mayıs	209			272			372	360
Haziran	156			205			311	210
Temmuz	186			251			227	185
Ağustos	150			198			253	190
Eylül	144			185			255	225
Ekim	182			248			447	275
Kasım	117			158			306	280
Aralık	203			272			390	220

ANKETİ DOLDURAN FİRMA TEMSİLCİSİNİN ADI VE ÜNVANI:

Personel ve Muhasebe Müdürü

TARİH: 16.03.2015

APPENDIX C

MONTHLY EPIs

Table C- 36 Montly EPIs for Foundry A1

Months (2014)	SEC	SWC	Sand recovery	Metal yield	
	kWh/ton	m3/ton	%	Iron (%)	Steel (%)
January	3,981.46	2.74	61.31%	79.35%	69.41%
February	4,088.12	2.93	60.89%	79.50%	68.51%
March	4,138.26	2.56	61.02%	74.31%	66.39%
April	3,704.54	2.45	60.90%	79.09%	68.71%
May	3,948.74	2.99	61.23%	83.08%	65.21%
June	4,034.28	3.02	60.80%	79.14%	74.11%
July	4,521.78	3.75	60.50%	75.71%	64.55%
August	4,737.63	3.41	60.82%	82.64%	63.87%
September	4,060.60	3.22	60.93%	79.72%	63.38%
October	4,239.15	2.93	60.71%	82.61%	66.49%
November	4,277.76	2.42	60.33%	75.68%	66.92%
December	4,142.10	2.64	60.46%	86.41%	66.62%
Average	4,156.20	2.92	60.82%	79.77%	67.01%
Standard deviation	269.70	0.40	0.29%	3.51%	2.93%

Table C- 37 Monthly EPIs for Foundry A2

Months (2014)	SEC	SWC	Sand recovery	Metal yield	
	kWh/ton	m3/ton	%	Iron (%)	Steel (%)
January	2,966.54	1.39	31.11%	80.90%	60.96%
February	4,531.56	1.77	29.78%	81.29%	54.25%
March	4,537.79	1.69	33.31%	83.33%	61.24%
April	3,906.54	1.65	34.35%	78.35%	62.92%
May	3,602.40	1.84	58.30%	73.79%	60.19%
June	3,344.61	2.18	49.78%	82.52%	65.39%
July	3,045.25	2.33	43.43%	81.36%	61.86%
August	3,787.38	1.96	45.00%	80.63%	63.22%
September	3,501.25	1.78	44.63%	82.98%	71.15%
October	2,868.94	1.50	46.12%	79.39%	68.58%
November	4,252.40	1.33	39.37%	85.92%	63.02%
December	5,183.16	1.73	45.47%	86.01%	67.51%
Average	3,793.99	1.76	41.72%	81.37%	63.36%
Standard deviation	718.28	0.29	8.43%	3.32%	4.42%

Table C- 38 Monthly EPIs for Foundry B

Months (2014)	SEC	SWC	metal yield
	kWh/ton	m3/ton	%
January	1,645.61	-	70.68%
February	1,652.29	1.48	69.89%
March	1,854.41	-	69.46%
April	1,851.88	-	67.18%
May	1,740.41	-	69.59%
June	1,728.27	-	68.34%
July	1,625.55	-	69.95%
August	1,735.42	2.59	71.00%
September	1,692.64	2.05	69.89%
October	1,666.42	1.82	70.02%
November	1,995.52	1.61	68.01%
December	1,803.20	1.68	68.47%
Average	1,749.30	1.87	69.37%
Standard deviation	109.28	0.40	1.14%

Table C- 39 Monthly EPIs for Foundry C

Months (2014)	SEC	SWC	Sand recovery ratio
	kWh/ton	m3/ton	%
January	1,754.18	2.36	-
February	1,748.61	1.70	71.22%
March	1,726.10	1.75	77.67%
April	1,650.66	1.68	-
May	1,264.80	1.18	-
June	1,526.56	2.06	-
July	1,671.18	2.64	-
August	1,430.08	1.64	-
September	1,536.34	1.36	79.83%
October	1,364.83	1.01	82.19%
November	1,352.83	0.89	78.46%
December	1,454.82	0.85	-
Average	1,540.08	1.59	77.87%
Standard deviation	169.08	0.57	4.10%

Table C- 40 Monthly EPIs for Foundry D

Months (2014)	SEC	SWC	metal yield (%)		Sand recovery ratio
	kWh/ton	m3/ton	iron	steel	%
January	2,292.63	1.46	55.31%	46.01%	91.43%
February	3,279.57	2.43	42.31%	8.92%	92.00%
March	2,692.13	2.00	55.92%	4.34%	92.00%
April	3,272.24	2.19	35.21%	45.70%	92.00%
May	2,258.23	1.46	54.94%	47.86%	94.29%
June	2,300.30	1.65	54.51%	71.23%	92.00%
July	1,704.17	2.16	85.98%	61.53%	90.00%
August	2,781.63	2.50	47.73%	38.82%	92.00%
September	2,208.34	1.52	55.76%	77.41%	91.43%
October	2,602.32	1.78	54.56%	29.60%	93.33%
November	2,523.77	1.46	57.41%	83.05%	96.00%
December	2,925.07	1.66	49.84%	19.02%	92.50%
Average	2,570.03	1.86	54.12%	44.46%	92.41%
Standard deviation	458.55	0.38	12.02%	25.89%	1.53%

Table C- 41 Monthly EPIs for Foundry E

Months (2014)	SEC	SWC	metal yield	Sand recovery ratio
	kWh/ton	m3/ton	%	%
January	1,469.64	1.52	76.33%	94.99%
February	1,585.04	1.53	74.48%	94.99%
March	1,566.55	1.09	76.97%	94.99%
April	1,437.71	2.29	75.41%	94.99%
May	1,446.67	1.87	77.95%	95.00%
June	1,636.07	2.11	78.93%	94.98%
July	1,917.54	-	79.00%	95.01%
August	3,777.69	-	77.40%	94.99%
September	1,507.66	-	75.79%	94.99%
October	811.08	-	79.66%	95.01%
November	1,577.87	-	77.68%	95.00%
December	1,541.88	-	77.69%	95.00%
Average	1,689.62	1.73	77.27%	94.99%
Standard deviation	703.95	0.44	1.56%	0.01%

Table C- 42 Monthly EPIs for Foundry F

Months (2014)	SEC	metal yield	Sand recovery ratio
	kWh/ton	%	%
January	1,407.88	75.09%	47.75%
February	1,648.84	76.67%	76.17%
March	1,743.10	77.27%	60.52%
April	1,309.21	76.42%	68.44%
May	1,516.63	76.84%	96.77%
June	1,621.72	76.10%	67.52%
July	1,370.83	74.10%	81.50%
August	1,516.58	75.76%	75.10%
September	1,661.90	77.84%	88.24%
October	1,295.76	73.39%	61.52%
November	2,040.69	74.05%	91.50%
December	1,452.25	74.63%	56.41%
Average	1,548.78	75.68%	72.62%
Standard deviation	211.53	1.42%	15.00%