Determination of Cleaner Production Options in the Iron and Steel Industry: Case Study for an Induction Furnace Plant

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Abstract

This study was performed as part of the "Determination of Cleaner Production Options and Their Applicability in Industry (SANTEM)" Project, jointly carried out by the General Directorate of Environmental Management, Turkish Ministry of Environment and Urbanization and TÜBİTAK Marmara Research Center, to establish policies and strategies for cleaner production and integrated pollution prevention and to draft related legislation. Main objectives of the SANTEM Project were to examine the status, sectoral needs, cleaner production potentiality, incentive mechanisms and legal regulations of the iron and steel and yeast industries, and to evaluate the applicability of various cleaner production opportunities in Turkey. A pilot plant study was carried out within the framework of the project at a steel production facility with induction furnace technology. Induction furnace and ladle furnace processes were examined, and cleaner production options were determined.

Keywords

Cleaner production, iron and steel industry, Induction Furnace Plant

Introduction

Globalization, economic growth and climbing world population continuously increase the pressure and competition on natural resources. Recent investigations report that current natural resources are not at a sustainable level to meet the needs of world's population.

Cleaner production aims to mitigate environmental emissions by reducing and/or enabling resource use through approaches such as resource efficiency and prevention of pollution at the source. The concept of cleaner production consists not only of environmental strategies, but targets economic and social benefits as well [1].

The benefits that industries can gain with a cleaner production approach can be summarized as;

- Reduction of resource utilization resulting in lower operating costs
- Reduction of waste, wastewater and emissions
- Reduction of waste treatment and disposal costs
- Increased environmental performance
- Increased productivity
- Compliance with national and international environmental legislation
- Increased competitive advantage

Iron and steel industry in Turkey was launched in 1925. Today, a total of 32 plants (3 integrated, 24 electric arc furnace, and 5 induction furnace) are active [2]. Currently, only BOF and EAF are used in steel production in European Union countries. Henry Bessemer's idea of using oxygen instead of air for steel production has been applied since early 1950s following the emergence of technologies that enabled production of pure oxygen and water-cooled lance in sufficient quantities. The first BOF was used by Linz in 1952 in Austria [3].

In terms of crude steel production, Turkey was the third fastest growing country between 2007-2012, after China and India. Despite being the fastest growing country in 2011 and 2012, there has been a decline in crude steel production in Turkey in recent years [4].

In 2015, the share of billet and slab production were 76% and 24%, respectively. These numbers, however, remark a decrease in the amount of billet production by about 6% to 23.23 million tonnes and in the amount of slab production by about 12% to 8.29 million tonnes [5].

Turkey's crude steel production capacity was 50.4 million tonnes in 2015, of which induction furnace plants constituted about 2% of the total capacity [5].

Induction Furnace Process

During the induction furnace process; the melting heat is produced by induced currents due to the electromagnetic field created by a water cooled copper coil placed inside the furnace body and surrounding the refractory coating contacting the scrap/liquid steel. This electromagnetic field does not merely heat the charged material with the induced current, it also makes the metal bath well mixed by applying inductive force to the molten metal. The amount of mixing increases directly proportional to the amount of induced power; but it is inversely proportional

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to the square root of the furnace frequency. Many induction furnaces use grid frequency power (60 Hertz). Today, however, there exist high-power, medium-frequency furnaces used to melt ferrous metal charges [6, 7, 8, 9]. The advantages and disadvantages of induction furnaces are mentioned in Table 1 [8].

Table 1 Advantages and disadvantages of the induction furnaces

Advantages	Disadvantages
Higher flexibility in alloys and smelting regime.	Although the total energy consumption is low, the energy cost is higher because no chemical energy is used. However, the fact that not needed chemical energy investments reduces the initial investment cost of the plant.
Higher energy efficiency in total than the other smelting processes.	It has a low efficiency during holding because of the heat losses in the water-cooled induction coil.
Short meltdown times depending on the transformer power.	Other smelting techniques are more suitable for capacities higher than 30-35 tonnes per hour.
Homogeneous melt due to the intense stirring in the bath	Dry forging application requires more sensitive application of refractory than brick application used in other steel smelting furnaces.
Lower environmental burden caused by the foundry	Maintenance is more frequent than arc furnaces. Qualified workforce, frequent and intensive maintenance periods are required.
Minimum oxidation losses due to the unused chemical energy. Thus induction furnace is the smelting unit that has the highest metallic efficiency.	Regarding the suitability of scrap or metallic charge sizes, it must be treated much more precisely during charging.
Lower the metallic oxidation lower the level of dissolves oxygen in the steel compared to the arc furnaces. Thus deoxidant consumption is relatively less.	The cleaning action of the induction furnace on the melt is limited but not impossible. The formation of small amount of alkaline slag due to the refractory type, and the relatively small contact area between the slag and melt delimit the reactions between the slag and the metal. In addition, lower oxygen level and slag removal practice delimit the dephosphorization. However, lower oxygen level makes the desulphurization possible in combination with the motion of the bath.
Lower deoxidant consumption and nitrogen level makes the steel produced in the induction furnaces cleaner in terms of micro-cleaning	Scrap charging, dust collection, tilting and slag removal are bottlenecks for the high-speed smelting process. There are no proven applications that allow processing at speeds in the arc furnace process, and development studies are needed in this regard.
The use of solely electrical energy, makes possible to use computer support and full automatic operation which allow to high level process and optimum temperature controls.	Uncontrolled dust emissions caused by the use of cars or magnets during the scrap charging to open-mouthed, lidless furnaces are a serious problem and development studies are needed.
Maximum thermal efficiency is possible, if process parameters are locally calculated and set-up	The installation requires a high investment for induction furnace itself. However, considering the entire production line an induction furnace plant has much lower investment cost compared to the arc furnace plant at same capacity. Besides, the operator can save on additional environmental investments.
The less dust emissions because of the difference in dust collection and scrap charging systems compared to arc furnaces	Due to the fully encirclement of the furnace by copper coil in which the cooling water circulating; it has very high possibility of damaging the copper coil and leading to a very violent explosion in case of any steel leakage that can pass through the refractory plate. Therefore the safety risk is higher than the arc furnaces.

The two types of induction furnaces used in the melting of metals are channel and coreless furnaces. The coreless type induction furnaces are used for the smelting of ferrous metals [7, 6]

Coreless Induction Furnace

Coreless Induction Furnace is a furnace in which a batch melting process is carried out. The hearth is made up of a cylindrical body surrounded by a spirally wrapped copper tube. The tubular shape of the copper provide the water pass through and ensure the cooling of the copper material and the hearth which are heated by the induced current. The copper tube (bobbin) is fixed tightly from the top and the bottom in a circular manner so that it does not deform due to the magnetic field. The refractory layers applied to the interior surface of the furnace prevent the physical contact of the coil with the molten metal bath. Furnace refractories can be acidic (silica based), neutral (alumina, magnesite based) or basic, depending on the melting characteristics of the alloy. [6, 9].

Coreless furnaces allow the cold charge melting. In the production of structural steels, induction furnaces are operated by tap-to-tap method in which scrap or metallic charge is completely melted. The smelting process is carried out by adding smelting additives and removing the resulting slag from the surface [6].

The slag formed during the melting process accumulates at the upper part of the furnace at the end of melting process. The slag is removed from the furnace by tilting the furnace, along with other impurities due to deoxidation, if applicable. In structural steel applications, deoxidation is applied either in the ladle during the casting process or in the ladle furnace (if exist). Deoxidation of molten steel is necessary to achieve a good casting quality without defects caused by oxidation. In induction furnaces, 10-40 kg of slag per tonne of metal charge and between 0.006 and 3 kg of dust are formed [10].

Coreless induction is used for melting, but there is a limited use for smelting. For this reason, in steelworks, the raw material with the right chemical composition must be charged into the induction furnace. The smelting process is then carried out in ladle furnaces [8].

Ladle Metallurgy (Ladle Furnace)

Ladle metallurgy is a terminology that encompasses the latest steel making processes applied in a separate station before the steel is fed into the continuous casting machine [11].

When scrap loaded into the induction furnace reaches the ready-to-cast liquid steel conditions after limited metallurgical operations applied, all of the charge is casted into the ladle. It is then taken to the ladle furnace to perform the final metallurgical process to achieve appropriate quality standards. Simultaneously, the temperature is increased to the suitable temperature to be able to transfer the charge to continuous casting machine. The metallurgical processes vary according to the type of steel to be produced.

Among the most important purposes of ladle metallurgy are [11];

1. Adjusting the temperature and ensuring a homogeneous temperature distribution,
2. Formation of slag required for metallurgical operations.
3. Precise control of alloying, and adjustment of carbon, sulfur, phosphorus and oxygen amounts according to chemical composition,
4. Controlling of inclusions
5. Performing phosphorus removal operations, if necessary,
6. Performing degassing and performing other operations.

Methods

Description of the production processes

Bilecik Iron and Steel Works Industry and Trade Co. (BDÇ) incorporated to Kılıçlar Solid Waste Aluminum Scrap Iron and Steel Industry and Trade Co., has been performing steel production by utilizing induction furnace process since 2014. The plant has started to produce rebar steel in compliance with the Standard “TS708 Constructional Steel for Concrete Structures”, in the recently installed hot rolling mill unit.

BDÇ, is one of the pilot plants that acts in the iron-steel sector and during the first on-site visit to the plant, information was gathered about the studies on the cleaner production options that have been or will be performed in the plant. Besides, data was obtained relevant to the applied production technologies (especially induction furnace and ladle furnace) and used raw materials, water and energy. By utilizing the data obtained from the plant, process-based specific consumption values were calculated and mass and energy balances were set up. During the other visits done by the project team to the plant, completed calculations were checked and “The Best Available Techniques” associated with the induction furnace based steel production process were discussed.

Induction Furnace

Iron and steel scrap materials which are supplied from nearby provinces are subjected to weighting and classification following the input quality control. Scrap, having been classified and stacked, is reduced down to a size convenient for charging into the induction furnace by cutting and pressing processes and is prepared in a manner of being suitable to the equipment of scrap transfer and loading.

The prepared scrap materials are brought over the induction furnaces by the help of magnetic lifting cranes and loaded into induction furnace charging carriers. Scrap is charged into the furnace through these vibrating carriers, two of which are run accompanying one induction furnace. The plant has six induction furnaces, two of which have 25 tonnes, the other two furnaces have 28 tonnes and the remaining two furnaces have 30 tonnes of capacity. These induction furnaces have been grouped in three sets (A1-A2, B1-B2 and C1-C2) each of which comprises two furnaces. Dust and gases caused by the induction furnace process are transferred to dust collection system through two mobile fume hoods placed above the furnaces. The transformer capacities of the C set furnaces are 16 MW while that of the A set and B set furnaces are 10 MW.

Scrap, having been melt in the induction furnaces, is filled into 35 tonnes ladles that have been laid up by refractory bricks and pre-heated. Ladles are transferred to the ladle furnace for alloying treatments by being carried in a ladle conveyor.

Ladle Furnace

In the ladle furnace utilized in BDÇ, heating is achieved by an electrical arc formed by using three electrodes (3-phase) in the ladle over which a lid is placed. Furthermore, all of the alloying materials are added to the steel in the ladle furnace and the desired steel quality is obtained in this unit.

Entrance and exit of the ladle to/from the unit are provided by the reciprocating movements of the ladle conveyor. The lid is lowered and closed in a controlled manner when the ladle conveyor arrives at the position just below the ladle furnace. After the lid is closed, by utilizing the control panel, the electrodes are lowered and put into operation. The electrodes are made up of graphite, having a length of 180 cm and a diameter of 30 cm. The functions of the electrodes are to maintain the temperature of the molten steel in the desired level by forming an arc between the bath and themselves and to provide heat. Taken samples are analyzed and secondary steelmaking treatments are applied to the steel according to the results of these analyses. Liquid steel is sent to the continuous casting machine after the secondary steelmaking treatment completed and the final temperature which is appropriate for casting, achieved.

Whilst the preparation of the ladle before steel casting from induction furnace, the inside of the ladle is laid up with magnesite-carbon refractory bricks and after the laying up is completed, the ladle is pre-heated in the vertical ladle heating.

Continuous Casting Machine

Liquid steel reaching the suitable quality standard in the ladle furnace is carried in a ladle to the continuous casting machine having three flow ways. Here, the bottom sliding gate of the ladle which is full of liquid steel is opened and liquid steel starts to flow into the tundish (a narrow and shallow transferring container covered with refractory material and used to control the flow during pouring the molten steel into moulds). Liquid steel is poured into water-cooled moulds from tundish. Solidification starts in the water-cooled moulds, proceeds in the spray-cooled region and inside the flow way support relays. The solidified steel is finally oriented in the drawing-straightening unit and cut with a torch. Steel billets having a 130 mm×130 mm cross-sectional area and a 12 m length are produced according to the desired quality. The produced semi-finished products are sent to the rolling mill plant to be processed.

Hot Rolling Mill

The rolling mill plant is consist of a 25 meter long pusher type heat treatment furnace, a roughing train, a rod rolling train and a finishing train. The roughing train consist of four vertical workbenches used for cross-section reduction and four horizontal workbenches used for circular cross-section transformation of the square cross-section. The rod rolling train consist of four horizontally positioned workbenches and the finishing train consist of six workbenches.

The steel which has gained a certain shape and cross-section is cooled by high-pressure water nozzles in a controlled manner on the controlled cooling line. Having been cooled down, steel is downsized to the 12 meters length which is the final packaging length by cutting. Finally in this unit, circular rebar steel sized at the final packaging and shipment length is packed in the required weight, before they were sent to the stack yard for shipment.

Mass-energy balance

In this study, it is aimed to determine the opportunities for improvement through examining the processes in detail by means of the cleaner production audit conducted in the pilot plant and to gather information about the cleaner production activities that has or had been realized.

In order to set up the mass and energy balance and perform the cleaner production audit in the pilot plant, some information such as good housekeeping, process techniques, resource efficiency (raw material, chemicals, water and energy), and environmental performance improvement (end-of-pipe applications) were gathered.

Additionally, by taking into consideration the flow diagram (Figure 1) and process inputs/outputs of the plant; the quantity of raw material, water, energy and chemical consumptions and the quantity of waste, waste water and waste gas emissions of each production process for the year 2015 were compiled.

Initially, units of all inputs and outputs, except electricity, were converted to tonne during the calculation of mass balance. The temperature and pressure values of the gas flows were taken into account in the conversion of the units of these flows (if not given as Nm^3). The data in the TEP Calculation Table in the EnVer Portal of the General Directorate of Renewable Energy and the tables in the literature were taken, in the calculation of the density of the gases.

The density of water and waste water flows was included as 1 kg/m^3. In order to be able to compare the amount of production and consumption in the pilot plant with the related values in the literature, all inputs and outputs were divided into product quantity of related process and specific production and consumption values were calculated.

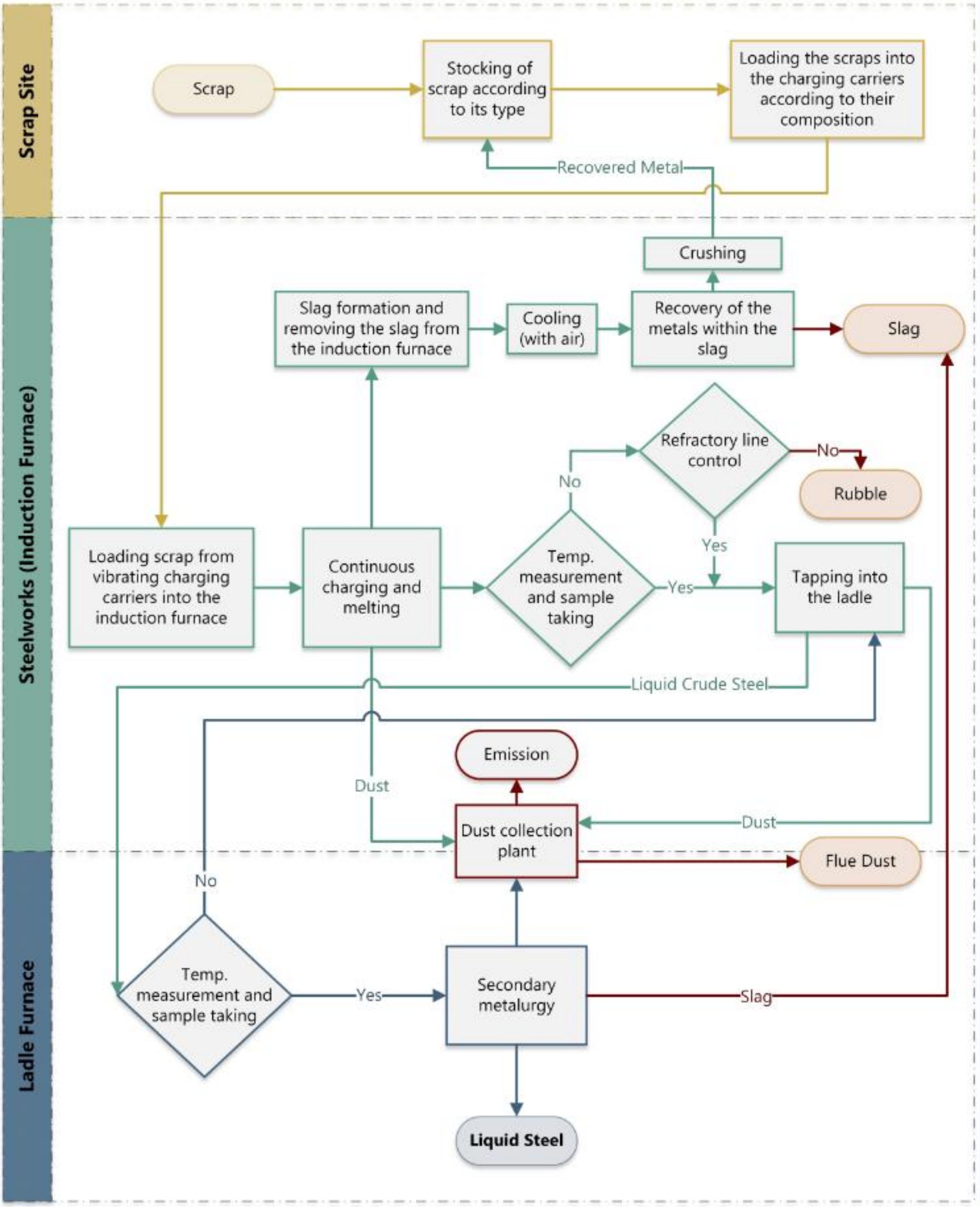

Figure 1 **Bilecik Iron and Steel Works Industry and Trade Co. (BDÇ) Production Flow Chart for LS**

In the following stage, the mass balance was set up over specific production and consumption values based on the following equation.

$$L_s = \frac{\sum_{i=0}^{n} I_i}{P} - \frac{\sum_{j=0}^{m} O_j}{P}$$

Hereby;

L_s = Lost quantity per tonne of main product produced (tonne/tonne product)

P = Main product produced (tonne/year)

I_i = Type of input (tonne/year)

n = Number of input

O_j = Type of output (tonne/year)

m = Number of output

While the energy balances were setting up, only the electrical energy, the flows which have calorific value and the flows which have the usable energy values due to their high temperature were taken into account.

Amounts of flows were multiplied by their own calorific values. Some of the calorific values were obtained from the pilot plant and the others from the "TEP Calculation Table" in the EnVer Portal of the General Directorate of Renewable Energy and from the tables in the literature. The calorific values of the steam flows at different pressures were obtained from the "Saturated Steam Table by Pressure Increase" in the EnVer Portal.

Energy contents of input and output flows with high temperature were calculated using the specific heat of the regarding material. When a mixture is of concern, the specific heat capacity for the mixture material was calculated by multiplying the percentages of ingredients in mixture by their specific heat.

In order to be able to compare the information associated with energy generation and consumption in the pilot plant with the related values in the literature, all inputs and outputs were divided into product quantity of related process and the specific energy generation and consumption values were calculated.

In the following stage, the energy balance was set up over specific production and consumption values, based on the following equation.

$$L_{e,s} = \frac{\sum_{i=0}^{n} I_i \times CV_i}{P} + \frac{\sum_{i=0}^{n} I_i \times c_{p,i} \times \Delta T_i}{P} - \frac{\sum_{j=0}^{m} O_j \times CV_j}{P} - \frac{\sum_{j=0}^{n} O_j \times c_{p,j} \times \Delta T_j}{P}$$

Hereby;

$L_{e,s}$	=	The quantity of lost energy per tonne of main product produced (kcal/tonne product)
P	=	Main product produced (tonne/year)
I_i	=	Type of input (tonne/year)
n	=	Number of input
O_j	=	Type of output (tonne/year)
m	=	Number of output
CV	=	Calorific value of the material (kcal/tonne)
c_p	=	Specific heat of the material (at constant pressure) (kcal/tonne.K)

Results and Discussion

Mass Balance

Induction Furnace

The mass balance, which includes the specific inputs and outputs of the induction furnace process, was set up. Because no wastewater data was available, 75% of the raw water used was considered lost water while the mass balance was set up. It is observed that in 2015, 1.1798 tonnes of input was provided for 1 tonne of Liquid Steel (LS) production. The most important part of this input is the raw material. In 2015, approximately 1.0388 tonnes of scrap was used for 1 tonne of LS production. Meanwhile, 1.1336 tonnes of output was produced for 1 tonne of LS production. A difference of 46.6 kg/tonne LS between the inputs and the outputs were calculated. This difference is considered to be caused by the uncertainty of the assumption made for the amount of lost water and waste that has not been measured by the facility. In addition, because the data for the amount of combustion air and flue gas mass flux cannot be obtained, they are not included in the calculations. For this reason, the emissions and the immissions in the flue gas (excluding the flue dusts) were not included in the mass balance. This is also one of the factors that cause the aforementioned difference [12].

Ladle Furnace

The mass balance, which includes specific inputs and outputs of the ladle furnace process, was set up. It is observed that in 2015, for 1 tonne of LS production, 1.0646 tonnes of input was provided in the process. The most important part of this input is crude steel. However, according to the data obtained from the plant, 1.0352 tonnes of output was produced for 1 tonne of LS production in 2015. A difference of 29.4 kg/tonne LS between the inputs and outputs were calculated. This difference is considered to be caused by the uncertainty of the assumption made for the amount of the wastewater data and waste that has not been measured by the facility [12].

Energy Balance

Induction Furnace

Energy balances which includes detailed specific inputs and outputs of the processes are given in Table 2 and Table 3. When these two table are examined together, a total of 630,734 kcal electricity consumption was realized for 1 tonne of LS production in 2015. The electricity consumption of the induction furnace comprises the main part of this value with an amount of 543,062 kcal. In addition to the electrical energy, the chemical energy covered from the scrap was calculated and included in the total amount. The factor needed to calculate the chemical energy of the scrap was obtained from literature studies [13]. The total energy consumption of the induction furnace is calculated as 681,839 kcal/tonne LS.

Table 2 Energy Balance for Induction Furnace Process

	Inlet Temp. (°C)	**Outlet Temp.** (°C)	**Specific Heat**	**Calorific Value** (kcal/kWh, Nm^3, tonne)	**Specific Value *** (kWh, Nm^3, tonne/tonne LS	**Energy*** (kcal/tonne LS)
Energy Inputs						
Electric Consumption (kWh)				859.85	631.58	543,061.62
Scrap – Chemical Energy (tonne)	25	-	5,343.3 (kcal/tonne.K)	133,582.72	1.0388	138,767.97
Mill scale - Thermal Energy (tonne)	25		120 (kcal/tonne.°C)	3000.00	0.0032	9.63
Total						**681,839.22**
Energy Outputs						
Liquid Crude Steel - Thermal Energy (tonne)		1640	120 (kcal/tonne.°C)	196,800.00	1.00	196,800.00
Induction Furnace Slag - Thermal Energy (tonne)		1580	235.83 (kcal/tonne.K)	436,997.59	0.04	18,158.41
Water- in	30		998.66 (kcal/tonne.°C)	29,959.80	0.08	2,399.76
Lost water- out		50	999.19 (kcal/tonne.°C)	49,959.50	0.08	4,001.72
Thermal energy loss from the lost water (tonne)						**1,601.96**
Recirculated water - in	32		998.61 (kcal/tonne.°C)	31,955.52	0.0042	133.37
Recirculated water - out		39	998.66 (kcal/tonne.°C)	38,947.74	0.0042	162.55
Thermal energy loss from the recirculated water (tonne)						**29.18**
Total						**216,589.55**
Difference (kcal/tonne LS)						**465,249.67**
Difference (Gcal/tonne LS)						**0.46**

* 2015 data

References: [14, 13, 12]

Energy production in the plant, has not been taking place. Approximately 32% of the energy given to the induction furnace comes out as thermal energy by liquid crude steel and slag. The thermal energy of the liquid crude steel is used as the energy source for the next process, but the thermal energy of the slag (approximately 18,000 kcal/tonne LS) is released into the air as waste heat during the cooling of the slag. The specific heat value used to calculate the thermal energy that slag has was derived from the literature [15]. Besides these, the energy losses come up from lost water and recirculated water. In order to calculate these lost energies, the specific heat of the water and the inlet and outlet temperature differences were used. Since these temperatures cannot be obtained, the temperatures of 30°C and 50°C was assumed as inlet and outlet water temperatures, respectively. The same situation applies for the recirculated water and the inlet and outlet temperatures were assumed to be 32°C and 39°C respectively. The specific heat of the water was found from the tables in the literature [14].

The difference between energy inputs and outputs in the induction furnace is 465,250 kcal/tonne LS. This difference is due to the unaccountable energy losses. In addition, the data for the amount of combustion air and flue gas mass flux cannot be obtained and they were not included in the calculations. For this reason, the energy loss from the flue gas was not calculated. However, energy losses occur from the surface of the furnace. These losses were not calculated within the scope of this study.

Ladle Furnace

About 66% of the energy given to the ladle furnace comes out as thermal energy by liquid steel and slag. The thermal energy of the liquid steel is used as the energy source for the next process, but the thermal energy of the slag (about 4200 kcal/tonne LS) is released into the air as waste heat during the cooling of the slag [15]. Besides these, the energy losses come up from lost water and recirculated water. In order to calculate these lost energies, the specific heat of the water and the inlet and outlet temperature differences are used. Since these temperatures cannot be obtained, the temperatures of 30°C and 50°C was assumed as inlet and outlet water temperatures, respectively. The same situation applies for the recirculated water and the inlet and outlet temperatures were assumed to be 32°C and 39°C respectively. The specific heat of the water was found from the tables in the literature [14].

The difference between energy inputs and outputs in the ladle furnace is 92,165 kcal/tonne LS. This difference is due to the unaccountable energy losses. In addition, the data for the amount of combustion air and flue gas mass flux cannot be obtained and they were not included in the calculations. For this reason, the energy loss from the flue gas was not calculated. However, energy losses occur from the surface of the furnace. These losses were not calculated within the scope of this study.

A total energy of 790,418 kcal/tonne LS is consumed for the induction furnace and ladle furnace processes. When the two processes are considered together, the difference between energy input and output is 557,415 kcal/tonne LS. The energy losses mentioned in the context of the processes are also valid here. However, the amount of energy lost here includes the energy losses that occur during transfer from the induction furnace to the ladle.

Table 3 Energy Balance for Ladle Furnace Process

	Inlet Temperature (°C)	**Outlet Temperature** (°C)	**Specific Heat** (kcal/kg.K)	**Calorific Value** (kcal/kWh, Nm^3, tonne)	**Specific Value *** (kWh, Nm^3, tonne/tonne LS	**Energy*** (kcal/tonne LS)
Energy Inputs						
Electric Consumption (kWh)				859.85	101.96	87,672.03
Natural Gas Consumption (Nm^3)				8,768.23	2.28	20,030.84
Liquid Crude Steel - Thermal Energy (tonne)	1540		120 (kcal/tonne.°C)	184,800.00	1.00	184,800.00
Argon (Nm³)				2,175.00	0.40	875.75
Total						**293,378.62**
Energy Outputs						
Liquid Steel - Thermal Energy (tonne)		1640	120 (kcal/tonne.°C)	198,800.00	1.00	198,800.00
Ladle Furnace Slag - Thermal Energy (tonne)		1500	242.95 (kcal/tonne.K)	430,742.56	0.01	4,183.22
Water- in (30°C)	30		998.66 (kcal/tonne.°C)	29,959.80	0.03	872.63
Lost water- out (50°C)		50	999.19 (kcal/tonne.°C)	49,959.50	0.02	1,091.36
Thermal energy loss from the lost water (tonne)						**218.74**
Recirculated water - in (32°C)	32		998.61 (kcal/tonne.°C)	31,955.52	0.002	53.35
Recirculated water - out (39°C)		39	998.66 (kcal/tonne.°C)	38,947.74	0.002	65.02
Thermal energy loss from the recirculated water (tonne)						**11.67**
Total						**201,213.63**
Difference (kcal/tonne LS)						**92,164,99**
Difference (Gcal/tonne LS)						**0.09**

* 2015 data
References: [14, 15, 13]

These calculated energy losses can be reduced by applying the suitable cleaner production options. In this study it was researched into several options mentioned in the literature and the related options were determined. These options were categorized into two main groups such as cleaner production options that can be used in all plants and cleaner production options specifically for induction furnaces. The cleaner production options that can be used in the iron and steel plants (and more other) in general and the references used in the compilation of these techniques are given in Table 4 [12].

Table 4 Cleaner production options that can be used in all plants (BATs)

Option	References
The use of automated dosing systems for dosing of chemicals	[16]
Preference of materials with low corrosion sensitivity in the choice of materials and equipment	[17]
Planning of equipment (elbows, valves, etc.) that creates loss of load, in order to provide energy efficiency in the installation design	[18]
Reduction of diffuse emissions from materials storage, handling, transport and blending	[3]
Controlling the releases to water from raw materials handling, blending and mixing	[3]
Assortment of scraps, by controlling the scrap composition beginning from the purchasing stage and the usage of these scraps according to the steel quality desired to produce	[3]

Option	References
Installation of the rainwater collection systems and the use of the rainwater as an alternative water source at the plant cleaning works or suitable other areas	[19, 20, 21, 22]
Reduction of water consumption and discharge by application of closed or semi-closed systems	[23]
Installation and optimization of (counter-current) cascading flow system in combination with squeegee rolls in the rinsing plant	[23]
Monitoring and optimization of the fuel-air ratio	[24, 25]
The use of online monitoring and control systems for critical energy flows and combustion processes	[24]
The use of reporting and analyzing tools (Pinch Analysis, etc.) to control the energy consumption of each process	[26, 27, 24]
Installing capacitors in the AC circuits to decrease the magnitude of reactive power	[28]
Avoiding the operation of equipment above its rated voltage	[29, 28]
Use of lighting management control systems including occupancy sensors, timers, etc.	[30, 31]
Recycling of heat from products, hot wastewater streams and waste gas emissions	[3]
The use of variable speed drives to reduce loads in fans, compressors and pumps	[32, 28]
The use of frequency-controlled pumps, fans and electric motors	[3]
Maximization of the heat exchanger surface areas for adequate air circulation	[33]
The prevention of the reaching of the plume to the ground level in the cooling towers	[34]
Optimization of the number, shape and size of the air ducts in cooling systems	[28]

Beside the given options in Table 4 there are several cleaner production options such as monitoring of all inputs and outputs in terms of quantity and quality of the unit (raw material, chemical, energy, water, product, byproduct, wastewater, air emissions, sludge, solid and hazardous waste); identification of the leaks in equipment such as tanks, reactors, pumps, compressors and valves and taking measures for them; choice of chemical and raw material that has the least risk in terms of environment and human health; isolation of pipes, valves, tanks and machinery; avoidance from the use of motors which are oversized compared to the real load they have to run; minimization the idle operation time of equipment; increase the use of natural light that can be used in all plants [16, 35, 24, 28, 36, 37]

The cleaner production options that can be used specifically in induction furnace plants and the references used in the compilation of these techniques are given in Table 5 [12].

Table 5 **Cleaner Production Options for Induction Furnaces**

Option	References
Use of clean scrap for melting	[8]
Optimization of charging and handling of raw materials	[3]
The installation of more powerful furnace transformers to reduce tap-to-tap times	[3]
Reduction of tap-to-tap times by carrying out some production steps (like desulphurization, alloying, temperature and chemistry homogenization) in other vessels out of the induction furnace	[3]
Change from mains frequency to medium frequency furnaces	[8]
The use of the sensible heat in the off-gas for scrap preheating	[3]
Reduction of dust emissions from slag processing	

Conclusions

Pilot plant studies carried out within the scope of the SANTEM Project involved data gathering from induction furnace and ladle furnace processes. Specific input and output based on production processes were analyzed, and areas of improvement, by setting up process-specific mass-energy balances, were determined.

Upon examination of power consumption of the plant, a reduction of electric energy from 632 to 550-600 kWh per tonne of liquid steel (LS) in the induction furnace, corresponding to savings of 5% to 13%, is deemed achievable. It is also possible to reduce the energy consumption of the induction furnace by applying one or more of the methods including transition from mains frequency furnaces to medium frequency furnaces, scrap preheating by using the hot waste gases of the furnace, or foamed slag application [3].

According to EU documentation [8], 10 to 40 kg of slag and 60 gr to 3 kg of flue dust per tonne of LS production were detected in induction furnaces. 41.6 kg/tonne of LS induction furnace slag and 3.4 kg/tonne of LS flue dust recorded in the plant are well above these values. Using clean scrap for melting in induction furnaces reduces the amount of slag and flue dust, and rusty and dusty raw materials should be avoided to increase production and energy efficiency [8].

It is possible to lower the zinc level, although the amount of zinc released from the dust holding chamber remains within the limit values. It has been evaluated that by improving the methods for holding the zinc in the flue gas in the dust holding system, it may be possible to increase the amount of zinc in the flue dust, so that the zinc can be recovered at a higher rate.

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