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A Case Study of Energy Recovery in Ferro-Alloys Industry

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The process of ferrosilicon alloy production is very complex, characterised by high consumption of energy and raw materials. The main objective of the study presented in this paper was to identify some energy efficiency projects and options in a ferro-silica production company in Macedonia and to analyse their feasibility. Another important goal was to recommend further steps and to suggest which measures to focus on in the near future that would result with energy savings, environmental and financial benefits. In the analysed facility, hard coal and lignite are added as very important input materials in the chemical reduction process and as energy resources in electric arc furnaces. Due to the technology applied, large quantities of thermal energy and dust are generated in the process and released with furnaces off-gas in the air. Energy balances of the electric arc furnaces are established, showing that significant part of energy is used for the chemical reactions, but the largest share is discharged in the atmosphere, as off-gas waste heat. Technical, financial, and environmental aspects of implementation of heat recovery system have been analysed, including potential barriers and limiting factors.
The main conclusion drawn from the analysis is that, under certain conditions, the potential for implementation of energy efficiency measures is significant. With waste heat recovery system, it is possible to reduce the needs for electricity purchase for about 20%. Additionally, the waste heat recovery option qualifies for clean development mechanism project, meaning that, the sale of CO_2 certified emission reduction could significantly improve the profitability of the investment.

Key words: *energy recovery, fero-alloys industry, clean development mechanism projects*

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Introduction

The industry sector is one of the largest contributors in the energy balance in Macedonia on the side of final energy consumption [1]. The available energy for final consumption in 2006 was 1729188 tonnes of oil equivalent (toe). The industry is on the top of the list, with contribution of 34% (588547 toe) in 2006, followed by the residential sector with 29.1% and transport with 20.2%. The total greenhouse gases (GHG) emissions in the country for the year 2002 amount to 12497.6 kt CO_2-eq. [2]. The main contributor is the energy sector with about 70% of the total emissions, which accounts mostly for the emissions from the lignite-fired power plants, but also industrial energy transformations are significant contributor to the total GHG emissions [2, 3]. In general, similarly to the other SE European countries, the GHG emission per capita in Macedonia is not very high, but the net emission per gros domestic product is unacceptably high, which is a consequence of an insufficient economic activity [4]. However, such situation offers a potential for trade with certified emission reduction (CER) quotas under the clean development mechanism (CDM), which can be a stimulus to the sustainable development.

The process of ferrosilicon alloy production is very complex, with high energy and raw materials consumption and with large potential for negative environmental effects. Therefore, the main objective of the study presented in this paper was to identify and elaborate energy efficiency options in a ferro-silica production company in Macedonia.

Brief process description

Ferro-alloys are master alloys containing some iron and one or more non-ferrous metals as alloying elements. Ferro-alloys enable alloying elements such as chromium, silicon, manganese, vanadium, molybdenum *etc*. to be safely and economically introduced into metallurgical processes, thus giving certain desirable properties to the alloyed metal, for instance to increase the corrosion resistance, hardness, or wear resistance. Their importance grew with progress of steel metallurgy, which implied more diversified alloying elements, in better controlled quantities and in purer steel [5]. The ferro-alloys are usually classified in two groups [5]:

- bulk ferro-alloys (Fe-Cr, Fe-Si together with silicon-metal, Fe-Mn, and Si-Mn), which are produced in large quantities in electric arc furnaces (EAF) and used exclusively in steel making and steel or iron foundries, and
- special ferro-alloys (ferro-titanium, ferro-vanadium, ferro-tungsten, ferro-niobium, ferro-molybdenum, ferro-boron, and ternary/quaternary alloys), which are produced in smaller quantities, but with growing importance.

The principle scheme of the main operations of the production process in the company under consideration is shown in fig. 1 [6]. The process can be divided in the following separate activities: raw material preparation (crushing, washing, *etc*.), storage, alloy smelting, cooling, crashing, and separating of the ferrosilicon. The main input materials are: scrap, quartz or quartzite, coal, and lignite. Quartz and scrap are stored in

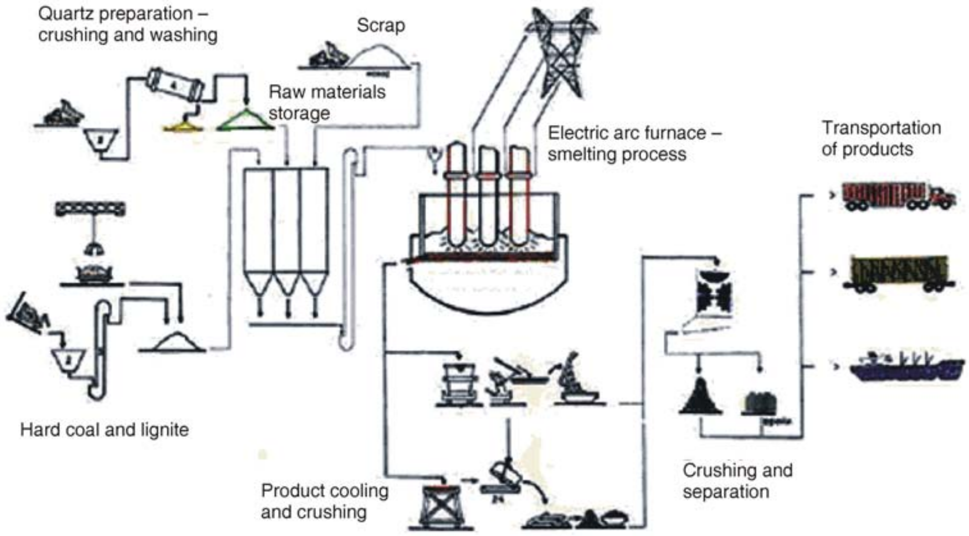

Figure 1. Main operations in the production process [6]

an open space. The hard coal and lignite are stored in covered storage places, because of the danger of self-ignition and their hydroscopic properties. From the storage tanks, a proper mixture of raw materials is continually brought into the electric arc furnace. A typical submerged EAF is presented schematically in fig. 2. The smelting process is characterised with huge consumption of electrical energy. Due to the applied technological process in the considered company in the present study, a huge quantity of heat energy is released and a lot of dust is discharged with off-gas in the atmosphere.

Produced alloy is casted in pools and it is cooled on ambient temperature. Cold ferrosilicon is crashed and separated in proper granulation: 10-50 mm, 10-80 mm, 3-10 mm, 0-3 mm, or other size, in accordance with the customers request [6]. Final products are stored mainly in 12 closed storages, depending on the quality [6]. In the production process, water is used as coolant of the flue gases in the gas ducts. The cooling water that leaves the production facilities with temperature of about 40 °C, is brought to open cooling pool and then, at a temperature level of maximum 25 °C, it is discharged into the nearby river.

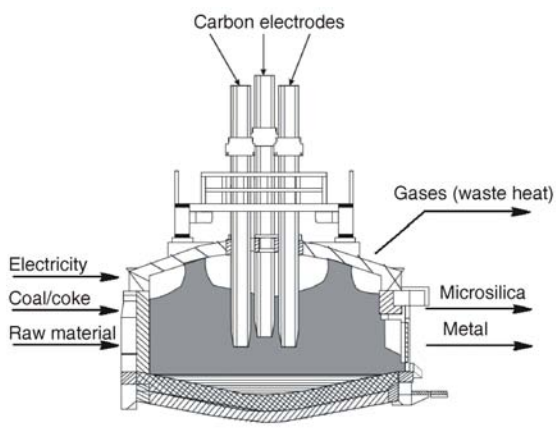

Figure 2. Typical design of submerged electric arc furnace (EAF)

The production of ferrosilicon is a high energy consuming process, since high temperatures are needed for the smelting and reduction. In the technology process, hard coal and lignite are added as chemical energy carriers, but they are also very important in the reduction process of metal oxides. As a result, significant quantity of thermal energy is generated in the process of smelting due to the coal and lignite combustion. The supplied energy in an electric arc furnace is transformed into chemical energy formed by the reduction process, as well as off gas energy (CO rich gas) and heat. A typical reaction producing ferrosilicon is [5]:

$$Fe_2O_3 + 2SiO_2 + 7C = 2FeSi + 7CO$$

The electric arc furnaces are classified as open, semi-closed and closed furnaces [5]. The open furnace itself has not a significantly higher electrical or coal consumption, but huge amounts of ambient air are sucked into the furnace to burn the generated CO, which is present in the off-gas. This, consequently, results in a very large volumetric flow of waste gas, which does not allow the recovery of its energy content, because the temperature level is low and the flow rate large to build technically and economically efficient steam generating system. The CO generated by the smelting process in this case is transformed into CO_2 and heat without using its energy content that is lost.

Recovery of the flue gasses sensible energy

Approximate energy balance of one of the furnaces (internally assigned as No. 7, with electrical capacity of 32 MW), is presented as a Sankey diagram in fig. 3. The electrical energy consumption of the furnace in the analyzed working regime is almost 11000 kWh per ton of product, while the normative is about 9000 kWh/t. The largest part of the energy output, about 60%, is discharged in the atmosphere as flue gases waste heat, via three gas channels that enter the lower part of the chimney. Also, significant share is

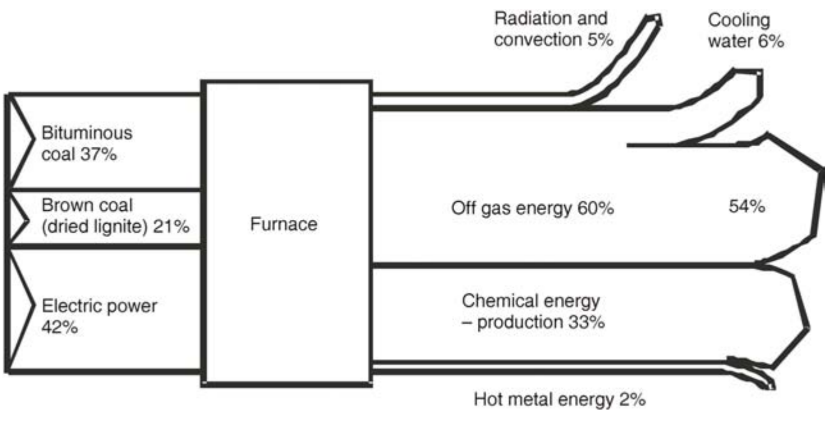

Figure 3. Rough Sankey diagram of the energy flow in the furnace No. 7

used in the process as chemical energy (about 33%). The heat losses from the furnace outside walls, structure and openings, due to thermal radiation and convection, are estimated at about 5%, and the sensible heat of the alloy (at 1600-1800 °C) is about 2% of the total energy output.

The furnace off-gas is partially cooled with water in a closed cycle, with a heat exchanging surface installed in the lower part of the chimney. The system is designed to operate with water flow rate of 160 l/s.

Although the electric arc furnaces No. 7, 8, and 9 in the company under consideration are declared as semi-closed, they are functioning more like as open type furnaces. At least, some of the measured parameters, like the flow rate of exit gases, the contents of CO_2, O_2, and CO, are in favour of that statement. It is evident that, during the operation of the furnaces, huge amount of ambient air is sucked into the working space. The consequences are: combustion of CO, generated by the smelting process; very large volumetric flow of flue gases, characterized with high content of O_2; as well as low temperature level, in the range of 300-400 °C, which does not allow implementation of relatively simple technical solutions for recovery of the flue gases sensible energy.

In order to recover as much as possible of the process energy, the off-gas volumetric flow rate needs to be reduced. A process flow diagram for the production of ferro-silicon and silicon metal, with integrated waste heat recovery (WHR) equipment, is presented in fig. 4 [5].

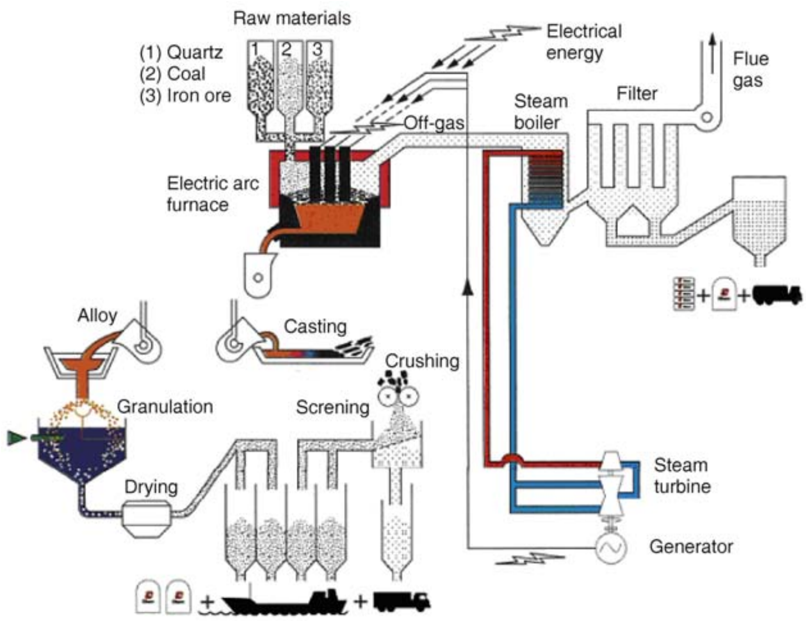

Figure 4. Process flow diagram for a modern production of ferro-silicon and silicon metal [5]

This can be done by installing a hood that is nearly closed to the furnace. A furnace hood will reduce the off-gas volume flow rate and that will result in higher average off-gas temperature, in that way, making possible energy recovery by using a waste heat steam boiler, steam turbine, electric generator, and other equipment for implementation of steam power generation cycle. The positive effects of such technical measure are:

- recovered energy can be used to produce electricity that can be used on and off site,
- the overall energy consumption of the plant will be reduced,
- the emission of pollutants, including greenhouse gases, will be reduced, and
- with appropriate technical solution, the furnace hood can be integrated as a part of the super heater system in the heat recovery boiler.

This measure has to be considered in combination with the installation of bag-house filters, which makes possible the option to recover micro-silica dust. Off-gas micro-silica dust trapping, collection, and selling would bring environmental and financial benefits. The measure is very complex, due to the design characteristics of the company's electric arc furnaces and the overall condition of the equipment, but also, due to the market conditions concerning the ferro-silica stock price, the costs for electrical energy and various other factors. Also, it helps the company to meet the obligations concerning the country's environmental legislative.

Very important fact that makes the described off-gas waste heat recovery project more attractive is the potential for reduction of CO_2 emission, which is large enough to qualify the project for CDM.

Another important issue that must be kept in mind is the fact that, with reduction of ambient air inflow into the furnace, high content of CO, generated during the ferrosilicon production process, will appear in the flue gas. Therefore, any proposed technical solution must include a solution for proper handling of CO from energy and safety point of view.

A rough estimation of the waste heat recovery project profitability, with and without CDM component, is presented in tab. 1.

Barriers and limiting factors

There are various barriers and limiting factors for implementation of effective options and measures for energy efficiency improvement. Some of them are:

- discontinuities in the work of the furnaces and of the company as whole; sometimes, with breaks lasting several months,
- variations of the company products prices, which are typical stock products,
- changes in the ratio of the ferro-silica price, *vs.* the price of electrical energy on the market,
- design and operation problems arising from the semi-closed, to open working regime of the furnaces, that increases the emission of flue gasses/per ton product by 2.5 times more than the world benchmarks,
- not well defined supportive legislation for energy efficiency improvement, energy saving, and environmental protection measures in the industrial sector in the country,

Table 1. Rough estimation of the waste heat recovery project profitability with and without CDM

	Low estimated investment	High estimated investment
Waste heat recovery (WHR)		
Electrical capaciaty, furnace No.7, Elkem, [MW]	32	32
Electricity, furnace No. 8, Krupp, [MW]	15	15
Sum electrical furnace capacity, [MW]	47	47
Recovery of electricity 20%, [MW]	9,4	9,4
Electricity price, [EUR/MWh]	45	45
Value of recovered electricity, [EUR/year]	3384000	3384000
Specific investment WHR, [EUR/kW_e]	1700	2200
Investment WHR, [EUR]	15980000	20680000
CDM component		
Grid emission factor, [ton CO_2/MWh_e]	0,915	0,915
CO_2 emission reductin, [ton/year]	68808	68808
CER price, [EUR/ton CO_2]	10	10
Income from sale of CER, [EUR/year]	688080	688080
Gas purification		
Investment air cooler	1598000	2068000
Microsilica (MicSi) recovery		
Price MicSi, [EUR/ton]	200	200
Amount of MicSi (200 ton/MW) [ton/year]	9400	9400
Value of MicSi, [EUR/year]	1880000	1880000
Project economy WHR + MicSi + CDM		
Sum investments, [EUR]	17578000	22748000
Sum income WHR + MicSi + CDM, [EUR/year]	5952080	5952080
Payback, [years]	3.0	3.9
Payback without, CDM	3.4	4.4

- there is no governmental support for companies that are huge consumers of electrical energy, for implementation of energy saving measures, and
- lack of financial resources as support for energy saving investments.

Conclusion

The main conclusion from the provided analysis is that there is a great potential in energy saving options and measures that could be implemented in the considered company. It must be noted that only a few potential issues for energy efficiency improvement and energy saving have been studied and there is need for further in-depth analysis concerning the ways for implementation. The main recommendations can be summarized as follows.

- The potential for implementation of energy efficiency measures in the company is significant, but the focus has to be put on WHR system. Implementation of WHR system could result in around 20% reduction of the needs for purchasing electricity. This measure should be considered in combination with the installation of baghouse filters, making possible the option to recover microsilica dust. Off-gas microsilica dust trapping, collection and selling would bring environmental and financial benefits. The measure is very complex, due to the design characteristics of the company's electric arc furnaces and the overall condition of the equipment, and also, due to the market circumstances concerning the ferro-silica stock price, the costs for electrical energy, and various other factors.
- The WHR project qualifies for CDM. This means that, if the project is approved by the UN as a CDM, the sale of CO_2 certified emission reductions could improve the profitability of the investment. The estimated calculations of profitability indicate that the pay back time for the investment without CDM could be 3.9 to 4.4 years, while the payback with CDM could be slightly over 3 years. These estimates indicate that the project may be considered as additional, which is one of the requirements for approval as a CDM project.

Acknowledgments

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Апстракт

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Студија искоришћења отпадне топлоте у индустрији феро легура

Процес производње феро-силицијумских легура је веома сложен и карактеришу га велика потрошња енергије и сировина. Главни циљ истраживања у овом раду био је да се идентификују могући пројекти енергетске ефикасности у производним погонима феро-силицијума у Македонији као и анализа њихове изводљивости. Други важан циљ је био да се предложе даљи кораци и мере на које би требало да се обрати пажња у блиској будућности, који би за последицу уз уштеду енергије дали и додатне еколошке и финансијске погодности.

Главни закључак анализе је да је, под одређеним условима, потецијал за спровођење мера енергетске ефикасности веома значајан. Са имплементацијом система за повраћај отпадне топлоте, могуће је да се смањи потреба за електричном енергијом за око 20%. Поред тога, употреба отпадне топлоте га квалификује у пројекте чистог развоја (CDM) што омогућује да, евентуална сертификована продаја емисије CO_2, може значајно да побољша профитабилност улагања.

Кључне речи: *искоришћење отпадне топлоте, индустрија феро легура, пројекти чистог развоја*

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