Waste Heat Recovery for EAF — Innovative Concepts and Industrial Implementation

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The development of a waste heat recovery plant requires extensive knowledge as well as long experience of the entire plant. Primetals provides waste heat recovery solutions for EAFs, some of which are presented in this article. A waste heat recovery plant is introduced, which was installed in Italy. Waste heat is used to produce steam for two pickling lines, which are a large distance from the EAF. The substitution of the existing gas-fired boilers led to a decisive reduction of operating costs of the steel plant. A heat recovery plant was installed at a steel plant in Sweden, where hot water at high pressure is produced and utilized for the local district heating system. The implementation of waste heat recovery systems for EAFs will be presented in detail, and operational results achieved will be discussed.

In recent years, waste heat recovery in the steel industry has attracted more and more attention. Environmental regulations, public funding, as well as required revamps of old dedusting systems lead steel plant operators to discuss and to evaluate possibilities of recovering waste heat.

The development of a waste heat recovery plant requires extensive knowledge as well as long experience of the entire plant, including water-steam cycle as well as the electric arc furnace (EAF) process and dedusting system. Innovative waste heat recovery solutions are introduced and discussed in this article.

Another challenge for waste heat recovery at EAF plants is to identify a possible utilization for the recovered energy. Thus, possible applications for a heat consumer inside or outside the steel plant are discussed.

Industrial implementations of waste heat recovery plants are presented to demonstrate economic and reliable utilization of EAF waste heat for different applications.

Introduction

In recent decades, global steel production has increased continuously, driven by the big demand of growing markets and economic expansion. Nowadays, steel demand has decreased and the global steel industry is dealing with overproduction. Therefore, steel plant operators are forced to reduce production costs and to optimize their steelmaking processes.

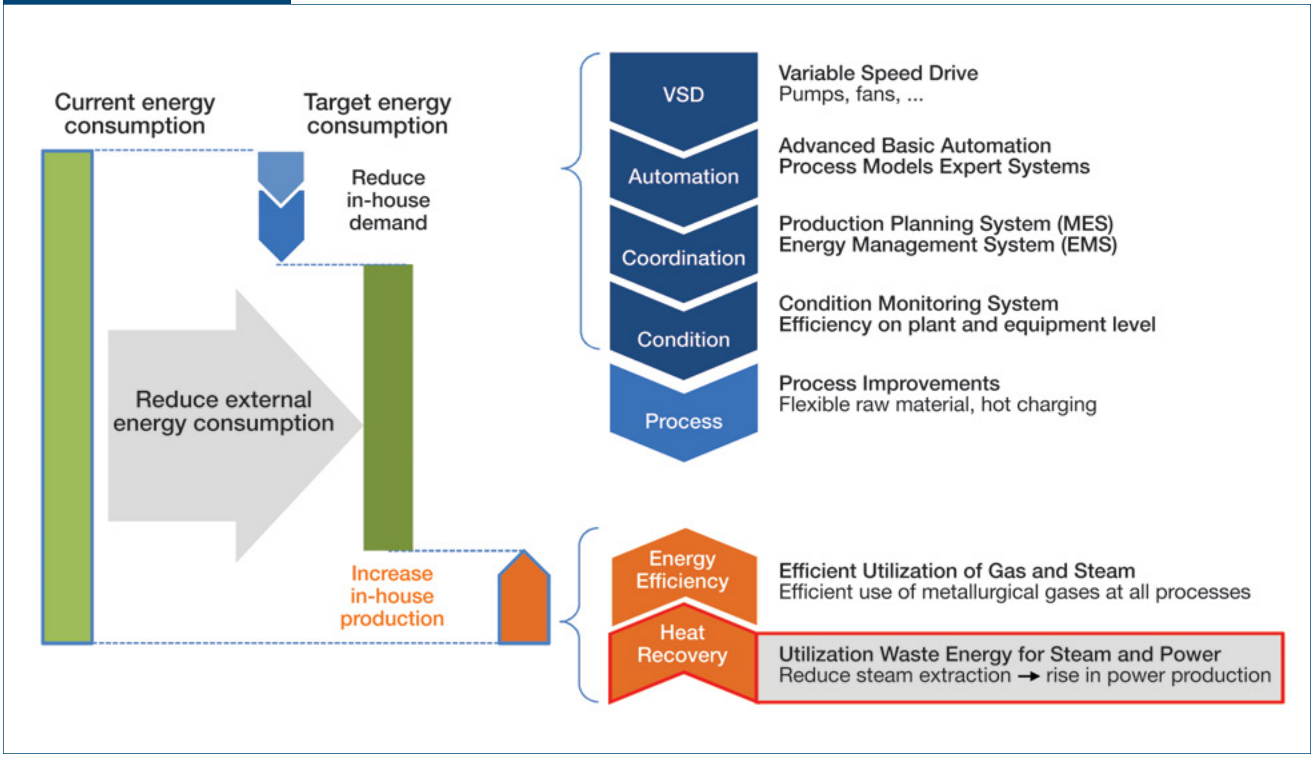
Furthermore, due to growing environmental consciousness and tightened emission control by authorities, environmental technologies and energy efficiency have become more and more in the focus of steel plant operators.

Energy is one of the most important cost factors for integrated iron and steel plants as well as for electric steel mills.[1] The vast amount of electric energy in electric steel plants forces operators to improve the overall energy situation, in order to reduce the specific costs per ton of steel and also to comply with legal requirements in terms of energy efficiency.

There are various opportunities along the steelmaking route for implementing energy efficiency measures.

Smaller improvements can be implemented in terms of process optimization. The identification of improvements requires a survey of the existing installations and elaboration of the individual improvements in terms of feasibility, reliability, as well as cost-benefit considerations. Such measures can be done with low or moderate effort.

Figure 1



Typical measures to reduce energy consumption.

However, for a more decisive impact on the energy balance of a steel plant, bigger actions are required. By recovering waste heat, a large amount of offgas energy can be utilized within the steel plant, leading to a significant reduction of energy costs. The largest amount of waste heat within electric steel mills can be found at electric arc furnaces, where approximately 30% of the total energy input is emitted in the offgas.

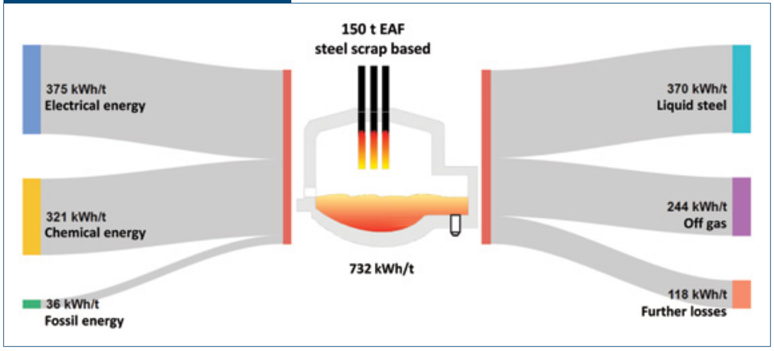
The economic feasibility of an EAF waste heat recovery solution is mainly driven by the type of waste heat utilization. Therefore, the waste heat utilization has to be a major focus during project development. In the following, economically feasible solutions will be presented even though the price of electric energy is low in current markets.

Waste Heat Recovery Solutions

Waste Heat Potential of EAF — In most electric steelmaking plants, the EAF is the main metallurgical unit for steelmaking, since it is used for melting and refining of the raw materials. Also, considering the energy balance of electric steel plants (mini-mills), the EAF is the biggest energy consumer along the steelmaking route. This means the energy consumption per ton of the final steel product is mainly caused by the EAF.

In Fig. 2, the energy balance of a typical scrap-based furnace is given. It is shown that about 50% of the required energy input is provided by electricity via the electrode. The residual energy is mainly related to exothermic chemical reactions in the steel bath. Additional energy input is provided by gas burners in the furnace. Depending on the EAF operation and input materials, approximately 30% of the total energy input is dissipated to the offgas.

Figure 2



Energy balance (Sankey diagram) of a scrap-based electric arc furnace (EAF).

However, EAF offgas does not correspond directly with the energy input and the charged material in terms of flow, temperature and composition. Sudden occurring combustion processes and CO gas production (e.g., combustion of oil from a collapsing scrap bulk) within the furnace do not allow gas recovery in terms of downstream CO gas recovery. Thus it is state of the art to maintain a large amount of excess air in the gap at the entry of the offgas system to ensure a complete combustion of the offgas during the whole melting period of the EAF.[2]

In the offgas system, the offgas is cooled down by a water-cooled duct, followed by a second-stage gas cooler, which can be from a type of evaporation cooler or a forced-draft cooler. In this part, most of the energy is dissipated to the ambient. Offgas temperature is further decreased by dilution with air from other suction sources before entering the filter plant. Eventually the offgas is emitted via the stack at temperatures of approximately 100–130°C. This means that the remaining energy is emitted to the environment. The energy balance along the offgas system as well as the process flow diagram are shown in Fig. 3.

Waste Heat Recovery Systems for EAF — Even if the waste heat potential is high enough, there are several challenges for designing a waste heat recovery plant. Due to the dynamic operation of the EAF process, as well as idle periods of the furnace, the offgas parameters are fluctuating intensively. This results in a discontinuous waste heat supply and thus a discontinuous output. Therefore, heat recovery systems require a buffer to equalize the heat supply for downstream consumers.

Furthermore, the offgas parameters from EAF offgas are more difficult compared to conventional heat recovery boilers. The maximum offgas temperature exceeds the usual offgas temperature of comparable boilers of other industries. Also the high dust content and the specific gas composition have to be considered carefully.[3]

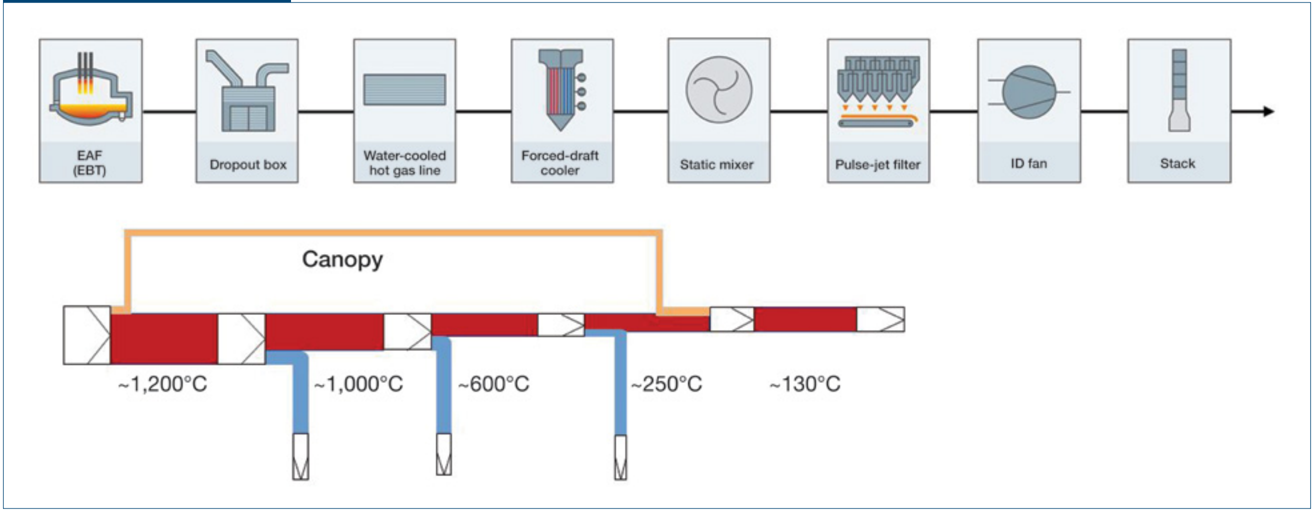
Apart from the above-mentioned issues, the steel plant situation is crucial for the design of the plant. A deep understanding of the plant layout, space availability, infrastructure and interfaces is fundamental for the design of a waste heat recovery plant. Depending on the plant situation, a tailor-made solution has to be developed.

An integral waste heat recovery approach is based on a modular system, which is referred to the setup of a dedusting system. State-of-the-art dedusting systems, as shown in Fig. 4, consist of a water-cooled hot gas line followed by a second-stage cooler. After mixing with dilution air or air from other suction points, the offgas is cleaned in the filter and discharged via the stack.

Waste heat can be recovered by replacing the conventional water-cooled hot gas line by a heat recovery duct. In this case, the offgas cooling is done with pressurized water at elevated temperatures. The hot water is consequently used for steam or power generation or any other suitable application.

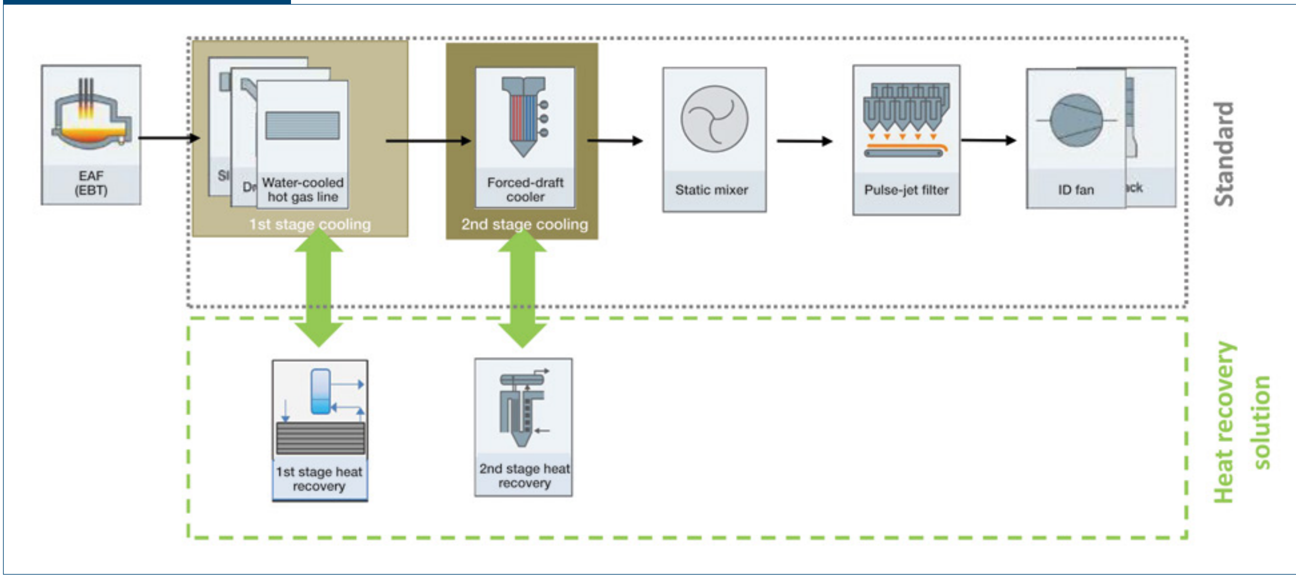
Alternatively, the second-stage cooler can be replaced by a waste heat boiler. Due to lower offgas temperatures, the boiler is from a type of bundle heat exchanger to recover the waste energy and for cooling of flue gas. Thus offgas is ducted through the boiler at moderate flow velocities, whereas water and/or steam are flowing inside the tubes.

Figure 3



Energy flow along offgas system.

Figure 4

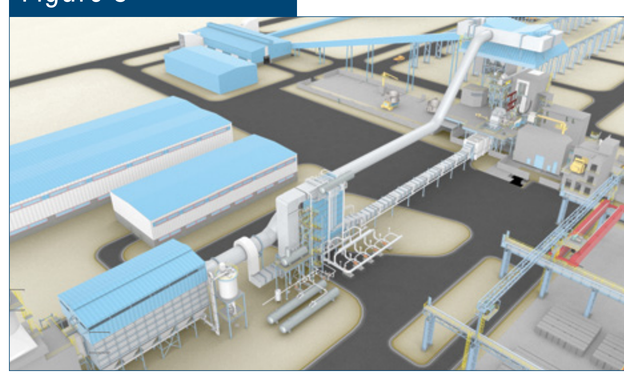


EAF dedusting system setup.

Depending on the plant situation, as well as on the operator requirements and downstream heat utilization, a proper waste heat recovery concept will be developed. Thus, either the first stage or the second stage will be incorporated in the heat recovery concept. For maximized heat utilization, the first and second stages can be combined.

In Fig. 5, the layout of an EAF dedusting system including waste heat recovery system is shown. Offgas coming from the EAF is routed through the heat recovery duct and the second-stage waste heat boiler before entering the filter. It can be seen that the footprint is similar to conventional dedusting systems.

Figure 5



Waste heat recovery system for EAF.

Efficiency Increase and Benefits — The above-mentioned considerations show that the main benefit of a waste heat recovery system is the reduction of overall energy consumption. Additionally, there are several other benefits that may apply. The main benefits are:

- Reduction of overall energy consumption: With a heat recovery system, the waste heat is utilized for a certain application. The savings due to heat recovery helps steel plant operators to reduce their operational costs.
- CO_2 reduction: Following the trend for industrial plants to reduce carbon dioxide footprint, heat recovery systems help to reduce the demand for fossil energy.
- Dewpoint corrosion: Higher tube wall temperatures in the cooling duct reduce the risk of sulfur corrosion, since the wall temperature is above the dewpoint of sulfur-oxides in the offgas.
- Inner corrosion: Less inner corrosion in the water tubes occur above 200°C because of self-passivation of the tubes.
- Operational safety: Heat recovery systems are designed and operated under high pressure. Therefore, the design of these systems must be according to pressure vessel design code. This leads to the benefit that the design is according the high standard of the code and the risk of failures is minimized.[4]
- Plant layout: The footprint of a waste heat recovery system is similar to conventional dedusting cooling systems. An additional building is required for the equipment of the plant, such as pumps, tanks, heat exchangers, etc.

- Public funding: Waste heat recovery technologies are in many cases funded by public authorities, since energy efficiency and environmental footprint is improved with such measures.

Figure 6

Compact chiller unit (source: BROAD air conditioning).

Figure 7

Organic rankine cycle (ORC) turbine unit.[6]

Utilization of Recovered Energy

In contrast to integrated iron and steel plants, electric steel plants have only a limited demand for steam (e.g., steam ejectors for vacuum oxygen degassing, VOD). Due to the low steam demand, electric steel plants often ask for a waste heat recovery system with power production. However, the installation of a power block (organic rankine cycle (ORC) or steam turbine) requires an additional investment, which has a significant influence on the system's return on investment. This section discusses the most important applications for waste heat utilization.[5]

Hot Water Production/District Heating — The simplest method of energy recovery is to use waste heat to produce hot water for heating purposes. The generated hot water can be used either internally or distributed to an external district heating system. Offgas is cooled at elevated temperatures, depending on the required hot water parameter. Additionally a storage tank is required, in order to provide a continuous output.

Steam Generation — Production of steam is a simple and economical possibility for waste heat recovery. However, a prerequisite is the availability of a steam consumer. The following steam consumers are typically available within electric steel plants:

- Galvanizing and/or pickling lines.
- Steam ejectors for vacuum degassing plants (VD/VOD).
- External steam consumer (e.g., seawater desalination, pulp and paper industry, other industries).
- Air separation plants.

Chilled Water Production — Usually, chilled water production for comfort and process cooling applications is done by compression-type chillers, driven by electrical motors. An alternative technology for producing chilled water is thermal-driven chillers. A widely spread and proven technology for such thermal chillers are absorption-type heat pumps.[5]

Power Generation With ORC Turbine — The recovered waste heat can be used to generate electric energy. Considering the fluctuating heat production of an EAF and the comparable low water/steam parameter of such waste heat recovery systems, ORC turbines are the most economical means of power generation.

The main difference of an ORC turbine compared with conventional steam turbines is the working fluid, where a refrigerant is used instead of water. Due to the lower boiling point of the refrigerant, low-temperature heat sources can be used for power generation. Thus, the ORC fluid is pre-heated and evaporated by the external heat source (in this case hot water) and expanded in a specially designed turbine. The ORC fluid is then recooled in the condenser.

The entire turbine unit, including its auxiliary equipment, is located in a separate building, which is located near the waste heat recovery system. A typical ORC unit is shown in Fig. 7.

Industrial Implementation

This section introduces examples for waste heat recovery systems at EAF for different applications.

Heat Recovery Pilot Plant — A pilot plant was installed at a steel plant in Germany, using a bundle heat exchanger. The plant is operated with a molten salt mixture and is operated at fluid temperatures of up to 450°C. The purpose of the plant was to examine, amongst others, the following issues:

- Design of bundle heat exchanger.
- Testing of various boiler materials at very high temperatures.
- Influence of particle erosion from dust-laden offgas.
- Influence of high-temperature corrosion (chlorine corrosion).

Waste Heat Recovery With District Heating — As part of a revamp of the dedusting system of the EAF at a steel plant in Sweden, an innovative heat recovery system was installed. Thus, recovered waste heat is used to generate hot water for district heating.

The water-cooled hot gas line is operated with pressurized water. The recovered heat is transferred via heat exchangers to a district heating network and is fed to the nearby city. To equalize fluctuations of the EAF and to supply constant heat flow to the heating network, a thermocline-type buffer tank is used.

Steam Generation for Pickling Lines — An innovative waste heat recovery system was installed at the EAF of a steel plant in Italy. For the new 150-ton EAF, the dedusting system was equipped with a waste heat recovery system.

The offgas is cooled with pressurized water at temperatures of approximately 200°C. The hot water is fed to two different pickling lines at distances of 0.9 and 0.3 miles. However, for hot water feed to the consumer, a distance of 2 miles can be realized. A layout of the piping routing through the entire steel plant is given in Fig. 10.

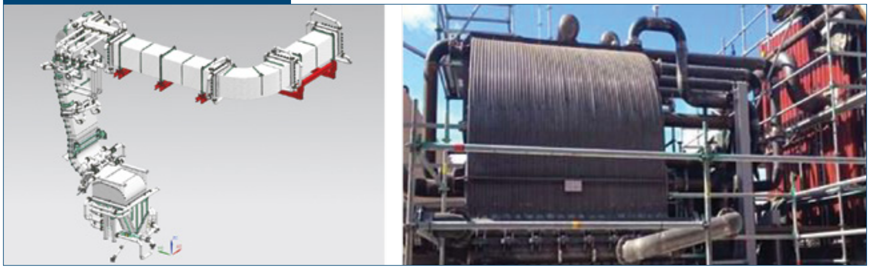
In the case of high heat supply of the EAF, water is fed to the storage tank and to the pickling lines (Fig. 11). During EAF idle times, water is circulated, while water from the storage tank is fed to the pickling lines. In case of no steam consumption at the pickling lines, the water is cooled via a heat exchanger, in order to provide continuous EAF operation. Steam is generated at the pickling lines with a Kettle reboiler heat exchanger (Fig. 12).

With the newly installed system, the existing gas boilers are substituted. The overall steam production is 17 tons/hour, which leads to annual savings in natural gas of 8.2 million m^3.

Figure 8

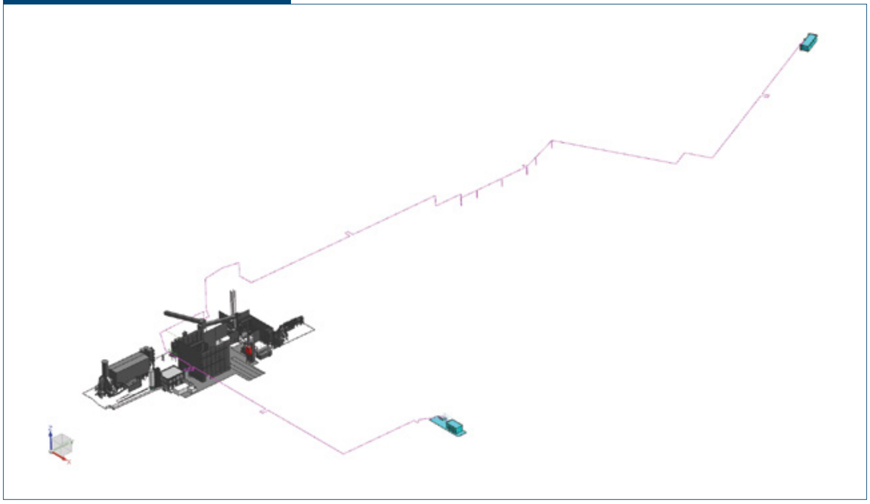
Heat recovery pilot plant at a steel plant in Germany.

Figure 9



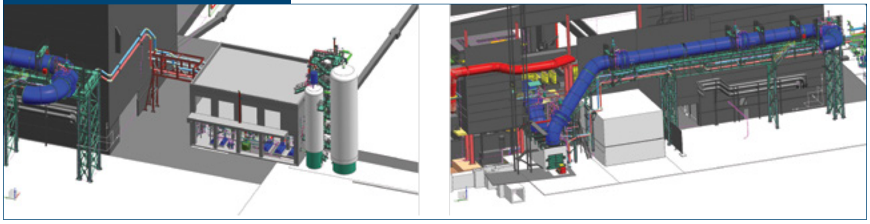
Waste heat recovery with district heating.

Figure 10



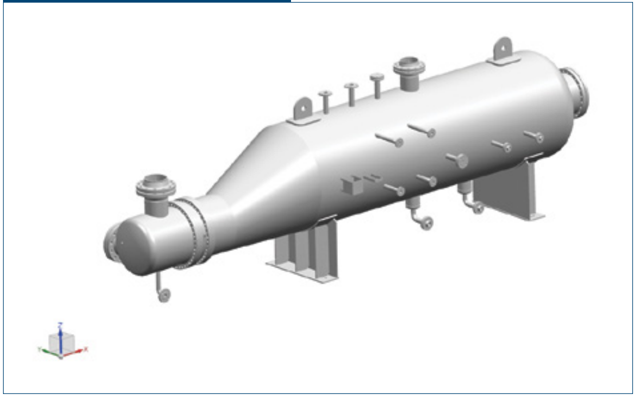
Heat supply to two pickling lines.

Figure 11



Heat recovery plant with steam generation for pickling lines.

Figure 12



Steam generator at pickling line.

Conclusions

In times of increasing awareness of energy costs, growing environmental consciousness and tightening emission control, steel plant operators are interested in reducing the overall energy consumption or utilizing process waste heat. Due to the vast amount of waste heat of EAF offgas, energy recovery has become more and more in the focus of interest.

The utilization of the recovered energy plays a decisive role in the design of a waste heat recovery system. In contrast to integrated iron and steel plants, where a lot of steam consumers are available, electric steel plants have only a limited demand for steam. Thus, several possible waste heat consumers were discussed. However, for a waste heat recovery plant, a customized solution has to be developed, in order to provide an economic solution for utilizing waste heat. Using waste heat to produce steam for the on-site pickling lines can be an attractive method of heat utilization.

Industrial plants were introduced to demonstrate how innovative waste heat recovery solutions led to a reduction of energy demand and hence to a reduction of specific costs per ton steel.

Waste heat recovery from EAF has a large potential to reduce the overall energy costs and to create additional benefits for steel plant operators. However, due to the characteristics of the EAF and the specific offgas conditions, as well as the plant situation and layout, a holistic plant view is required to develop a tailor-made solution for a waste heat recovery plant.

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Did You Know?

SSAB Introduces Water-Quenchable Steel for Reliable Performance and Easy Quenching

Sweden's SSAB has begun selling a new type of steel that can be quenched in water, but doesn't need to be immediately tempered, it has announced. Called M43, the new grade offers a high degree of hardness and impact strength, the company said.

SSAB M43 steel can be quenched in plain water without an immediate need for tempering, and still reach exceptionally high values for hardness and impact strength. SSAB M43 includes a number of innovations in steel production. The chemical composition (patent pending) and unique rolling parameters provide outstanding workshop properties and performance of the final products.

SSAB M43 can be quenched in water instead of aqueous quenching fluids or oil for a cheaper, safer and more environmentally friendly process. It saves energy and time in production and reduces CO_2 emissions.

Heat treatment results in a fully martensitic, fine-grain microstructure with an unmatched hardness to toughness ratio. SSAB M43 can reach 3 times higher toughness than a medium alloyed chrome-vanadium or chrome-molybdenum steel. Typical hardness and toughness values are 58 HRC and 25 J/cm^2 at +20°C.

For even greater toughness, low-temperature tempering is enough to reach >30 J/cm^2 with hardness still at a level of 56 HRC. Shearing, blanking and piercing can be executed without a risk of microcracking, thereby avoiding more time-consuming and expensive processing.