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SINTER PLANT AND BASIC OXYGEN FURNACE WASTE HEAT UTILIZATION – NEW CONFIGURATION WITH ORC MODULES FOR POWER GENERATION

Abstract

The demand for increasing energy efficiency and CO_2 reduction is one of the global megatrends of our time. Although the steel industry suffers from a volatile economic environment, the steel plants are interested to find opportunities for sustainable cost reduction and put efforts into healthy solutions for the environmental. Integrated steel plants are trying to cut electrical power and energy costs as these are among the biggest cost factors that can be influenced and taking all the advantages they can.

For the integrated iron and steel making route the interaction of waste energy utilization along with process energy demand, natural and metallurgical gases, steam and heating systems as well as power generation has to be considered. Potential energy sources, such as sinter plant, basic oxygen furnace (BOF) cooling stack or reheating furnaces are considered in order to elaborate an integrated energy concept.

Especially electric power generation is an attractive option for steel plant operators since it can easily be connected to the existing power grid of the steel plant. When direct local use of waste heat is limited, the best option is to convert it to mechanical/electrical power with a Rankine Cycle. A stand-alone system, compact design with minimum operational costs in order to fit into the existing steel plant layout, are the main requirements of such units.

The objective of this paper is to demonstrate economic feasible opportunities for energy recovery for sinter cooler and basic oxygen furnace with focus on electric power generation via ORC modules taking at the same time advantages of CO_2 reduction by utilizing waste heat from the process. Furthermore typical arrangements and layouts of such solutions as well as basic economic calculations will be presented in the paper.

Key Words

Sinter Cooler, Basic Oxygen Furnace, Waste Heat Recovery, CO_2 emissions reduction, Energy Efficiency, ORC modules, electric power generation.

Introduction

In times of increasing awareness of energy costs, growing environmental consciousness and tightening emission control, energy efficiency is one of the global megatrends of our times. For integrated iron and steel plants as well as for electric steel mills energy is one of the most important cost factors [1]. Especially the vast amount of electric energy forces operators to improve the overall energy situation, in order to reduce the specific costs per ton steel and also to comply with legal requirements in terms of energy efficiency.

There are numerous opportunities along the iron- and steelmaking process for implementing energy efficiency technologies. Smaller improvements can be easily implemented without big actions. Such measures can be a modified plant operation, simple plant upgrades, or smaller automation packages.

For a more decisive impact on the energy balance of a steel plant, bigger actions are required. With the installation of a waste heat recovery system a large amount of off gas energy can be utilized in form of heat and electricity, and hence reduce the specific energy costs of the plant. Above all turning waste heat into electric power is a very attractive option for steel plant operators.

Although some integrated steel plants have power plants on site, smaller or older steel plants do not have the opportunity to use the existing steam turbines of a power plant for electric power generation. Especially for these operators the installation of an ORC module for decentralized power generation is an interesting alternative.

Besides the unutilized waste heat potential of various heat sources in the iron- and steelmaking route and the technical feasibility of such waste heat recovery systems, these projects have to be also feasible from an economic point of view.

In the following, the most important waste heat sources for the integrated steel work as well as electric power generation based on ORC modules will be presented. Following the metallurgical process chain the two major heat sources like the sinter cooler and the basic oxygen furnace will be presented. Other major heat sources like blast furnace will not be covered since state of the art technologies as top gas recovery turbines are the most preferable solutions.

Waste heat recovery system for sinter cooler

A major heat source in the integrated steel plant is the sinter cooler. Basically there are two types of sinter coolers which can both be combined with a waste heat recovery system:

- Circular cooler and similar cooling principles – cross flow cooling
- Shaft cooler – counter flow cooling

The shaft cooler design allows an efficient heat transfer between the hot sinter and the air. Thus, nearly the total heat content of the hot sinter can be used leading to a maximization of the off gas temperature. Although the shaft cooler has advantages in terms of waste heat recovery potential, focus of this paper will be the circular type sinter cooler since it is more common in steel industry. For more information regarding shaft cooler please refer to [2].

Depending on the plant setup and boundary conditions, several options are possible. The off-air of the cooler can be directly brought back to the sinter process (either as combustion air at the ignition furnace for saving fuel consumption or as part of the waste gas recirculation process). Alternatively a waste heat recovery system can be fed by the off-air from the cooler for the generation of electrical energy or for the production of steam.

A dedicated burn through point control utilizes process data from the cooler in addition to thermal data from the suction chambers to both stabilize the sinter process and to assure optimized recovery of waste energy.

The bulk of the thermal energy in hot sinter can be efficiently recovered applying the sinter cooler heat recovery system. By means of specially designed cooler hoods and dedicated heat exchanger steam can be produced and fed either to the local steam network for various on-site applications, or used to produce electricity in an ORC module. A schematic picture of a circular type sinter cooler waste heat recovery system with off-gas recirculation is given in Figure 1.

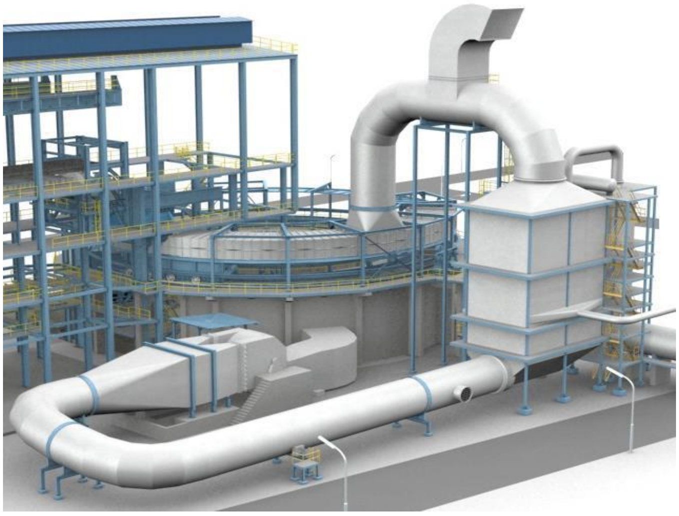

Fig. 1: Waste heat recovery at Sinter Cooler

The potential energy recovery from the sinter cooler is 50–80 kWh of steam per ton of sinter, corresponding to the generation of 40–60 tons of steam per hour for a sinter plant with an output of 4.5 million t/a. The actual figures depend on the sinter discharge temperature, sinter characteristics, type of sinter cooler and required steam parameters. Superheated steam can also be produced by sufficient off-gas temperature or supplementary firing with natural or coke oven gas. The waste heat boiler itself can be either tube bundle type or smoke tube type depending on the exhaust air flow and cost efficiency.

The waste heat recovery system can either built up as closed cycle system regarding the exhaust air flow or as an open cycle system. Main advantage of the closed cycle is to recirculate the boiler exhaust air and therefore feedback the energy to the sinter process. The basic process flow diagram respectively flow principle is shown in Figure 2.

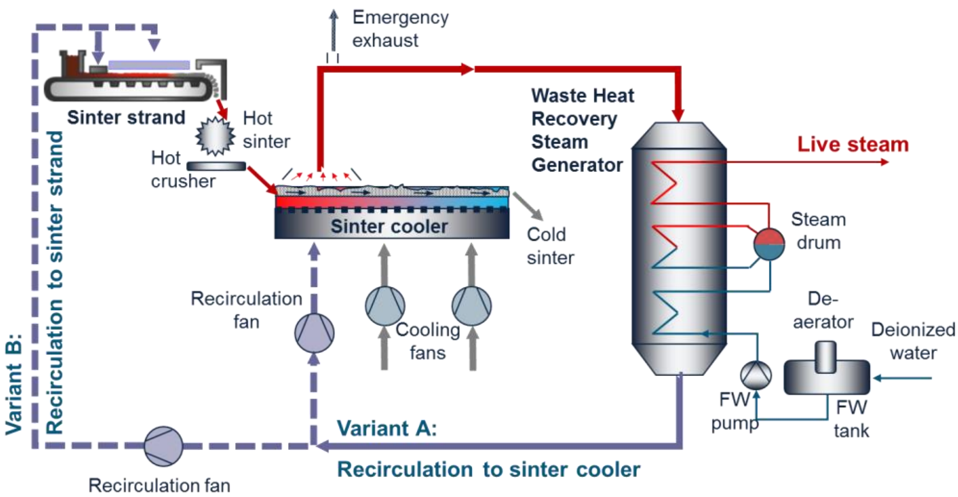

Fig. 2: Waste heat recovery at Sinter Cooler with internal recirculation system

The live steam can afterwards be fed to an organic Rankine cycle system to turn the heat into electricity. The ORC heat recovery electricity generation path gives also the possibility to use alternative heat carrier systems to the ORC module rather than steam. One simple solution would be a hot water system. By pressurizing water, heat can be transferred from the sinter cooler off-gas far above the evaporation temperature at ambient conditions. This means an acceptable ORC-module efficiency can be reached by realizing a much less complex heat transfer system compared to the steam generation solution.

The new configuration of a sinter cooler waste heat boiler and an ORC module leads to the advantage of decentralized power generation. The specific advantages of an ORC power generation unit are presented in a later section of this paper.

Heat recovery from Basic Oxygen Furnace

Following the integrated process route the next step after producing the pig iron is its conversion into liquid steel. Therefore the second major waste heat source within an integrated steel works is the basic oxygen furnace (BOF). The first part of the BOF off gas system is the cooling stack, where the hot off gas of the BOF is cooled down from approx. 2000°C to 900°C. The membrane walls of the cooling stack are either hot water or evaporation cooled. Primetals Technologies has various references in BOF cooling stacks and EAF waste heat recovery systems based on saturated steam or hot water technology. For example, in 2016 plants in Germany and Sweden have been successfully commissioned and one further start up for EAF waste heat recovery is planned for 2017.

The evaporative cooled stack is a state of the art waste heat recovery system, which is widely used. Due to the batch wise steelmaking process only saturated steam can be produced. A typical steam based cooling stack system is shown in Figure 3. More information regarding steam cooled stacks can be found in [3].

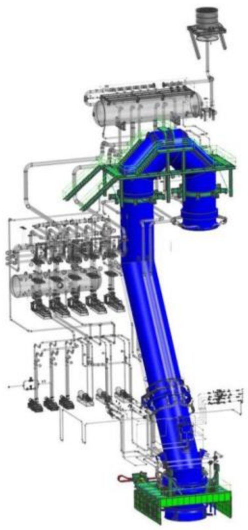

Fig. 3: Cooling stack with steam generation

Concerning the combination of BOF waste heat recovery and power generation based on ORC technology hot water cooled cooling stacks are also an attractive opportunity for waste heat utilization. In most steel plants operated with hot water systems the energy potential of the hot water is not utilized at the moment and is dissipated to the environment. Typically hot water cooling stacks are operated at water temperatures around 120-160°C. Using ORC modules also this relatively low temperature level can be used to generate electricity.

A schematic process flow diagram of such a system is shown in Figure 4. Depending on the design and lifetime of the cooling stack even a re-usage of the existing cooling stack for waste heat recovery can be possible. Nevertheless, this has to be checked for each project individually. Thermal energy storage systems link hot water tanks can be used to equalize outlet temperatures for downstream consumers. In case of maintenance or malfunction of the waste heat recovery system, the cooling stack can be operated with the conventional water cooling as well.

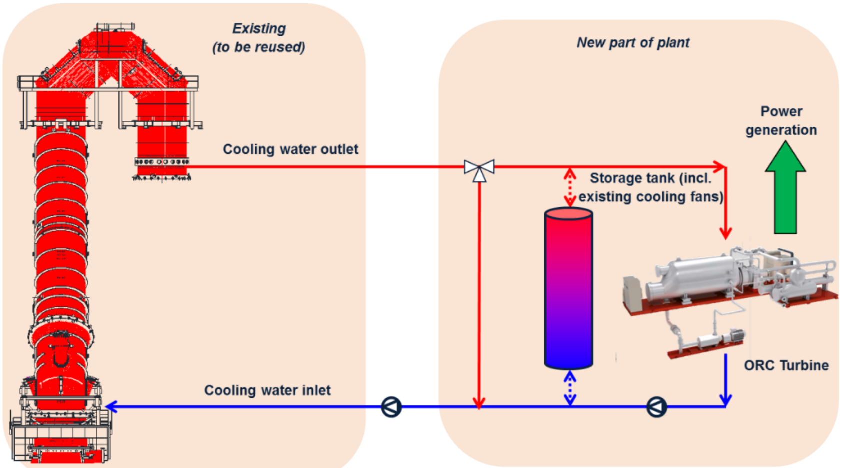

Fig. 4: Waste heat utilization for hot water cooling stack

Further waste heat recovery potential in integrated steel plants

If a waste heat recovery concept for an integrated steel works is investigated, also smaller waste heat sources like reheating furnace should be considered. Thermal energy output is lower compered to sinter cooler and BOF waste heat recovery systems, waste heat can be more easily recovered due to the more stable process conditions. Regarding these system the advantages of an ORC module are obvious again. Low temperature would lead to low efficiency in power generation with steam turbines. ORC modules can handle the lower temperatures more efficiently. Furthermore the waste heat of a reheating furnace can be combined or bundled with a large heat source like sinter cooler or BOF and guided to the same ORC for combined power generation.

A schematic process drawing of a reheating furnace waste heat recovery system with an ORC module can be found in Figure 5. All shown data are for reference only and have to be calculated in detail during a project.

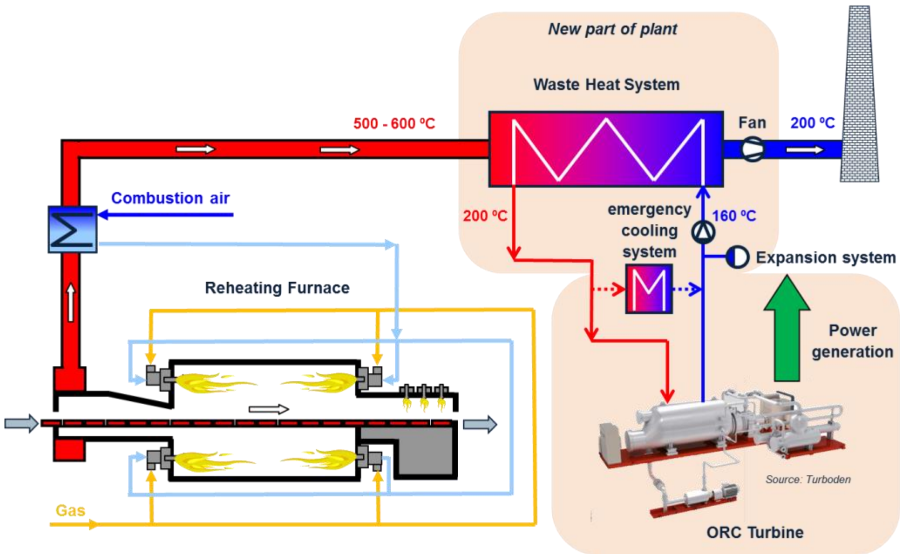

Fig. 5: Reheating furnace with waste heat recovery system and ORC power generation

Direct exchange configuration is also possible when one single heat source is present thanks to the cleanness and stability of the reheating furnace exhaust gas compared to other exhaust gas available in the steel plant.

Electrical power generation with ORC technology

ORC is a proven and reliable technology and ORC units are widely used in renewables and distributed power since the '70s. Typical ORC size ranges between few hundred kW electric up to 15 MW and above. Most common applications are in geothermal and biomass fields where several hundred ORC power plants are in operation. In the last 15 years, heat recovery application has grown in interest and there are more than 20 ORC units supplied by Turboden in small combined cycle (in combination with both gas turbines and reciprocating engines) and in energy intensive industries like steel, cement and glass.

The table below shows the ORC supplied by Turboden in several applications.

Table 1: Turboden references in ORC

APPLICATION	**SIZE MW**	**PLANTS no.**	**MW**
Wood Biomass	0.2 – 8	285	371
Geothermal	0.5 – 16.5	10	49
Combined Cycle (bottoming of gas turbines or reciprocating engines)	0.5 – 4	11	16
Waste to Energy	0.5 – 5.3	11	27
Industrial Heat Recovery (Cement, Glass, **Steel**, **Aluminium**, etc.)	0.5 - 5	17	49
Solar thermal power	0.6 – 3.8	5	8
Total Turboden Plants	0.2 – 16,5	**337**	**520**

Updated in January 2017

When the main heat source is in the gaseous phase (e.g. streams of dust laden BOF or EAF exhaust gases), a Heat Carrier loop is typically interposed between the hot source and the ORC. When the exhaust gas is relatively clean and the flow is stable (no batch process) the heat carrier loop can be avoided and the organic fluid can be evaporated in a gas/organic fluid heat exchanger (direct heat exchange ORC).

The ORC unit produces electricity and makes available low-temperature heat through a closed thermodynamic cycle which follows the principle of the Organic Rankine Cycle.

In the ORC process, designed as a closed loop, the organic working medium is pre-heated in a regenerator and in a pre-heater, then vaporized through heat exchange with the hot source (heat carrier or exhaust gas). The organic vapour is expanded in a turbine that drives an electric generator converting mechanical into electric power. Leaving the turbine, the organic working medium (still in the vapour phase) passes through the regenerator that is used to pre-heat the organic liquid before vaporizing, therefore, increasing the electric efficiency through internal heat recovery. The organic vapour then condenses and delivers heat to the cooling water circuit or directly to ambient air through air-condenser. After the condensation, the working medium is brought back to the pressure level required (for turbine operation) by the working fluid pump and then preheated by internal heat exchange in the regenerator.

The proper organic fluid is selected depending on power size and temperature level. Turboden has used more than 10 different fluids among siloxane, hydrocarbons and refrigerants.

Traditional Rankine Cycle systems use water and steam as working fluid. They are the common solution for power plants above 20 MW, with efficiencies above 30% when using superheated steam at high pressure/temperature. Steam turbine Rankine Cycle systems are preferred in large utility size power plants where fuel is the most important cost factor outweighing the higher O&M costs due to steam at high temperature/pressure.

ORC technology, employing high molecular weight working fluids (siloxanes, hydrocarbons and refrigerants) that guarantee dry vapour expansion in every operating condition, is typically preferred for smaller scale power systems up to 15 MW, due to good efficiency, high flexibility and minimum running costs.

The use of an organic working fluid enables efficient use of an unexploited medium-to-low temperature source, to produce electricity with an automatic self-adjusting system.

The ORC modules are remote monitoring controlled and require no dedicated operator and minimal yearly maintenance activities; thereby they allow the steel plant technicians to remain focused on the steel production process.

The following figure shows the main differences between traditional Rankine Cycle with Steam Turbine and ORC (Figure 6).

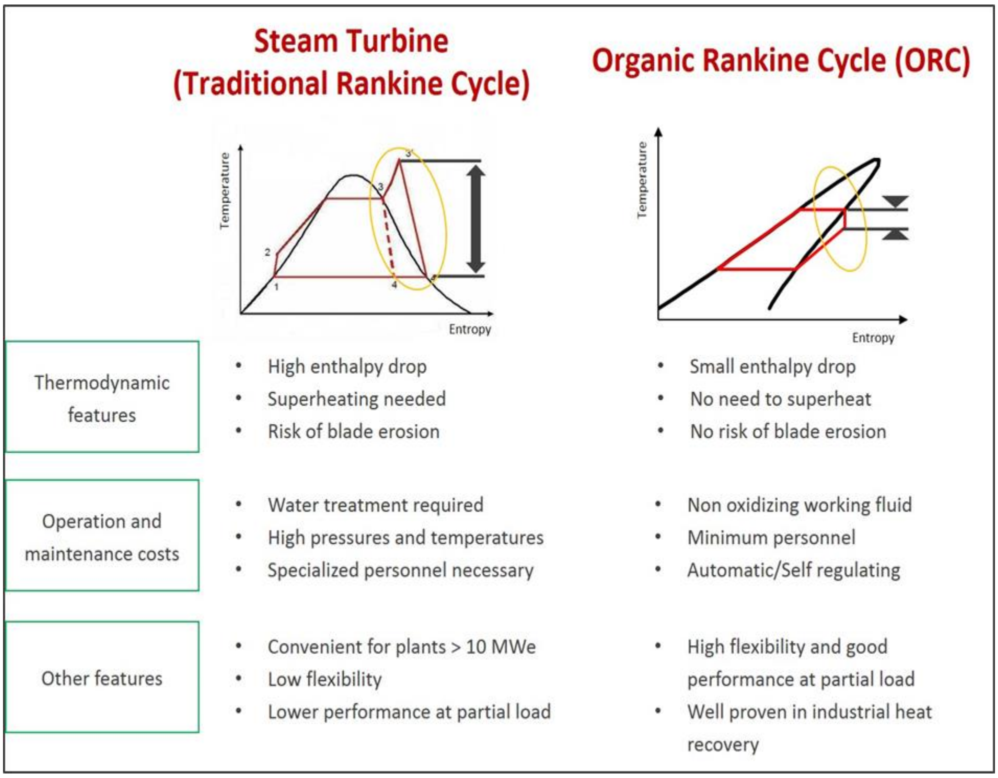

Fig. 6: Comparison traditional Rankine cycle vs. organic Rankine cycle

Turboden ORC clients recognize the following advantages for ORC based heat recovery systems:

- Totally automatic system, no need of supervision personnel: ORC does not need supervision personnel in normal operating condition nor in shut down procedure. No additional personnel is needed
- Flexible operation in a wide range of thermal power loads: ORC module has a high level of automation and it is designed to automatically adjust itself to the actual operating conditions: variations on exhaust gas temperatures and flows will not affect the functionality of the system, but just the power output
- High efficiency even at partial load
- Long life with no major overhaul
- Minimum maintenance requirements: ORC units are remotely monitored and require minimal yearly maintenance activities.
- Possible configuration with no water consumption

At present, there are 4 Turboden ORCs successfully working in the Iron&steel industry and 2 units will be started up at the end of 2017/beginning 2018. EAF was the first application in the heat recovery in Iron&steel industry with the first 3 MW_{el} unit started up in 2013 in Germany recovering the heat from a 90 tons EAF.

The very first ORC R&D application in the steel industry was back in the 90's in a Cupola oven in Italy. Recently, the heat recovery plant was upgraded and the ORC turbine substituted with a higher performing turbine highlighting the development done in the ORC technology.

See below the list of ORC references in the steel and non-ferrous industry

Table 2: Turboden ORC references in steel and non-ferrous industry

PLANT	• **TYPE**	**CAPACITY**	• **GROSS ELECTRIC POWER OUTPUT (kW)**
• **NATSTEEL - Singapore** • (Start-up: February 2013)	• STEEL • ROLLING MILL BILLET RE-HEATING FURNACE	• 125 ton/h	• 555
• **ELBE STAHLWERKE FERALPI – Riesa, Germany** • (Start-up: December 2013)	• STEEL • ELECTRIC MELTING FURNACE	• 100 t	• 2,700
• **UNDISCLOSED CUSTOMER** • **(Start up: July 2015)**	• ALUMINIUM • GAS FIRED MELTING FURNACE	• N.A.*	• 1,706
• **ORI MARTIN – Brescia, Italy** • **(Start-up: January 2015)**	• STEEL • ELECTRIC MELTING FURNACE	• 85 t	• 1,885
• **FONDERIA DI TORBOLE – Torbole Casaglia, Italy** • **(Start up: January 2017)**	• IRON • CUPOLA FURNACE	• 30 ton/h	• 690
• **AICHI STEEL– Japan** • **(Expected Start up: end 2017)**	• STEEL • ELECTRIC MELTING FURNACE	• 100 t	• 2,500

• **ARVEDI– Italy** • **(Expected Start up: third quarter 2017)**	• STEEL • ELECTRIC MELTING FURNACE	• 250 t	• 8,000

Economic Feasibility

Even if above presented solutions are feasible and well proven from a technical point of view, economic feasibility has to be analysed in detail for each project. Considering electric power generation simple payback is mainly driven by price of electricity. Furthermore public subsidies or incentives can play a major role regarding economic feasibility.

In Figure 7 an exemplary economic evaluation considering typical figures can be found.

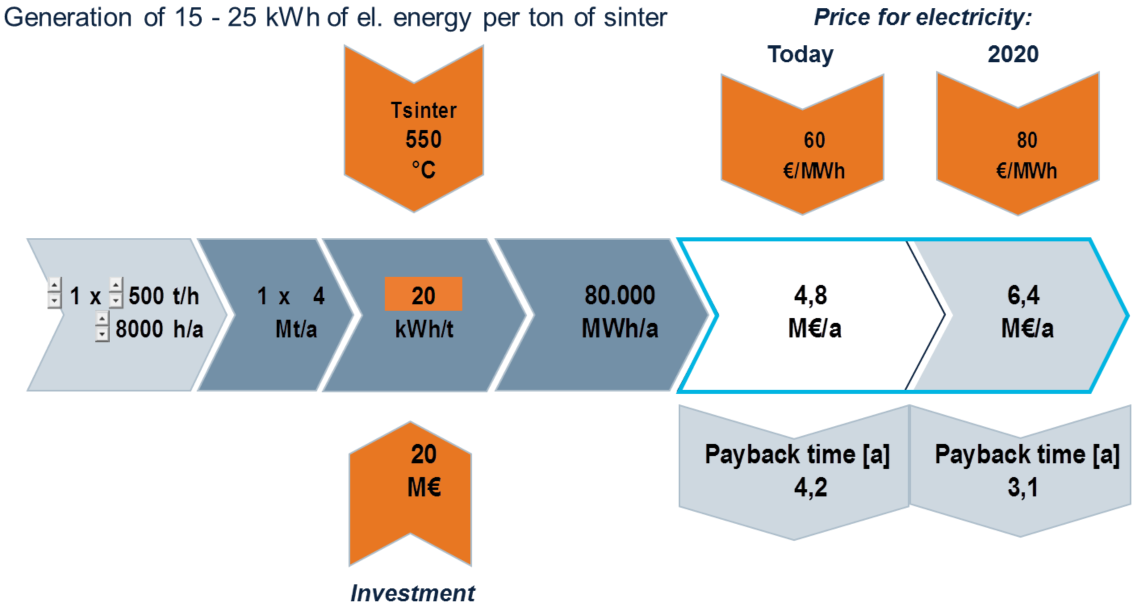

Fig. 7: Exemplary economic feasibility calculation for sinter cooler waste heat recovery system with ORC module

Besides static payback waste heat recovery solutions combined with ORC modules help to strengthen the green reputation of a company reducing carbon dioxide emissions. Furthermore carbon dioxide reductions often allow to obtain public subsidies.

In the following table an overview regarding carbon dioxide savings based on the above presented technologies is shown. The calculation of the emission reduction is based on the European energy mix for electric power generation with 0,622 kg of carbon dioxide per kWh of electric energy (cf. [4]).

Table 3: Carbon dioxide reduction based on waste heat recovery installation

Waste heat source	Specific CO_2 reduction
Sinter Cooler	~ 13 kg_{CO2}/t_{Steel}
BOF Cooling Stack	~ 7 kg_{CO2}/t_{Steel}
Reheating Furnace	~ 4 kg_{CO2}/t_{Steel}

All given figures are based on typical values and are therefore only exemplary. For serious estimation of cost savings and emission reduction a detailed investigation has to be done.

Conclusion

The paper shows that there are opportunities for turning waste into value. The above presented waste heat recovery solutions in combination with ORC technology will be a corner stone towards an energy efficient future in steelmaking.

The steel producers, who are concentrated in developing and improve their production processes, should now also aim for the implementation of systems that improve efficiency of the processes and bring environmental benefits. Primetals and Turboden solution constitutes an appropriate response to the need to diversify the supply of electrical energy and reduce energy waste and global CO_2 emissions.

References

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