High efficient energy recovery solutions for melt shops

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Energy efficiency, reduction of environmental impact and higher product quality will be the drivers of innovation in the steel industry over the next few years. The increasing demand for energy and its consequent increase in prices are pushing steel companies to develop new solutions. The efficient use of resources is an integral part of Tenova's mission. Related to that, the Tenova's iRecovery® technology represents reliable and sustainable concepts and solutions to cope with future global challenges and is part of the iSteel technologies portfolio. It consists of several heat recovery cooling systems for different industrial furnaces, among others the electric arc furnaces (EAF), submerged arc furnaces (SAF), basic oxygen furnaces (BOF), walking beam furnaces and pusher type furnaces. The difference between iRecovery® technology and conventional cooling systems is that energy losses in the waste gas are now recovered as steam. That means iRecovery® technology allows recovering 35-70% of these losses, so bringing back 10-25% of the primary energy input. This paper presents current technical solution and an outlook of further improvements for the field of electric steelmaking.

KEYWORDS: HEAT RECOVERY - ENERGY EFFICIENCY - STEAM PRODUCTION - POWER GENERATION - WASTE HEAT BOILER

SOLUTIONS FOR AN ELECTRIC ARC FURNACE (EAF)

It is well know that approx. 30% of the total energy is lost due to the chemical and sensible energy content inside the off gas. This energy can be recovered by a steam boiler system.

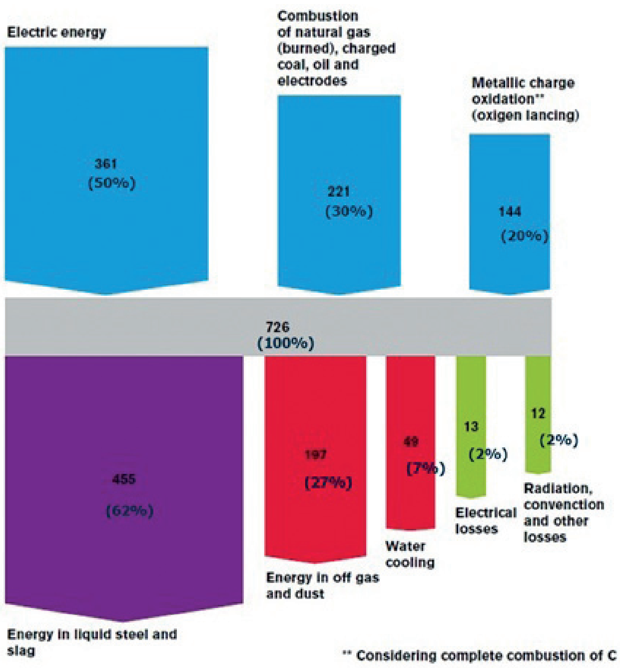

Fig. 1 - EAF Energy Balance

Next to the environmental aspect of the heat recovery approach based steam production the transformation into a usable and storable media is the key to make it profitable. There are different concepts using steam to transfer it into electric energy by using ORC modules with included turbine or transfer steam into a superheated stage to use with conventional turbines. Despite of that, direct use of steam should always have priority, since the exergy of steam transferred into electric energy is much lower than if steam is utilized directly.

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HOW DOES IT WORK?

Approved standard technology for EAF off-gas heat recovery is available from Tenova; the product is called iRecovery®. The basics of the technology have been introduced in different former articles of the author [1], therefore only a very short description is provided in Figure 2.

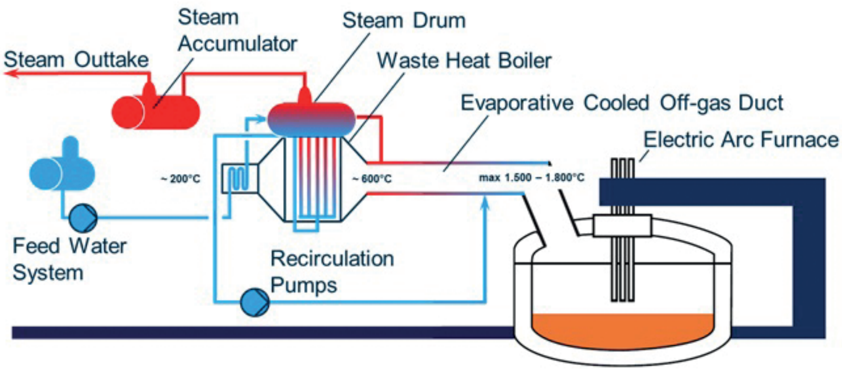

Fig. 2 - Scheme

Compared to conventional cold water cooling an iRecovery waste gas duct is a pipe-web-pipe construction with the same look. The main difference is the pressure and temperature level inside; while cold water cooling typically uses 20-50 °C, an iRecovery system works with boiling water of app. 180-250°C inside the ducting (high temperature section) and decouples the off-gas energy through the process of evaporation. This is called Evaporative Cooling System (ECS) and well known and applied in various applications.

In addition, the remaining thermal power which is usually dissipated my means of a quenching tower or trombone coolers, is decoupled inside a low temperature section. Inside this so called waste heat boiler bundles of superheats (if applicable) evaporator and economizer bundles is located. The steam-water-mix generated inside the heat exchangers is led into a steam drum where steam and water is separated. The steam is taken out and replaced by condensate/fresh water coming from a feed water station.

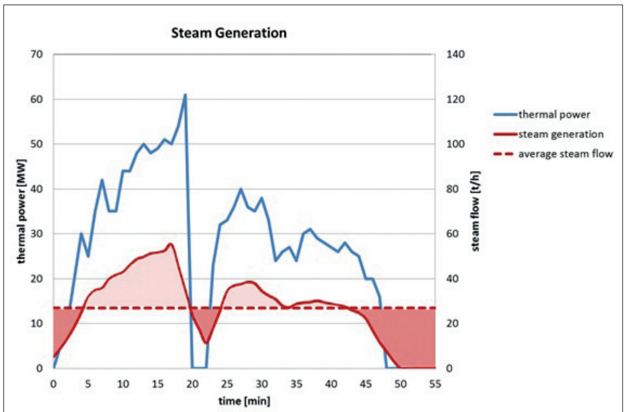

Fig. 3 - Steam Delivery

In one sentence: iRecovery turns a cooling system into a boiler. Since the process is a batch process it underlies strong differences between minimum and maximum thermal power. At the same time steam consumers are fluctuating as well. Therefore the iRecovery system is equipped with a Ruth steam accumulator which equalizes steam off take in synchronizes steam generation with steam consumption.

TECHNICAL DEVELOPMENT OF IRECOVERY SINCE 2007

The first iRecovery project, the EAF of Georgsmarienhütte GmbH, Germany, was engineered in 2007/2008 and was commissioned early 2009. This plant works for more than 6 years without major problems and without a single day of unplanned downtime. [2]

The follow-up project for Elbe-Stahlwerke Feralpi, Riesa, Germany, was the first iRecovery installation with the heat recovery for the complete waste gas line; downstream the steam generating waste gas duct a horizontal type compact waste heat boiler was connected. Special focus of this project was the cooling speed inside the waste heat boiler in order to avoid de novo synthesis (recombination of dioxins and furans). The produced steam is brought to two different consumers. One part is used in a nearby tire plant. The process steam produced in natural gas fired boiler is replaced by the steam coming from the melt shop. The remaining steam is converted in an ORC (Organic Rankine Cycle) into electric energy. [3]

Also the two projects for the EAFs of Hyundai, Incheon, South Korea, are equipped with iRecovery waste gas duct and waste heat boiler. Here the change to a shorter waste gas duct and a – relatively - bigger waste heat boiler was realized the first time. The systems were commissioned in 2014 and 2015. After those projects a big design step was accomplished by establishing a partnership with the engineering company Eckrohrkessel, based in Berlin, Germany, which holds the patent of the so called corner tube boiler. This kind of boiler was installed more than 6000 times worldwide.

Fig. 4 - Corner Tube Boiler

The first corner tube boiler of Tenova Metals Deutschland was installed downstream a rotary hearth furnace at Tenaris, Dalmine, Italy. The clean, hot off gas is converted into steam and fed into the plant steam grid which is connected to steam based power plant. Another iRecovery system equipped with a corner tube boiler was installed after the EAF at Ori Martin, Brescia, Italy. Ori Martin operates a Consteel EAF, where the energy of the off gas is used for scrap preheating.
Here, only a waste heat boiler was installed. The entire produced steam is utilized in an ORC module and converted into electric energy. At TPCO, Tianjin, China, an iRecovery system composed by both waste gas duct and waste heat boiler (corner tube type) was installed after a 100 t EAF. In order to gain a more attractive pay back model to the steel plant, Tenova sold the iRecovery system to a Chinese contracting company which operates the plant and sells back the steam to the steel shop. Since the commissioning in 2015 the steam is utilized inside the plant steam grid which feeds VD plants. Generally the positive operation experience with EAF waste heat boilers allows the identification of some trends and positive experience:

a) As far as hall layout/mechanical restrictions allow such adjustment, shorter waste gas ducts can be designed. The reason is simply economical; the same amount of heat transfer capacity is typically cheaper in a waste heat boiler than in a cooled duct.
b) The horizontal boiler design with pneumatic rapping devices for boiler cleaning delivers reliable operation conditions.
c) Utilization of steam on the plant infrastructure or at nearby industries reduce the pay-back time significantly.
d) End of dew point problems - cooling system elements always stay above dew point of sulphuric acid
e) End of inner corrosion of tubes - above 200 °C a self-passivation of tubes by the Schikorr reaction occurs
f) iRecovery means less thermal stress - the system works with a constant temperature during all different energy input phases of the melt.
g) Drastically reduced cooling water consumption - iRecovery® is a closed loop, cooling towers consume 3-8% of water every circuit
h) In case of emergency situations iRecovery offers more safety due to more redundancy compared to typical cold water cooling

Tab. 2a - Gives an overview about performance and technology of the three finished iRecovery EAF projects.

	Georgsmarienhütte GmbH, Georgsmarienhütte, Germany	Elbe-Stahlwerke Feralpi GmbH, Riesa, Germany	Hyundai Steel, Incheon, South Korea (EAF 90)
EAF	140 t/h top-charged	133 t/h top-charged	120 t/h top-charged
Ø off gas energy during P-on	~ 44.800 kW	~30.000 kW	23.000 kW
Decoupled in Waste gas duct during p-on	~18.800 kW	~13.000 kW	4.800 kW
Decoupled in Waste heat boiler during p-on	-	12.300 kW	11.100 kW
iRecovery efficiency	~ 42%	~ 84%	69%
Waste heat boiler design	none	Horizontal boiler with forced circulation, one central steam drum, pneumatic rapping devices	Horizontal boiler with forced circulation, one central steam drum, pneumatic rapping devices

Since the Japanese marked underlies high energy costs, Tenova Metals Deutschland was able to sell the first iRecovery system in Japan. The waste gas duct and the waste heat boiler convert the waste energy into process steam, which replaces an existing

natural gas fired boiler for a RH plant. The remaining steam is used in an ORC module. Commissioning will be in 2016.
The newest project is an iRecovery system connected to the Consteel at Acciaieria Arvedi, Cremona, Italy. This huge 230 t EAF equipped with a Consteel delivers the hot off gases to a waste heat boiler. After commissioning in 2017, the full amount of steam will be utilized in an ORC module.

Tab. 2b - Overview about performance and technology of 3 finished iRecovery EAF projects

	Hyundai Steel, Incheon, South Korea (EAF 80)	Ori Martin S.p.A., Brescia, Italy	TPCO Steel, Tianjin, China
EAF	120 t/h top-charged	90 t/h Tenova Consteel	130 t/h top charged
Ø off gas energy during P-on	22.000 kW	10.700 kW	33.200 kW
Decoupled in Waste gas duct during p-on	4.500 kW	-	17.900 kW
Decoupled in Waste heat boiler during p-on	11.100 kW	9.100 kW	11.800 kW
iRecovery efficiency	70%	85%	89%
Waste heat boiler design	Horizontal boiler with forced circulation, one central steam drum, pneumatic rapping devices	Horizontal compact self-supporting package boiler with integrated steam drum and natural circulation, pneumatic rapping device	Horizontal compact self-supporting package boiler with integrated steam drum and natural circulation, pneumatic rapping device

FRACTAL PROCESS ENGINE AS NEXT GENERATION DESIGN TOOL

Main technical challenges in the future will be related to modernization projects in a brown field setting. This leads to following design demands:

- Minimized base ground on order to be more attractive for brown field projects
- Increased dust removal by special designed WHB parts upstream bundles
  ➔ Reduces cleaning effort for bundles and increases transfer efficiency of the heat exchanger
- Reduction of false air entrance to minimize total off gas flow rate by intelligent waste gas / delusion air control ➔ Overall size reduction of downstream fume treatment plant and water treatment plant (OPEX) as well as CAPEX in case of new installation

To cover these demands the fractal process engine (FPE) was developed to execute the basic design of the evaporative cooling system (ECS) duct and the waste heat boiler (WHB) for electric arc furnaces or similar furnace types in terms cooling surface calculation, number of bundles, dimension of duct and WHB and finally the produced steam. This engine, combined with our experience in technical design and layout, puts us in a position to immediately estimate the investment costs (CAPEX) and melt shops in a position to investigate their potential in terms of energy saving, reduction of GHG emissions and return of invest calculation.

With the data base of furnace and its input / output balance the energy content of the off gas is calculated. Based on that, the dimension of the high temperature section and low temperature section is specified. With optimizing algorithms the floor space is minimized to fit reduced space in existing steel plants. With this FPE Tenova is able to react very fast on customer inquiries and can so support steelmakers to optimize their plant.

FUTURE PROSPECTS

- New applications
  The iRecovery system has proven that the former wasted energy potential inside the EAF off gas can be utilized for various applications. The system can handle dusty hot off gases evolving from a batch process. In the steel making industry plenty similar heat sources are existing. Therefore Tenova is approaching new furnace types with a similar heat recovery system as for the EAF in order to reduce unused heat emissions on a wider field.

- Contracting partners should be considered
  The iRecovery system could be purchased by an energy contracting company, who is familiar with such kind of projects. This company would build, own and operate the system for a certain period. After a full pay back (including profit), the heat recovery equipment can be transferred into the ownership of the steel plant. The advantage of the steel plant is that no investment has to be made. The steel plant is not responsible for any operation or maintenance staff.

And the steam or electricity can be bought for a reasonable price. The investment and the personnel will be borne by the contracting company which sells the steam/electricity. Such model has been worked out very well for TPCO, China. Tenova is in contact with such kind of companies and can provide individual concepts worldwide.

- Increase of efficiency:
  The Carnot cycle limits the efficiency of thermodynamic processes to a theoretical value. Since it is depending from the temperatures of energy conversion Tenova is searching for a possibility to increase to steam temperature at the take-over points constantly. Increase efficiency would lead to a reduction in pay-back time.

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