Heat recovery from EAF off-gas: a new benchmark

Energy optimisation is currently the focus of many activities in steel plants, but there is still a huge potential for energy recovery, as approximately 30% of the input energy is lost in the off-gas. Tenova's iRecovery® system recovers energy by generating useable steam by cooling the off-gas down to either 600°C in the waste gas duct or 200°C using a waste heat boiler. The technology and steel plant examples are described.

Authors: Carsten Born and Ralf Granderath
Tenova RE Energy GmbH

Energy optimisation is currently the focus of many activities in steel plants, and it is always better to avoid 1MWh of input energy than recover 1MW/h from the outputs. However, there is still huge potential for energy recovery. In the EAF process, for instance, ~30% of input energy is lost in the off-gas – a very significant quantity.

A range of examples is shown in *Table 1*.

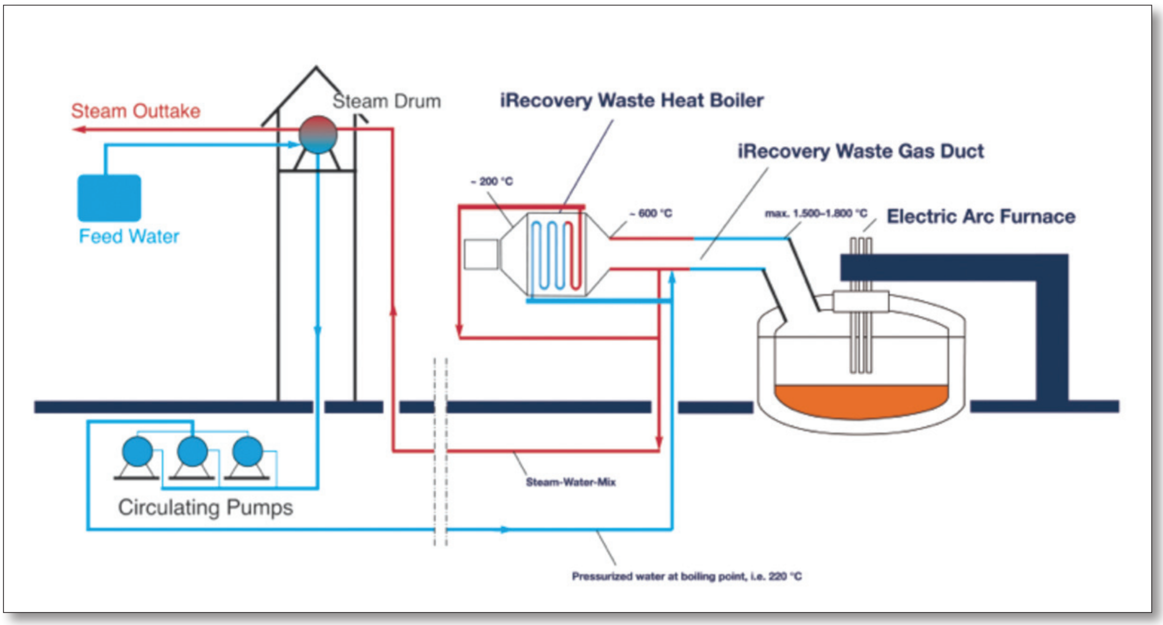
THE TECHNOLOGY

Approved standard technology for EAF off-gas heat recovery is available from Tenova; the product is called iRecovery®. With iRecovery level 1 the off-gas is cooled down to ~600°C in a steam generating off-gas duct. With iRecovery level 2 it is cooled down to ~200°C using a waste heat boiler to generate steam as well as in the duct (see *Figure 1*).

Compared to conventional cold water cooling, an iRecovery waste gas duct is a tube-tube construction with the same basic design and working principle. The main differences are the pressure and temperature inside; while cold water cooling typically uses water at 20-50°C, an iRecovery system works with water at ~180-250°C at the ducting and decouples the off-gas energy through the process of evaporation. iRecovery can work with a wide pressure range from ~7 bar to 45 bar according to the customer's needs. For process steam, ie, vacuum degassing typically ~15 bar are sufficient and a lower pressure saves costs. For power generation typically higher pressure is chosen.

This steam-water mix is led into a steam drum where steam and water are separated. The steam is removed and replaced by condensate/fresh water, then the water goes back into the circuit.

A mixed form, eg, with unusually long ducts or very large post-combustion chambers and resulting ▷



Ⓐ **Fig 1 Simplified scheme of an iRecovery® system**

Output source	Energy output kWh/ tls EAF Low chemical energy	EAF High chemical energy	Process route Consteel	100% DRI
Liquid steel	385	385	385	385
Slag	50	50	50	50
Scrap preheating	0	0	50	0
Off-gas content	170	240	130	260
Radiation losses	10	10	10	15
Cooling water	65	70	60	80
Total output	680	755	685	790

Table 1 **Energy output of 80-120t tapping weight EAFs**

temperatures somewhere between is also available.

iRecovery does not come with any operational disadvantages, rather it brings additional advantages:

- No more dew point problems – elements are always above the dew point of sulphuric acid
- No more inner corrosion – self passivation of tubes by the Schikorr reaction
- Less thermal stress – constant temperature of all elements during all operation phases
- Lower water consumption – iRecovery is a closed loop, cooling towers consume 3-8% of water every circuit
- Lower water volume flow due to higher heat transfer – smaller pumps, smaller piping, less maintenance cost
- Higher safety in different emergency situations by different redundant backup levels

It should be noted that the precursor technology of iRecovery®, the Evaporative Cooling System (ECS) was often used for reheating furnaces in the 1980s and 1990s and there are quite a few examples of furnaces that run ECS without taking advantage of the generated steam.

INFLUENCING FACTORS FOR HEAT RECOVERY

The first important parameter for the amount of energy recovered is the remaining temperature of the off-gas downstream of the heat recovery system. As described above, the decision is typically to cool down to ~600°C (duct, iRecovery level 1) or to 200°C (duct and boiler, iRecovery level 2).

The second key parameter is the amount of dilution air. Many EAFs work with huge amounts of dilution air and, although this strategy increases the volume for the bag house filter and the required fan power, it is still a cheap and reliable way to reduce off-gas temperature.

For heat recovery purposes, however, dilution air is counterproductive because every cubic metre of air going through the stack carries away energy so the higher the off-gas volume, the higher is the lost energy.

For example, if 80,000Nm^3/h off-gas (burned natural gas) at 1,500°C is sent through an iRecovery system down to 250°C, approximately 7MW of energy remain in the off-gas.

If the same amount of off-gas is mixed with 100,000Nm^3/h of dilution air to 700°C before entering the iRecovery system, approximately 15.5MW of energy remain in the off-gas at 250°C and the system's efficiency is reduced by ~22%.

In summary, three main factors determine the heat recovery potential of an EAF:

- The steel plant design/operations
- The targeted off-gas temperature
- The amount of dilution air

EXAMPLE FOR IRECOVERY LEVEL 1

The Georgsmarienhütte GmbH (GMH) operates a 140 t/h DC EAF in Georgsmarienhütte, Germany. A unique feature of this EAF is the duct cooling system. When GMH switched from the blast furnace/BOF route to EAF in 1996, some of the main parts of the cooling system from the former plant were used for the new EAF.

In 2007, GMH decided to replace the ECS after almost 25 years of continuous operation (including the time it was used for the BOF). The cooling system had deteriorated considerably and GMH wanted to replace the steam from the gas-fired boiler house with steam generated in the

	GMH	Feralpi Riesa
Furnace output, t/h	140	133
Tap to tap time, min	~59	~45
Off-gas energy, kWh/tls	~240	165
Off-gas energy during power-on, kW	~44,800	~ 30,000
Decoupled in Level 1 during power-on, kW	~18,800	~ 13,000
Decoupled in Level 2, kW	–	~ 12,300
Decoupled energy sum, kW	~18,800	~25,300
iRecovery efficiency, %	~42	~84
Steam temperature, °C	216	250-228
Steam pressure, bar	13-20.5	27-35
Steam generation power-on, t/h	28.5	40,8
Steam generation net contribution, t/h	21	29
Steam buffering capacity, t	12	5
Off-gas temp. after L1, °C	~650	~665
Off-gas temp. after L2, °C	–	~200

Table 2 **Comparison of iRecovery systems GMH and Feralpi Riesa**

new iRecovery system. This system – the first iRecovery system for an EAF – was commissioned in early 2009 and produces steam without major problems. These technical challenges were solved by steam buffering with two steam buffers (storage) working by the Ruth principle. (In a Ruth-type steam accumulator the steam pressure drops during discharge). Additionally, some energy is stored in the feed water tank during energy peaks. Overall, 42% energy is recovered from the off-gas.

After the iRecovery duct a water quenching tower is installed and no downstream oxygen control is installed. See *Table 2* for plant operating details.

EXAMPLE FOR IRECOVERY LEVEL 2

Elbe-Stahlwerke Feralpi GmbH operates a 133t/h AC EAF in Riesa, Germany. In 2011, the decision was made to retrofit the furnace with an iRecovery level 2 system including oxygen control. A main factor in the decision was the opportunity to sell excess steam to a local energy supplier.

The plant is currently under construction and will be commissioned in early 2013. In this plant energy recovery will be 84% .

A similar system was also installed at the Hyundai plant in Incheon, S Korea.

REASONS FOR THE DIFFERENT DECISIONS

It is apparent that the iRecovery level 2 waste heat boiler provides higher efficiency and, although the investment is higher, the cost per t/h of steam capacity decreases when the complete potential is used.

GMH GMH decided to choose only the waste gas duct solution for three reasons:

The first, and main reason is steam demand. GMH could provide sufficient steam for its operations with the level 1 system. The main steam consumer is the vacuum degasser (7t/h), followed by heating energy during winter. Steam also gets sold to an oxygen production plant on site. The fourth heat sink is the standby for fired boilers which are kept under pressure to guarantee constant steam supply when the EAF is shut down. This standby is done with a small portion of steam from iRecovery. On cold winter days the steam is completely used, but during summer some excess steam is condensed.

Second, when the decision for iRecovery was made in 2007, additional investment in power generation was not attractive given the price for electrical energy. The production of additional steam would only have led to condensing more steam.

Third, Tenova adapted the iRecovery technology from the rolling mill to the melt shop for the first time with the GMH project, hence there were a lot of 'first time details' in the engineering, and it's generally a good idea not to use too many new changes in one project.

The payback of the iRecovery project is realised by avoiding costs for natural gas, which have reduced by 95%.

Feralpi Feralpi can use all the steam generated in a level 2 system and, in the intervening years since the GMH project, power became more expensive so Feralpi went for power generation provided by this system. A total of 10 t/h of steam will be sold to the local energy carrier who will send the steam directly to a nearby tyre factory, saving on natural gas. As in GMH, the boilers of the energy carrier will be kept under pressure to guarantee a constant steam supply for the tyre plant when the EAF is shut down. ▷

Additionally 20t/h steam will be consumed by a Turboden Organic Rankine Cycle (ORC) turbine producing up to 2.5MW of electrical energy. Financial details are confidential, but it's relevant to know that the steam sales are more attractive than the steam going to the turbine.

LEVEL 2 WASTE HEAT BOILER: ADDRESSING THE CONCERNS

The authors know from meetings with steelmakers that there are three main concerns about using waste heat boiler technology in the melt shop:

Fouling The high dust load of the EAF off-gas is not ideal for tube bundle heat exchangers and sticky dust could lead to heavy dust settlements.

Tenova Re Energy has analysed the dust from a number of EAF plants. The ash melting point has been above 1,000°C in all cases and, as the inlet temperature of the level 2 system is significantly lower, the dust will not stick to the tubes.

Nevertheless, dust settlements can occur, so to avoid this rapping gear boiler cleaning equipment is used whereby a pneumatic hammer hits against the boiler tubes. This technology is successfully used for waste incinerators and a submerged arc furnace (SAF) waste heat boiler where the dust loads are comparable to or even higher than with an EAF.

Dioxins When the off-gas temperature is in the range ~250-500°C, DeNovo synthesis can occur, where destroyed dioxins and furans can recombine if the rate of gas cooling through this range is not fast enough. The allowable time is not consistently specified in the literature, but 1.5 seconds is considered acceptable.

In most steel plants water quenching towers are used to pass the critical range, mainly with good results, but in some plants additional active carbon injection is required, either because the off-gas already arrives at the quenching tower within the critical temperature range, or because dioxins have not been burned completely. There is common understanding that the off-gases must stay above 800°C for at least two seconds and EAFs with high dilution air usage often fail this condition. For these furnaces, quenching does not fully work – they prevent recombination but do not destroy existing dioxins and furans.

iRecovery level 2 waste heat boilers are designed in a way that the residence time is no longer an issue and fast quenching does not depend on water injection. On the other hand, the flow speed of the off-gas must be low enough to take care of abrasion problems. It should also be noted that waste incinerators face the same situation and found reliable solutions.

O_2 reduction

The importance of dilution air reduction has been discussed above. Theoretically a zero O_2 content downstream of the cooled duct would be ideal; in fact a value of 6% O_2 is required to guarantee complete CO combustion and minimise explosion risk.

The basic concept is to reduce dilution air entry at the fourth hole and other gaps in the duct to an amount that would end below the target value of 6% O_2. Then additional dilution air is added in a controlled way.

Three elements must be realised for this target:

- **O_2 measurement** A reliable and integrated oxygen measurement system is part of the EFSOP package from Tenova Goodfellow and which has been approved for use in the EAF environment

- **Control loop** At an early point of the waste gas duct a motor-driven flap for dilution air ingress is installed. The preferred position is at the inlet of the post combustion chamber to allow post combustion to happen at the desired place. This flap is set by a control loop with the O_2 measurement

- **Closing the duct** A challenge not to be underestimated is making the EAF off-gas duct air leakage-proof. First of all a sliding snout is placed at the first section of the waste gas duct; this element slides towards the elbow element of the furnace roof and closes the gap between furnace and duct. Expansion joints are installed between different sections of the off-gas duct.

SUMMARY AND CONCLUSIONS

In 2009, Tenova's iRecovery steam generation technology was applied to an EAF for the first time at Georgsmarienhütte GmbH, and generated great interest. Three years later the projects at Feralpi and the Hyundai plant extended the technology scope with additional innovations. For instance, whereas Georgsmarienhütte uses heat recovery down to 600°C off-gas temperature, at Feralpi heat recovery is designed down to 200°C and, with additional control of the downstream oxygen content, these features have turned the Feralpi EAF into probably the most energy efficient EAF worldwide.

For any potential customer, the decision to install the iRecovery level 1 or level 2 system depends primarily on steam demand and supply. **MS**

Carsten Born and Ralf Granderath are with Tenova RE Energy GmbH, Düsseldorf, Germany.

CONTACT: mattia.canovaro@it.tenovagroup.com