Waste heat – the biggest source for energy efficiency optimisation

Despite much design effort and technology into methods for saving energy at the input side of EAFs and reheating furnaces, there are still huge losses in off-gas and/or in the cooling water – typically 20-40%. Technology does exist to reduce these losses, but achievement is not easy. The article describes typical scenarios and their respective problems and solutions.

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Optimisation of industrial furnaces in a steelworks, namely EAFs in the melt shop and reheating type furnaces in the rolling mill, has a wide scope. However, there are only a few basic optimisation targets, including product quality, maximised output and cost reduction. Given the fact that scrap prices are not directly in the hands of the steel plant, energy costs remain the biggest cost driver that can be controlled by EAF plants.

Many steel producing countries are facing increasing energy costs and, in addition, many continue to sharpen their environmental laws. Therefore, it is no surprise that energy is the main topic of many discussions.

On the one hand, there has been good progress in reducing consumption of primary energy, including sophisticated control and measurement systems such as the Tenova iEAF©, *Figure 1* shows that improvements have declined in recent years. The values in *Figure 1* refer to the US steel industry, however such values are quite similar worldwide**[1]**.

A comparable scenario can be found in rolling mills: today, very few furnaces are not equipped with recuperators or regenerative burners and burner technology generally saw a lot of improvement during the last decade, and modern furnace control systems are widely established.

This leads to two conclusions:

- Most furnaces have already been modernised to maintain their competitiveness.
- This means that economic and/or technical limits have been achieved so it is difficult and therefore expensive to make further energy reductions once a furnace is equipped with the usual tools and systems.

Given these factors, the concept of heat recovery becomes an option. Even with high standards, approximately 30-40% of the energy input of EAFs and approximately 25-40% of the energy input of walking beam furnaces is lost (as described below), thus making heat recovery the biggest source for improvements to energy efficiency.

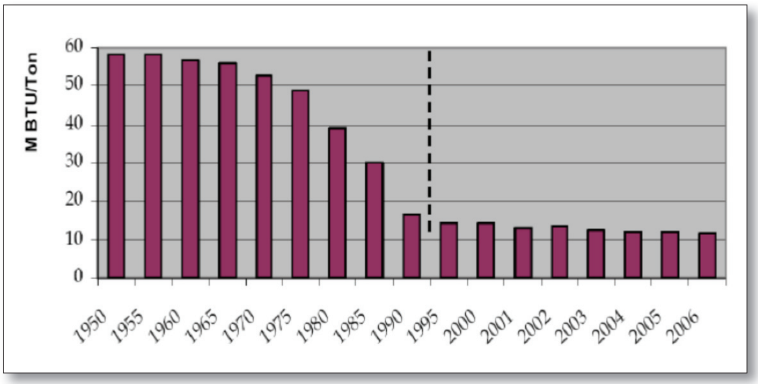

Fig 1 Trend of energy consumption per ton of steel in the US steel industry

POTENTIAL FOR EAF OFF-GAS HEAT RECOVERY

Table 1 shows the energy output of typical energy balances for various EAF types**[2]**. The energy in the waste gases is a significant proportion of the total energy, but for the classic top-charged EAF they greatly depend on the use of chemical energy, whereas furnaces with scrap preheating, such as Tenova Consteel®, have a lower value, and the DRI route has significantly higher off-gas energy content.

POTENTIAL FOR WALKING BEAM FURNACE HEAT RECOVERY

Table 2 illustrates the energy balance for a typical mid-size walking beam furnace with a capacity of 150t/h in two scenarios: a furnace with new refractory material and a modern recuperator vs one with 10% damaged refractory material and lower combustion air preheating due to old recuperators.

The biggest single source for heat recovery is the skid system, where the decision for an iRecovery® skid system is made either when the furnace is built or if it needs a major revamp. The heat recovery potential of a skid system varies significantly during a furnace life: the difference ▷

121-160t EAF	**Energy output kWh/ tls**			
	Low chemical energy input EAF	High chemical energy input EAF	Consteel	DRI
Liquid steel	385	385	385	385
Slag	50	50	50	50
Scrap preheating	0	0	50	0
Off-gases	170	240	130	260
Radiation	10	10	10	15
Cooling water	65	70	60	80
Total output	**680**	**755**	**685**	**790**

▲ Table 1 **Energy output of EAFS 80-120t tapping weight in kWh/tls**

New refractory and modern recuperators		
	Energy MW	%
Required burner power	51.5	100
Energy transferred to steel	37	72
Losses to skid system	5	10
Recovery with waste heat boiler at 350°C off-gas temperature	3.5	7
Remaining off-gas energy after boiler, temperature 200°C	4	8
Other losses	2	4
Worn refractory and older recuperators		
Required (maximum) burner power	63	100
Energy transferred to steel at max load	37	59
Losses to skid system	9	17
Recovery with waste heat boiler at 450°C off-gas temperature	6	12
Remaining off-gas energy after boiler, temperature 200°C	4.5	9
Other losses	2	4

▲ Table 2 **Example energy balance for a 150t/h walking beam furnace**

between new and worn refractory is nearly double.

The main impact on the respective values is of course the off-gas temperature at the recuperators.

Where a furnace is equipped with regenerative burners instead of recuperators, the situation is different, though heat recovery is still possible. With regenerative burners, typically 80-85% of the off-gas is led through them and arrives at the stack at ~200°C, which is unattractive for heat recovery. On the other hand, the remaining 15-20% of the off-gas still has a high temperature of 800-1,000°C, making this quite attractive for heat recovery.

TECHNOLOGY DESCRIPTION

Approved standard technology for EAF off-gas heat recovery, iRecovery®, is available from Tenova. The technology has been described elsewhere by the authors**[3]**, therefore only a schematic process outline is provided here (see *Figure 2*).

Compared to conventional cold water cooling, an iRecovery® waste gas duct is a tube–tube construction with the same look and working principle. The main difference is the pressure and temperature level inside; while cold water cooling typically uses 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.

This steam-water mix is led into a steam drum where they are separated. The steam is taken out (and replaced by condensate/fresh water), and the water goes back into the circuit.

iRecovery® waste gas ducts work with radiation heat transfer, which is efficient down to ~600°C. Below this temperature, heat transfer by convection becomes more effective. In other words, a waste heat boiler must be used to recover the energy between ~600°C and a filter inlet temperature of 180-250°C. Due to the extremely high dust load of EAF waste gas, the design of the waste heat boiler must be planned very carefully.

One main difference between the cooled duct and the waste heat boiler, is that the energy decoupling is essential – either by iRecovery® or cold water cooling – where the waste heat boiler is optional; since off-gas temperatures below 600°C do not damage mild steel, a waste heat boiler, trombone coolers or quenching can be used to recover energy.

The principle of iRecovery® skid systems for walking beam furnaces is the same as for the EAF, and the look and function of an iRecovery® skid system is very similar to cold water cooled skid systems.

While EAFs are a relatively new field of application for iRecovery®, there is a long tradition of their use in reheating furnaces. iRecovery® is the development of a technology called ECS (Evaporative Cooling System) which has been used for skid systems since the 1980s with numerous reference plants from Tenova. There are, however, a number of walking beam furnaces equipped with ECS where the operators did/do not take advantage of the generated steam.

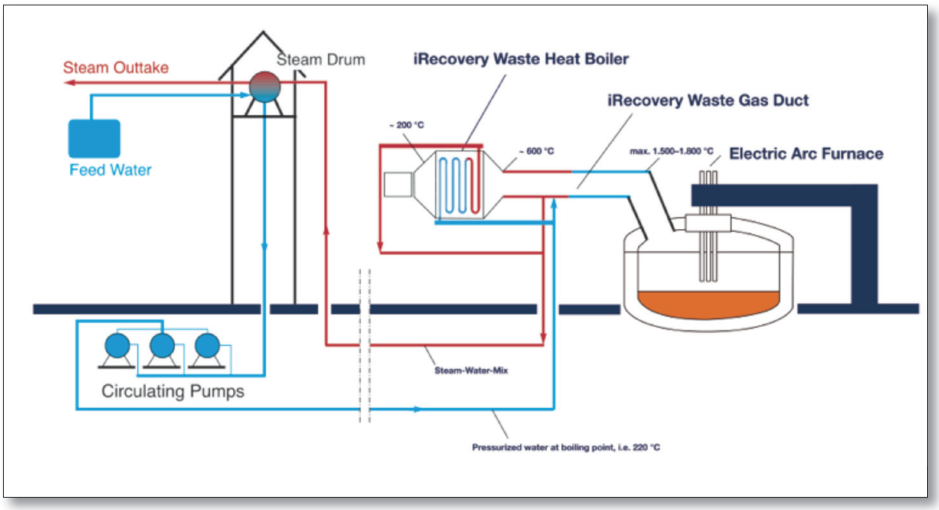

Fig 2 **Simplified schematic of an iRecovery® system (EAF)**

OPERATIONAL ASPECTS OF iRECOVERY®

A number of questions have arisen about the operational aspects of iRecovery® systems. One is the suggestion that the key advantage of heat recovery is off-set by operational disadvantages. In fact, it is the other way around – iRecovery® brings additional advantages, as illustrated below:

- No dew point problems as cooling system elements are above the dew point of sulphuric acid
- No inner corrosion of tubes, because once over 200°C, self-passivation of tubes (the Schikorr reaction) occurs
- Less thermal stress as the system works at a constant temperature during all different energy input phases
- Drastically reduced cooling water consumption as it is a closed loop system. Cooling towers, for instance, consume 3-8% of water every circuit
- In case of emergencies, iRecovery® offers more safety because it has more redundancy compared to typical cold water cooling.

ECONOMIC POTENTIAL – AN OVERVIEW

Steam use is central to success in all heat recovery projects. Different studies have concluded that technical restrictions are solvable by a combination of approaches, including integration of lower temperature heat sources.

Process steam use is the most economical solution. In some cases, plants have a steam network that provides an ‘unlimited’ amount of steam. These steam networks feed, for example, vacuum degassers, steel pickling, heating, air conditioning and oxygen production. Some big steel plants also run their own power stations and use steam from waste heat recovery to reduce fuel consumption.

In this situation, the savings calculation is easy: every tonne of steam from waste heat recovery replaces one tonne of steam formerly produced in a boiler house; and the price per tonne of steam from the boiler house is usually known.

This is the perfect scenario for heat recovery projects: steam is led to a Take Over Point (TOP), no additional infrastructure is required and amortisation is excellent. In most European countries, steam in industrial environments is valuated at ~€25/t, where ~€20/t is direct energy cost.

Unfortunately, this is the exception. In most projects, a concept for steam usage must be developed. For example, in many plants, vacuum degassing is a big steam consumer and a rule of thumb is that a VDG consumes a third of the steam produced in the level 1 (=duct) of an iRecovery® system, so the use for the remaining two-thirds must be evaluated.

Heating is another option, but two limiting factors must be taken into consideration: first, the required heating energy is (typically) also only a relatively small part of the potential from heat recovery energy; second, how many months per year will it be used? In cold regions with an 8-10 months/year heating period, it can be acceptable to have no usage of heating energy for 2-4 months/year. In warmer countries, heating energy is used much less, thus reducing payback.

Another interesting possibility is energy sales. Many industrial processes need steam for their production so if a plant is in an industrial neighbourhood, other steam sources may be available. Distances up to 2-3km are technically no problem and a steam pipeline of this length is still cheaper than a turbine. Additionally, sales revenues should be higher than revenues from power generation.

Regarding power generation, the main advantage is that it is always technically possible and there is always demand for electrical energy. The disadvantage from the economic point of view is that turbines are a major additional investment, especially if the electrical efficiency is low compared to regular power stations. Thus, power generation should only be taken into consideration when other possibilities are exhausted and a significant amount of energy is still available.

ADDITIONAL CALCULATION ELEMENTS

Greenhouse gases (GHG) If a boiler house exists on the plant and the steam output is decreased, less primary energy will be consumed, therefore less GHG will ▷

Fig 3 **iRecovery®skid system for a 200t/h walking beam furnace**

be emitted. This effect brings the possibility of selling GHG certificates on the emissions market or, if the plant is short of these certificates, to reduce the number that must be bought.

The same mechanism becomes active when steam is sold to a neighbouring factory that formerly used a boiler house. In this case the steam buyer has the certificate advantage which must be addressed during price negotiations.

GHG certificates are traded at special stock markets, and the price floats significantly. In 2012, the future price per tonne of CO_2 went up to €18.4. This compares to a tonne of steam produced with natural gas at ~€3.0.

The CO_2 price was down to €4.9 at the end of 2013 in Europe and €10.0 in California. A tonne of steam in Europe is only €0.80/t.

Although the price in the real market decreased, a survey among different companies concluded that, for internal calculations, a GHG certificate price up to €60/t CO_2 was typically used. A scientific study by Synapse Energy Economics yielded figures of $10-25 for 2020 and $40-90 for 2040. This might sound abstract and long-term, given the operation time of such furnaces, but it is part of the long-term operation cost.

However, when the decision about an investment in heat recovery technology has to fulfill a two-year ROI criteria, the CO_2 impact is currently low.

CHP If cogeneration of heat and power (CHP) is used, in some countries a bonus is paid on the regular power price. The problem mainly is whether the heat finds the necessary demand; a fuel-consuming CHP station starts and stops following the demand, while heat recovery follows the industrial process. CHP can be an attractive way of decreasing the payback time of a heat recovery project, but in many scenarios it is not suitable.

White certificates A second possibility is to gain so-called white certificates for the achieved energy saving. These certificates are issued by certifying bodies for measured energy consumption reductions and can be sold to other market participants that did not fulfil energy saving targets.

The rules for these certificates vary, even within the EU and are not even applicable in many countries. Still, it is necessary to look at these possibilities if one is targeting a heat recovery project. For example, in Italy a 4MW turbine running with heat recovery energy and which started in 2012, gained white certificate revenues of nearly €8 million, which surely made a difference to the investment decision.

SUMMARY

Today, most furnaces are already optimised in terms of energy input. There is room for further improvement, but the biggest prizes are gone, and heat recovery has become the biggest source for energy efficiency optimisation. Despite all improvements made over the years, between 25-40% of the energy input of EAFs and walking beam furnaces is lost, depending on the type and operation mode of the respective furnace.

While EAF heat recovery is relatively new (but with some reference projects), walking beam furnace heat recovery is long established. For both furnaces, steam generation from cooling water or off-gas is the first technical step.

The decision about a heat recovery project depends on steam usage. The golden rule is to use the steam directly as far as possible, however, 100% native steam usage is only feasible in very few projects. Steam sales is the second best approach and, while power generation is technically always feasible from the economic point of view, it is only the last considered option. It is always recommended to look at the option of alternate revenues, although these may not always be available. **MS**

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