Energy recovery from EAF off-gas

Considering the large amount of energy in EAF off-gas, energy recovery solutions have by far the biggest potential for improving the overall energy balance of electric steelmaking. The recovered energy can be used to satisfy internal meltshop demand or be sold to external consumers, and there are environmental benefits too.

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For decades operators of electric steelmaking plants have been well aware of the vast amount of thermal energy contained in hot off-gases. Various attempts have been made to capture this energy, but the widely varying off-gas flow and temperature caused them to abandon their efforts. Due to the steadily increasing costs of electricity meltshops, owners are now revisiting this topic, especially as local environmental restrictions regarding greenhouse-gas (GHG) emissions make these solutions even more attractive.

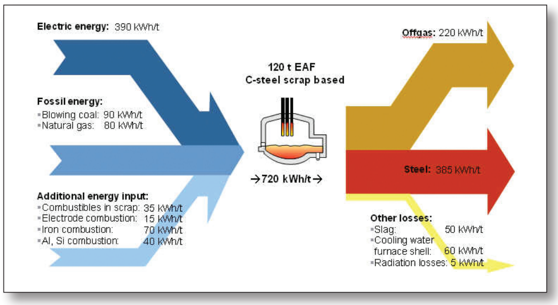

Fig 1 Specific energy balance for a typical EAF

POTENTIAL FOR OFF-GAS ENERGY RECOVERY

EAF-based steelmaking represents about a third of Europe's steel production. EAFs are quite flexible in terms of the charged materials and the steel grades produced, and they will continue to increase their share of steel production. However, EAF off-gases do not correspond directly with the energy input and the charged material in terms of flow, temperature and composition. Unlike the BOS converter, randomly occurring combustion processes and CO gas production (eg, combustion of oil from a collapsing scrap bulk) within the furnace, do not allow for energy recovery in terms of downstream CO gas recovery. Thus it is normal to maintain a large amount of excess air in the gap at the entry of the off-gas system to ensure complete combustion of the off-gas during the whole EAF melting period.

Figure 1 shows the energy balance (Sankey diagram) for a typical scrap operated EAF. The off-gas related losses amount to almost 31% of the energy inputs, so an efficient off-gas heat recovery system would contribute enormously to improving the energy balance of the process.

TAILOR-MADE HEAT RECOVERY STEAM GENERATORS (HRSG)

Like every steam boiler, an HRSG behind an EAF has to match the contradictory demand of maximum efficiency and cost-effectiveness, so it is essential to know the emissions of the furnace in advance, even if it is not yet operational. Therefore, a dynamic simulation tool, called DynEAF was developed. Based on the inputs of the furnace (electric power, charged materials, burners, etc.) and its geometric data, the program calculates the emissions, flow, temperature and off-gas composition. By comparison with measured off-gas data, DynEAF has proven its prediction accuracy, especially for scrap-based furnaces.

Once all required input parameters are calculated, the HRSG can be designed accordingly. The steam generator must be able to cope with the highest inlet temperature and off-gas flow. If the boiler is too small in terms of heat exchange area, the maximum filer inlet temperature might be exceeded. On the other hand, an oversized boiler would increase the investment costs significantly, so for this task a proprietary boiler design tool was developed. All relevant types of heat exchangers and their combination within a HRSG can be designed with its help. The results of the tool have shown good conformity with commercially available software packages.

Apart from the emissions, the layout of the melt shop is crucial to the boiler design. Two different situations are generally taken into account: The available space next to the furnace is (or is not) sufficient for the installation of a HRSG. Depending on the intended off-gas temperature at the outlet of the steam boiler, the entire cooling system is substituted, comprising water-cooled duct, quenching tower or forced draft cooler and the air-cooled connecting duct. Other than the formerly mentioned cooling devices, the steam generator behind the EAF also uses heat exchanger surfaces (tube bundles) perpendicular to the flow direction of the off-gas. This leads to improved efficiency of heat transfer and a compact boiler design.

However, sometimes there is not enough space available to situate the HRSG directly next to the furnace, which demands a horizontal duct between the drop out box for ▷

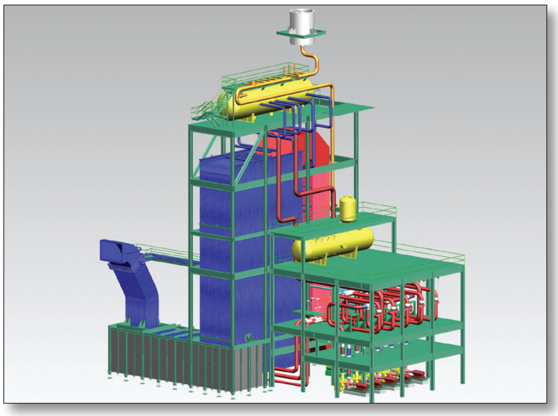

Fig 2 3D-Layout of a HRSG for a 150t DRI-based EAF situated on top of the drop out box

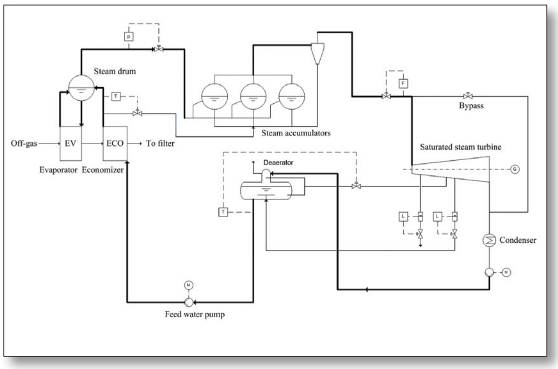

Fig 3 Process flow diagram: Electric power generation from saturated steam

the coarse dust settlement and the vertical steam generator outside the meltshop. The off-gas at the drop out box outlet is still relatively hot. To achieve maximum steam output the horizontal duct has to be designed as an evaporator, which can cause trouble with stratification of the water/steam mixture and or plugging of single pipes. A unique design for this heat exchanger section was developed which ensures a uniform flow distribution from the headers to each pipe and also sufficient gas cooling and steam production at all modes of operation of the furnace.

As mentioned above, the steam boiler could also be put right on top of the drop out box if there is enough space available next to the furnace (see *Figure 2*). Due to the high off-gas temperature under maximum load the heat transfer is dominated by radiation. As off-gas temperature decreases, the amount of heat exchanger surface perpendicular to the off-gas flow direction in the steam generator increases, and heat transfer by convection gradually begins to govern the energy exchange. The cross-current bundle heat exchangers make use of this phenomenon and help to keep the HRSG as compact as possible. Experience with forced draft cooler heat exchanger surfaces downstream of current water-cooled hot gas lines allows for an appropriate spacing between the pipes of the bundles. However, finned tubes with increased heat transfer surfaces were not implemented because of the high dust loads and the risk of clogging.

A waste heat recovery steam generator designed as above is able to turn a certain portion of the cooling water into steam. Nevertheless, the steam mass flow leaving the steam drum on top of the boiler shows the same unsteady behaviour as the off-gas enthalpy flow, but in a less erratic way. Since almost all downstream steam consumers call for a constant supply of steam, the next logical step in designing a comprehensive energy recovery system is the development of a suitable energy storage system.

LEVELLING THE RECOVERED ENERGY

There are many types of steam consumers:

- Steam turbines for power generation
- Steam ejectors for creating vacuum in VD/VOD plants
- Steam for process heating (eg, steel pickling bath, sea water desalination, pulp and paper industry)
- District heating

All of them call for different steam quality, but commonly they need a constant supply, even if it is just for a certain period of time. The Ruths steam storage for latent energy storage is well proven and widely used for energy recovery applications in the BOF steelmaking process.

ELECTRIC POWER FROM SATURATED STEAM

The system uses a turbine running on saturated steam to drive a generator for electric power generation (see *Figure 3*). Ruths buffer storages are used to level the steam production of the HRSG to provide the turbine with a constant steam mass flow at 50 bar(a). The steam boiler works at 80 bar(a) whereas the Ruths accumulators work between 80 and 50 bar(a).

The simulations of the whole heat recovery system with commercially available software resulted in a constant power production of about 7.7MW.

SUMMARY

Considering the large amount of energy in EAF off-gas, energy recovery solutions have by far the biggest potential for improving overall energy balance. The recovered energy can be used to satisfy internal meltshop demand or sold to external consumers. The indirect benefit due to the reduced demand for CO_2 certificates makes these solutions even more attractive. An energy recovery system for steam production only, is relatively easy to realise, but, due to the lack of adequate steam consumers in some meltshops, concepts recovering the energy in terms of electricity should be considered as another attractive solution. **MS**

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