# Single Bucket Telescopic furnace versus Continuous Optimised Single Shaft (COSS) furnace

*INTECO has available two types of EAF with high energy efficiency. One, the Telescopic furnace, uses the furnace height plus single bucket charging to enable the scrap to be preheated within the furnace during the pre-refining stages of the process. The other, the COSS furnace, combines the heating efficiency of shaft heating with the process benefits of continuous charging. Each process has its advantages over a standard EAF.*

**Authors:** Stefano Miani, Achim Ehle, Riccardo Gottardi, Adam Partyka and Luca Gemo
*INTECO*

EAFs are typically either bucket charged (one or two buckets per heat) or continuously charged with preheated scrap or cold or hot DRI. Single bucket charging has advantages over two bucket charging, but the furnace must be designed to cope with the greater volume of scrap. Scrap preheating systems preheat the scrap to about 600°C using waste gases and are typically either of a vertical shaft design or a horizontal conveyor design as used by Consteel. With the shaft design, scrap is preheated then charged as a batch. With the Consteel system, scrap is heated and fed continuously into the furnace.

INTECO has many years' experience in scrap preheating systems and in March 2015, it acquired the complete know-how, patents and sales rights of Fuchs Technology, both for the EAF and for the integrated scrap preheating systems technology (known under the brand name COSS). Fuchs Technology was and is considered a technology driver.

Today, INTECO has both types of energy efficient furnaces in its product portfolio – the single bucket charge 'Telescopic EAF' and the COSS furnace – so it is possible to make a comparison between the two technologies using real data from the field. In this article, two EAFs are compared: a 165t single bucket charge Telescopic EAF and a 110t tapping capacity EAF equipped with the latest COSS technical developments.

## SCRAP PREHEATING AND SHAFT DESIGN

The energy balance of an EAF indicates that the greater part of the heat losses are related to the fume enthalpy. If the aim of the scrap preheating system is the recovery of the fume enthalpy to preheat the scrap by using it as a heat exchanger, then increasing heat exchanger efficiency by increasing residence time and contact area are key performance improvers. The residence time of hot gases in contact with scrap is in direct proportion to the energy exchanged, and as a first approximation, a doubling of residence time doubles heat exchange.

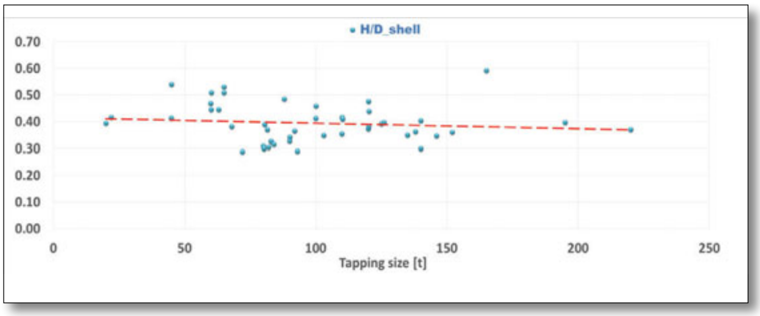


Fig 1a **H/D ratio and tap size**

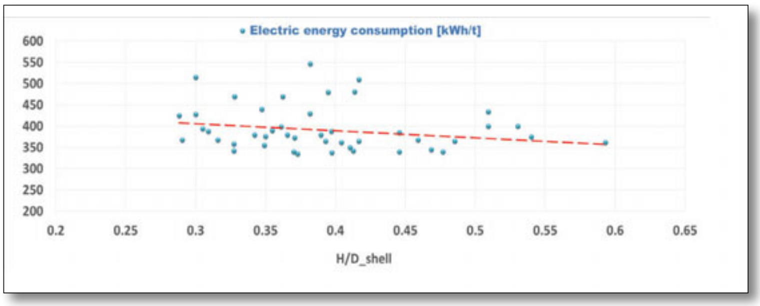


Fig 1b **Electricity consumption and H/D ratio**

As the gas residence time is linked to the furnace or to the preheating shaft design, in particular the ratio of height : diameter (H/D), this is an index that helps us to evaluate the potential efficiency of the heat transfer.

*Figures 1a and 1b* show for standard EAFs, typical H/D values and the relationship between this index and the electrical energy consumption.

This EAF population has an average ratio H/D of 0.38 and indicates that electric energy consumption is inversely

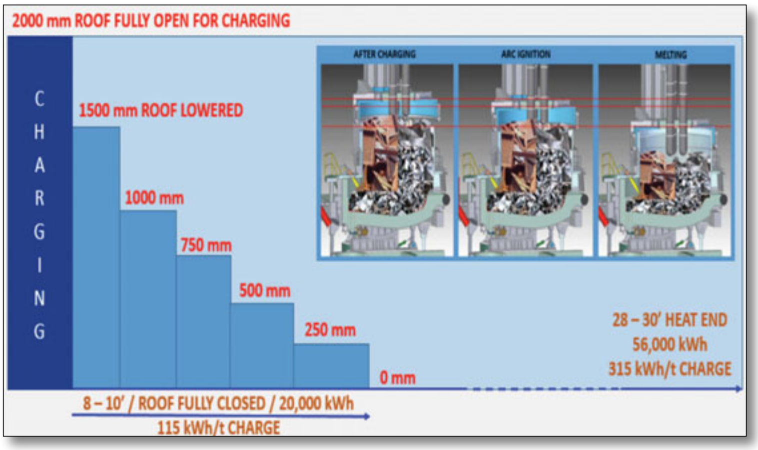

Fig 2 **Concept of the Telescopic furnace**


Fig 3 **165t Telescopic EAF and large single bucket charge operating in the Middle East**

related to H/D, illustrating the effect of greater gas residence time for preheating.

## TELESCOPIC FURNACE

Several furnaces operating with single bucket charging practice have proved to be extremely fast and highly productive steel melting tools, which can achieve tap-to-tap times of less than 30 minutes **[1] [2]**. Also, power-off times are low, typically below 7 minutes, since the furnace needs to be opened only once per heat. In addition, a single bucket charging furnace enables higher average power since charge perforation and initial melting times with unstable arcs are relatively short compared to furnace operation with multi-bucket charges.

The large furnace shell volume required for single charging results in longer off-gas residence time in the furnace and, thanks to this effect, the yield of chemical energy supplied to the furnace is better than a standard furnace design. With a high pile of scrap inside the furnace the heat generated by operation of the burners can be more efficiently transferred to the upper charge layers, creating favourable conditions for in-shell scrap preheating.

The Telescopic EAF includes some design features to overcome the problems typically associated with single bucket systems such as higher electrode consumption and breakages, as well as the necessity to manage variation in the scrap density. The maximum height of a furnace shell of an AC or DC furnace depends on its diameter and the free length of the available electrodes. Today, single charge furnaces have a shell height of 3,300 to 3,800mm and the roof is dome shaped, which is necessary to avoid contact between the water-cooled portion of the roof and the scrap at the beginning of the melting operation. The Telescopic EAF uses an electrode length much shorter than a standard single bucket furnace designed with same scrap density. This is possible because the water-cooled roof has a cylindrical portion of approximately 1.5m height and a flat, horizontal, water-cooled roof top, which is the reason that shorter electrodes, as compared to other single bucket furnaces, can be used, ie, a column length shorter by approximately 2m. Nevertheless, the construction of the telescope gantry must be very stiff, as for any single bucket charge EAF, and with the electrode column axis as close as possible to the shell in order to reduce the natural shaking of the long electrodes.

The upper shell height of the furnace is increased by the cylindrical portion of the roof, which slides over the upper shell as the scrap column decreases during operation. Together with the roof the electrode arms are also lowered. During the super heating phase, the roof rests on the upper shell as in the standard EAF. The design concept, roof/electrode movement and process changes are shown in *Figure 2*. An actual furnace is shown in *Figure 3*.

After the scrap is charged, the roof is lifted to a position where it is approximately on the same level with the upper edge of the shell. Provisions are made to allow the lower edge of the roof to move freely over the 'scrap mountain' if a change in the scrap density requires a higher scrap volume in the shell.

The total roof lift allows for a distance of approximately 2,000mm. For practical reasons, the roof should overlap with the upper shell for a few centimetres to minimise splashing during first boring. Due to the height of the cylindrical portion of the roof of approximately 1,500mm there is no contact of the scrap column with the horizontal portion of the roof even if there is a scrap mountain in the shell. The large distance between the scrap and the horizontal portion of the roof allows for an initial bore down with maximum power and long arc, increasing average power input. As soon as the scrap mountain starts to reduce, the roof with the electrode columns can be lowered to follow the diminishing scrap mountain and is able to reach a position that allows the electrode tips to reach the flat bath.

## COSS PREHEATING SYSTEM

The COSS concept **[3]** was born from the fact that scrap preheated in a shaft-like system has a much higher efficiency (approximately three times) than the Consteel system. Consteel, however, has the advantage of a flat bath operation, meaning very low electrical disturbances to the electric network (a very important fact where the short circuit power is weak) and works as a steady-state melting process.

To combine the advantages of vertical shaft and continuous feeding, Fuchs Technology developed the COSS preheating system, as shown in *Figures 4 and 5*.

A shaft is installed on a movable car next to the furnace and is connected to the furnace via a duct where, in counter-current mode, the hot fumes enter the shaft. The shaft is loaded from the top with a scrap bucket and it is sealed by a sliding gate on the top. At the base of the shaft a hydraulic pusher pushes the heated scrap into the liquid bath. For the considered study case, the shaft volume is 170m$^3$ and the pushing cycle is performed eight times. Charging is carried out with the power on and does not interrupt the furnace operation as it is not necessary to lift the electrodes. As the scrap is not directly changed via the shaft into the EAF shell, the risk of explosions linked to wet or icy scrap is eliminated.

The mass of the loaded scrap in the shaft is continuously weighed in order to control the scrap charging rate into the furnace, using a proper feed rate avoiding any risk of 'ferro-berg' formation.

During the entire period of charging and melting of scrap in the liquid heel, the liquid steel temperature is kept at 1,550–1,580°C by the electric power and the C/O injectors, similar to a flat bath operation EAF.

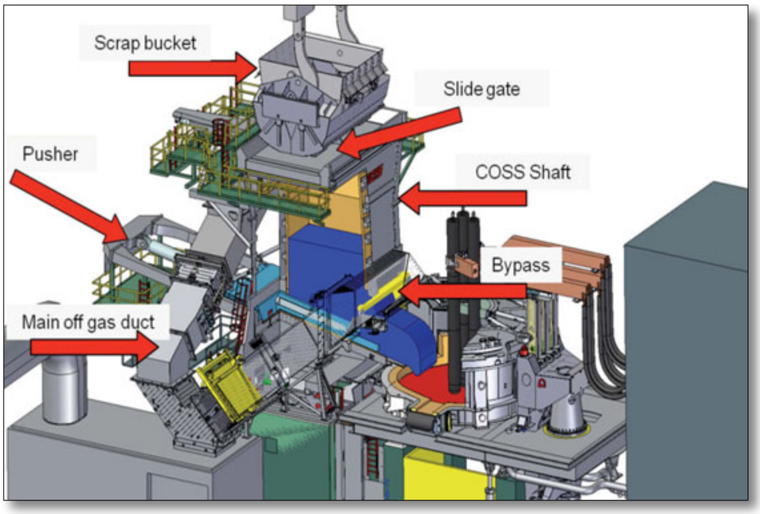


Fig 4 **The COSS scrap preheating system**

Fig 5 **110t COSS system operating in North Europe**

The gas duct is divided into two sections, the main one for scrap preheating in the shaft and a second water-cooled bypass section, stopping the hot fumes entering in the shaft. This is used, for instance, when the furnace is delayed, so avoiding the formation of liquid metallic droplets in the shaft, thus preventing the lower layer of scrap sintering, due to overheating.

One particular characteristic of the shaft is that only the lowest part containing the hottest scrap and in some critical transition parts are water cooled. With this design, no sensitive scrap impact fingers are necessary and the mechanical loads on the COSS structure are not high.

## TECHNICAL CONSIDERATIONS

**H/D** To provide a comparison of the effective hot fume residence time inside the scrap stack, the ratio between the ▷

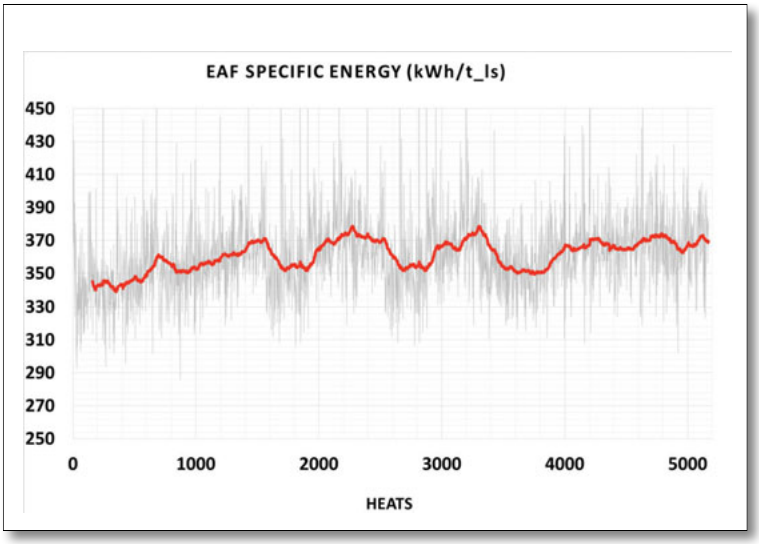


Fig 6a **Telescopic EAF – long-term electrical energy consumption**

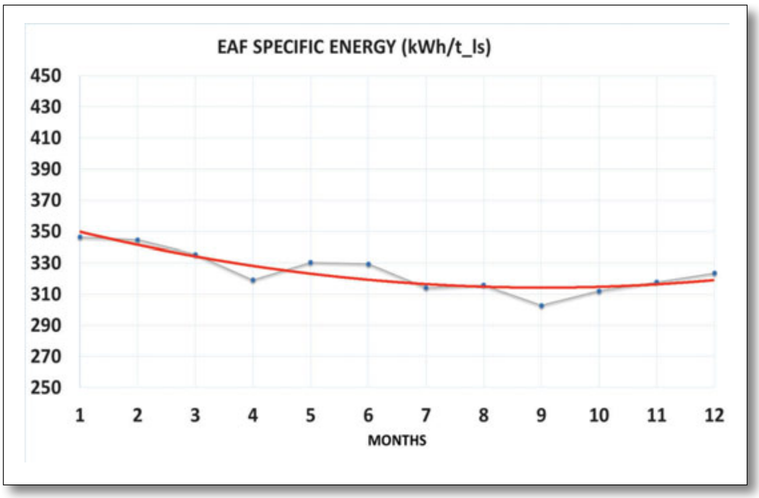


Fig 6b **COSS EAF – long-term electrical energy consumption**

height and the diameter H/D is used. For the Telescopic EAF, H is the upper shell height and D is the lower shell diameter and H/D=0.62. This compares to the average value of H/D=0.38 of the average two bucket charge furnace, so is 63% times higher and must have better heat transfer efficiency.

For the COSS, we can make similar geometrical considerations, but related to the preheating shaft instead of the EAF shell. Considering H as the height of the shaft and D as the equivalent shaft diameter (the shaft footprint is rectangular), the ratio H/D=1.12 so is 295% higher than a standard EAF.

**Scrap volume** Regarding preheating efficiency, we have to consider also that neither system is in a steady state situation since the scrap surface, acting as a virtual heat exchanger, in contact with the hot fumes is varying during the time (maximum surface when the scrap is just loaded and zero when all scrap is melted). In the Telescopic EAF, where scrap is melted in a standard way, the available scrap surface is proportionally decreasing with the meltdown time, from 100% availability in the first boring up to 0% at the beginning of the refining.

For COSS the situation is different. The scrap is batch fed into the shaft by bucket, but discharged virtually continuously, so its volume is continuously varying. When the empty volume in the shaft is sufficient, a new bucket is loaded. This means that the effective surface of the scrap available for preheating is more than the Telescopic EAF, but less than a traditional finger shaft preheater.

In a process simulation considering the generated process gas as the counter current gas exchanging the heat by convection with the scrap **[4]**, the average residence time (ART), of the hot gases in the upper shell of the Telescopic EAF or in the preheating shaft of the COSS has been calculated and compared to a traditional two bucket EAF. The ART values are 58% and 89% higher, respectively, for Telescopic EAF and COSS.

Since the melting of the scrap is in some way proportional to the meltdown time, the 'effective scrap surface' is the available scrap surface over the melting time, in contact with the hot gases (eg, for the Telescopic is 100% at melt start and 0% at end of melting; for the COSS it is 100% at melt start and 50% when the new bucket is ready to be loaded). The Effective Residence Time (ERT), defined as the contact time of the fumes with the 'effective scrap surface' of the COSS is 82% higher than the Telescopic EAF.

The result of this consideration is that the preheating efficiency of a COSS is higher than a Telescopic EAF, eg, if we estimate that in the telescopic EAF there is a 'self-scrap preheating' energy of 40kWh/t due to the heat exchange of the hot fumes with the scrap, we can expect a scrap preheating energy in the COSS of 74kWh/t. This is a difference of 34 kWh/t.

In *Table 1* the yearly average furnace performance of the two systems is indicated.

It is interesting to see that the ratio of the two electric energy consumption is Telescopic/COSS=89%, equivalent to a difference of 38kWh/t, so is quite close to the estimation made with the ERT.

In *Figure 6a and 6b* it is also interesting to see the consistency of the performance over time for both systems.

From **[5]**, we have good data of the electrical energy consumption of several EAFs as a function of oxygen consumption. With an average consumption of around 30Nm$^3$/t of oxygen, we can see that the Telescopic EAF performs better than the lower values indicated in *Figure 7*.

Since in every scrap preheating system we have to include in the energy balance, the energy input by fossil fuels necessary to reheat the waste gases up to ~750-850C for the well-known environmental issues and compliance to the BAT recommendations. This energy amount must be considered in the COSS.

The fumes have to be kept at this temperature for about 2 seconds followed by rapid quenching, which is necessary to break down the dioxins and fumes generated during scrap preheating. In general, this treatment is done with activated carbon injection into the fumes before the filters and with a temperature as low as possible.

With the COSS process, in order to be compliant with these techniques suggested by the BAT, an additional 5.7Nm$^3$/t of natural gas is required for the waste gas post combustion. It is clear that this additional energy decreases its potential for energy saving (as with all the other scrap preheating systems). If we provide 5.7Nm$^3$/t of natural gas to the Telescopic EAF with oxy-gas burners, the equivalent reduction of electrical energy consumption will be of the order of 35kWh/t – a significant amount.

## CONCLUSIONS

The conclusions as to which is the preferred process are not so black and white as might be expected. The selection of the Telescopic EAF or the COSS depends on several factors influencing the performance and operating costs, which must be carefully evaluated.

One factor in any scrap preheating system is the use of fossil fuels necessary for post combustion of the waste gases before hot quenching. This includes 4-7Nm$^3$/t of fuel in the EAF energy balance which can increase or decrease Opex depending on local circumstances. Today, this fuel consumption is considered necessary and a state-of-the-art technique suggested by the BAT. In the case of less expensive and effective techniques, such as those linked to activated carbons injected at very low temperature, the COSS must be considered a good choice.

Another influencing factor is scrap availability. If the scrap is heavy or high density, the Telescopic EAF is preferred. If the scrap is medium-to-low density, clean and without excessive tramp elements, or if the furnace is installed in countries where there is a risk of ice in the scrap, COSS has the advantage. COSS also has the advantage when the short circuit power of the network is particularly weak. Thanks to the continuous scrap feeding, the electric arc distortion is very much limited with a big benefit for flicker. Also, if the tap-to-tap time is not particularly short, the effect of scrap preheating becomes more efficient.

In the case of revamping with building height constraints and limited budget, the Telescopic EAF could be considered the right solution. MS

| Parameter | Telescopic EAF | COSS EAF |
|---|---|---|
| Capacity, t | 165 | 105 |
| Transformer, MVA | 150 | 80 |
| Tap-to-tap time, min | 41 | 59 |
| Power-on time, min | 32 | 43 |
| Oxygen, Nm$^3$/t | 27 | 28 |
| Gas, Nm$^3$/t | 3.2 | 4.3 |
| Total carbon, kg/t | 15 | 12 |
| Electricity consumption, kWh/t | 362 | 324 |
| Electrode consumption, kg/t | 0.9 | 1.0 |
| Gas for post combustion, Nm$^3$/t | 0 | 5.7 |

Table 1 **Yearly performance data of Telescopic and COSS EAFs**

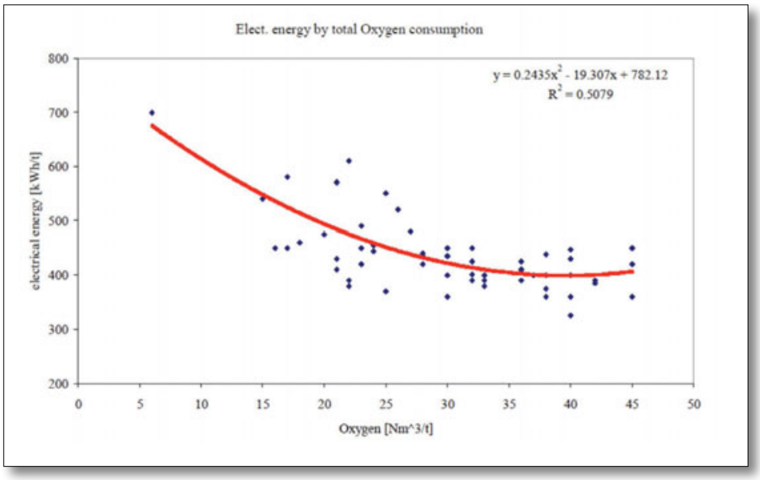


Fig 7 **Electrical energy, kWh/t versus total oxygen from GrafTech's technical database [5]**

*Stefano Miani, Achim Ehle, Riccardo Gottardi, Adam Partyka and Luca Gemo are with INTECO melting and casting technologies GmbH, Bruck an der Mur, Austria.*

**CONTACT:** stefano.miani@inteco.at

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