SINGLE BUCKET CHARGING PRACTICE
WITH TELESCOPIC EAF ROOF CLOSURE

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Single bucket charging – except for a pure savings with only one roof opening per heat and limited energy losses – allows for more efficient in-shell scrap preheating through the heat generated by the burners and oxygen injection and higher degree of CO post-combustion thanks to enlarged shell volume.

A furnace with telescopic roof closure has been invented by Fuchs Technology and installed at YOLBULAN BAŞTUG melt shop in Turkey with the main target to allow for single bucket charge even with low charge density. The unique feature of this furnace is a possibility of gradual shell volume decrease in function of the melting process progress reducing energy losses to water-cooled panels. Thanks to decrease of the electrode hot length also a substantial savings in the electrode consumption can be seen.

After 5 years of successful operation, Yolbulan searched for further increase of the EAF productivity in the present market conditions with continuous decrease of scrap quality. In August 2015, the EAF has been equipped with a new larger shell and bigger transformer. INTECO, being a new owner of Fuchs Technology was been invited to optimize the melting process parameters of the furnace working in new conditions.

The paper reveals the experience of the optimization work done on site in common with the presentation of the achieved results compared with the furnace operation in the original configuration.

KEYWORDS: SINGLE BUCKET OPERATION – HIGHLY PRODUCTIVE EAF UNIT – SCRAP PREHEATING – HEAT TRANSFER EFFICIENCY – OPTIMIZATION OF MELTING PROCESS

INTRODUCTION

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 35 minutes and power on times below 25 minutes [1 - 3]. Also power off times are respectively shorter since the furnace needs to be open only one time per heat. Besides, the single bucket charging furnace can work with higher average power since charge perforation and initial melting with unstable arcs are relatively short compared to the furnace operation with multi-bucket charge.

Large furnace shell volume required for single charging results in much longer off-gas residence time in the furnace. Thanks to this effect, the yield of chemical energy supplied to the furnace is apparently better than in case of standard furnace design. With a high pile of metallic charge inside the furnace shell, 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.

Minimum required charge density of 0.75 – 0.80 t/m³ used to be a typically applied limit for single bucket charging furnace design and decision regarding its shell diameter, height and resulting volume. Above certain limit, the influence of XXL shell size and resulting volume may simply ruin the single bucket operational benefits. For instance, the extended area of water-cooled panels drastically increases energy losses during flat bath operation.

In the present situation on the international scrap market, higher density scrap qualities are not cost effective anymore. Steelmakers are forced to work with lower density charges to keep raw material costs under control. Various attempts focused on utilization of alternative high density iron-bearing materials (pig iron, HBI) to make up more compact charges can be seen. However, the furnace performance can be reduced due to lower heat conductivity and poor heat transfer efficiency of various scrap alternatives.

If the charge density is too low, the furnace designed for single bucket operation is forced to work as standard furnace with 2-bucket charge. In most of the cases, its performance can be worse a standard furnace, especially when the large shell volume is not sufficiently filled with charge.

A furnace designed with a possibility to adjust its charging volume in function of available charge density is a next step of development, which apparently reduces known shortcomings of a standard single charge EAF.
TELESCOPIC FURNACE

Background
The main idea standing behind the design of the telescopic furnace or – to be more precise – the furnace with telescopic roof closure was to allow for flexible shell charging volume.

Key points of this special EAF design are as follows:

- Utilization of single bucket with average charge density even below 0.60 t/m³ without expanding shell diameter and height above acceptable limits.
- Possibility to reduce exposed area of shell walls in function of melting progress decreasing furnace thermal losses and increasing thermal efficiency.
- Possibility to reduce electrode columns length decreasing elevated risk of accidental breakages which is typical for single charge EAF working with extra-long columns required to match extended shell height.
- Flexibility in using relatively low average charge density in function of the actual situation at local scrap markets with less limitations to accept all possible variations.

The Telescopic EAF has been invented by Fuchs Technology AG – the company well-known for its very innovative approach and revolutionary solutions applied within the EAF technology [4].

The first Telescopic EAF designed for 140 t average tap weight and 1.4 million t of annual output was commissioned in the new melt shop of Yolbulan Baştug at Osmaniye Industrial Zone in Turkey in 2010.

In 2015, Fuchs Technology AS was taken over by INTECO Melting & Casting Technologies GmbH which continues to work intensively on further optimization of the design and process technology related to this unique EAF solution.

Telescopic EAF Design
The maximum height of a standard AC or DC furnace is selected in function of its diameter (which is determined by the liquid steel capacity and metal bath depth/area) and available space to lift the electrode columns.

The shell height of a standard single charge furnaces vary between 3,300 and 4,000 mm. The roof has a dome-shaped design required to avoid contact between water-cooled roof panels at the beginning of melting during arc ignition. The height of the dome-shaped additionally increases electrode column length. In the Telescope EAF the electrode column length can be significantly shorter than for a single charge EAF of the comparable volume and capacity. Additional features allow the Telescope EAF to accept about 25% lower charge density than similar single charge furnace. This is possible thanks to completely flat roof design which – being in upper position – creates an additional furnace volume, the so called telescopic extension. During melting, the roof gradually slides down to the lower, fully closed position resulting in almost complete overlapping of the roof and part of the upper shell (Fig. 1). The lifting systems for the gantry/roof and electrode are fully independent (Fig. 2). This solution allows the electrodes to follow continuously decreasing height of the charge pile in the furnace down to flat bath condition.

Fig.1 – Roof and Upper Shell Overlapping
Fig.2 – Independent Lifting Systems
Telescopic EAF Feature
Larger distance between the top of the scrap pile and the horizontal part of the roof allows for an initial charge bore down with higher power and longer arcs, increasing the average power input. As soon as the scrap mountain starts to melt, the roof with the electrode columns can be lowered to follow the gradual charge volume reduction. The complete cycle of telescope movement between the upper closing position after charging and fully closed position reached after 30 – 40% of the power on time is illustrated below (Fig. 3).

Fig.3 – EAF Telescope Roof Closing Sequence

In the lowest roof and electrode arms positions it is still possible to continue arcing on the flat bath level even if the overall length of the electrode columns is similar to the standard EAF design.

Telescope EAF Advantages
The main proven advantages of the Telescopic EAF solution can be highlighted as follows:
- Almost unlimited flexibility in accepting fluctuations of the charge density better matching the availability and the actual scrap market conditions.
- Successful single bucket operation with average charge density close to 0.55 m³/t.
- Definitively lower scrap costs compared to other single bucket EAF solutions.
- Absolutely higher efficiency compared to standard EAF operating with similar scrap quality and multi-bucket charges.
- Improved heat transfer efficiency and higher yield of chemical energy speeding up the melting process.
- Reduction of the specific electrical energy consumption thanks to in-shell scrap preheating during melting.
- Reduced emissions and lower impact on the environments.
- High productivity with lower fixed cost.
- Clearly visible conversion costs and shorter return of investment.
- Less electrode breakage occurrences compared to other single bucket furnaces thanks to shorter columns and reduced dynamic forces.

Standard EAF can be easily revamped into Telescope EAF operating with single bucket charge or at least with reduced number of charges per heat. Local melt shop conditions such as height of existing buildings and elevation of the charging crane rails as well as charging crane capacity are practically the only limits to decide whether a single bucket charge can be considered. Nevertheless even in case of 2-bucket operation there will be a clear advantage of complete elimination of scrap pressing after charging what improves working time utilization.

Last but not least – conversion into Telescope EAF can done at relatively low costs.

YOLBULAN EAF INITIAL STATUS
The Yolbulan EAF was originally designed for average tapping weight of 140 t and full liquid steel capacity of 165 t with average hot heel weight of 25 t. The useful shell volume (with 8,500 mm diameter x 5,400 mm height) was about 300 m³ and allowed to operate with single bucket charge using scrap mix with average density of minimum 0.58 t/m³.
During the following years of operation, the tapping capacity of this furnace was gradually increased to 155 t of liquid steel aiming on the melt shop output at the level 1.6 million ton of good billets per year. Increase of the tapping weight required to increase the weight of the charge as well. With unchanged shell volume, the scrap mix density allowing for single bucket charge increased to a minimum of 0.62 t/m³.

Furnace charges are typically prepared using more expensive higher density scrap qualities (imported from USA, Canada and West European countries) and low density (0.3 – 0.4 t/m³) grades available on domestic market or imported from neighbouring countries. Continuous charge cost optimization as well as availability of higher density imported scrap grades have a great influence on the resulting density of the EAF charge. If the minimum charge density cannot be guaranteed, the furnace has to operate with 2-bucket charge with a consequent productivity loss and worse performance results.

For instance, within the period between the 1st April and the 31st July, 2015 the average number of bucket per heats was 1.63 what means that the share of single bucket charges was about 40% only. The difference among single and 2-bucket operation can be clearly seen comparing furnace productivity and specific energy consumption (Fig. 4).

As far as the energy consumption is concerned, it is necessary to mention that the specific consumption of gas (2.5 Nm³/t good billets), oxygen (25 Nm³/t good billets) and carbon (5 kg/t good billets injected and 12 kg/t good billets of charged carbon) were almost the same for single and 2-bucket charges. The outcome of the result comparison leads to the conclusion that EAF operation with the single bucket charge is far more efficient. Since the observed difference is in the range of 40 – 70 kWh/t, i.e. much more than in case of a standard furnace design, it can be also concluded that in case of single bucket operation the EAF thermal efficiency is much higher – thanks to an obvious effect of in-shell charge preheating by the chemical energy supplied to the furnace (more efficient transfer of heat to upper charge layers during burner operation phase and carbon monoxide combustion combined with longer residence time of the whole charge batch in the furnace).

In case of 2-bucket operation, the available time of heat transfer to scrap is relatively shorter and that explains less efficient off-gas heat recovery and transfer.

MELTING TOOLS

Electric Power
The furnace has been originally equipped with 150 MVA transformer (Areva) connected to 34.5 kV primary line. On the secondary side with voltage range 951 – 1455 V / 16 taps it is theoretically possible to obtain close to 120 MW of active melting power. In practical operation, the average active power value was limited to about 107 MW due to problems with arc stability and resulting power losses in the middle of the melting phase.

The EAF utilizes also 45 MVA reactor (Areva) with 12 taps and 2.4 ohm reactance at the highest tap. On-load tap changer of the reactor additionally enlarges the range of available power input set points.

The electrodes (710 mm diameter / 1,400 mm pitch circle diameter) are controlled through FineArc regulation system developed and installed by Fuchs.

Power input program is managed by means of a dedicated HMI page on which transformer / reactor settings are inserted in a sequence program covering 10 steps for the first bucket and 6 steps for the second bucket melting.
The end of each step is defined by specific energy value related to the consumed energy divided by the actual weights of charged buckets. The energy triggers (program steps) of the power input program are also utilized for management of the chemical energy system operation.

**Chemical Power**

The furnace was originally equipped with five combined coherent burners and oxygen injectors together with slag door manipulator with consumable lances (2 x oxygen + 1 x carbon). Three carbon injection points were additionally installed on the shell panels. All carbon lines were connected to a single injection machine.

Such arrangement of chemical energy tools showed to be inefficient, mainly due to difficulties in proper balance among the furnace cold and hot spots. Melting was not uniform with frequent caving and unstable arcs resulting in relative low average power. Scrap was almost regularly sticking to the upper WC-panels and later falling down in the beginning of superheating was causing frequent electrode breakages. In cold spots, heavy slag skulls were accumulated causing a gradual decrease of the furnace volume and serious problems during charging. Operation of carbon injection system using only one injection machine was not allowing to control the flow rates separately. In practice, the major quantity of carbon was consumed by the slag door lance which had the simplest and shortest connection to the injection machine. The wall injectors connected through more complicated and longer distant lines were not receiving enough carbon due to significant transport air pressure drops on the way from the injection machine to the injection point.

The unsatisfactory performance of the chemical energy package demanded to implement necessary modifications. The number of coherent gas/oxygen injectors was increased to eight units. Each carbon injection lance has been connected to separate injection machine allowing for individual carbon flow control. The actual layout of the injectors on the furnace shell is shown below (Fig. 5).

![Fig. 5 – Chemical Energy Melting Tools Distribution on the Furnace](image)

The coherent injectors installed on the shell walls are located in the centre axis of the dedicated WC-panels. This has been decided for the WC panel inter-changeability. Two injectors installed on the horizontal panel covering the EBT shell extension are located symmetrically on both sides of the tap hole axis. All injectors are of the same design and allow to utilize up to 5 MW of burner power (with 500 Nm³/h of natural gas and 1000 Nm³/h of oxygen) and up to 2000 Nm³/h of oxygen in the supersonic lancing mode. Carbon is injected through shell walls at three points (each one with flow rate of up to 80 kg/min). The location of carbon injection points was decided to achieve better distribution of injected carbon thanks to the direction of the liquid bath rotation. Carbon injection through the door lance is used as a back-up for the wall injectors. Injection of oxygen through consumable door lance is limited to melting of scrap pieces resting on the slag door sill (200 – 300 Nm³ of oxygen per heat).

**PROBLEMS IDENTIFIED WITH YOLBULAN EAF OPERATION**

INTECO experts visited Yolbulan in May, 2015 with the aim to analyse the furnace performance and to define possible improvements to be implemented after some furnace modifications scheduled for August 2015.
The time spent on Yolbulan site was very short with a limited number of heats which could be monitored directly. Therefore evaluation of the EAF operation has been backed up with detailed analysis of the EAF performance data covering the period before and after the visit with the results of almost 2000 consecutive heats.

The main conclusions from the analysis of the EAF operations leading to recommendations for further improvements can be summarized as follows:

- The telescopic EAF concept proved to be successful. The specific energy consumption was significantly lower compared to a standard EAF operating with similar structure of charge materials and similar chemical energy input (specific gas, oxygen and carbon consumptions).
- The negative aspect of the actual operations was related to significant dispersion of the observed results. Consecutive heats produced with the same charge recipes indicated the specific energy consumption deviations exceeding 50 kWh/t. At that point it was necessary to identify possible reasons and to reduce those deviations to the level of less than 20 kWh/t.
- The actual melting rate of the furnace was below the optimum level and the main identified reason was utilization of the coherent injectors in burner mode at less than 40% of the available power (specific gas consumption below 2.0 Nm³/t) generating less heat that could be transferred to scrap for in-shell preheating [5]. Insufficient burner power and early beginning of oxygen lancing was resulting in frequent caving phenomena and arc disconnections when scrap pile starts to move down inside the shell (Fig. 6). The use of higher burner power allows for melting of scrap from the walls to the centre of the furnace in more intense way resulting in quite uniform sliding of the scrap layers.
- More precise coordination between the electrical and chemical power supply could significantly improve melting rate and the EAF productivity [6]. It was also concluded that the electrical power input needed to be revised with the focus on the average power increase.
- Much lower electrode consumption thanks to gradual reduction of the electrode hot length during melting and significantly lower side oxidation rate is another clear advantage of the telescopic EAF. It was considered that possible improvement of the melting behaviour with more uniform conditions should also reduce the actual occurrence of the electrode breakages. Except for pure cost saving, less electrode breakages could result in operational time savings.

![Graph](image)

**Fig. 6** – Typical Caving Phenomena Observed in the Middle of Melting Time

Already during the visit, some modifications into the burner operation mode had been introduced increasing the burner power from 3 MW to 4 NW with simultaneous extension of the burner operation time and further adjustment of individual burner power input focused on more uniform melting across the whole shell volume. Increase of the oxygen consumption in burner mode required to reduce lance oxygen consumption in order to maintain the total consumed oxygen below 30 Nm³/t of billets. Yolbulan defined this condition as a very critical one aiming to maintain the yield of good billets from charge at the level close to 90%.

It was clearly stated that future furnace melting process optimization cannot be based on simple replacement of electrical energy by higher oxygen consumption.

Some changes had been also introduced into electrical profile aiming on higher average power per heat and power on time reduction.

The introduced changes improved furnace performance, what can be seen on the graphs showing long term specific energy consumption trends (Fig. 7).
It can be seen that the gas consumption increase was a key factor allowing to stabilize the trend of decreasing energy consumption. Except for direct scrap melting with burner flames, the off-gas temperatures could be increased increasing the intensity of in-shell scrap preheating. Minor variations of the oxygen consumption practically had no influence on results. It should be mentioned, that the presented results were not filtered to eliminate the influence of other parameters on the specific energy consumption.

**SCRAP BUCKET LOADING AND PREHEATING EFFICIENCY**

Better understanding of heat transfer phenomena between the combustion gas and the steel scrap can greatly improve the melting process efficiency - for example by determining the time at which the heating efficiency drops below economically accepted levels and/or by determining the best scrap type, size and density to charge near the burners for making use of the in-shell preheating effect.

Numerous studies have been conducted to evaluate efficiency of scrap preheating. For instance, the graph below (Fig. 8) indicated the differences in the temperatures of various scrap types scrap above the oxy-gas burner operating with a power of 4 MW.

On the base of practical experience some valuable observations can be made:

- Scrap temperature increases to maximum after about 8 minutes of burner operating time; efficiency of preheating at that moment is 85 – 90%.
- Scrap type, its density / shape / specific surface have a significant influence on the achieved preheating temperature (+ 50°C higher temperature for HMS1 scrap compared to small size shredded scrap).
- Smaller size scrap captures the heat more efficiently because of a greater surface to volume area.
- If more heat is transferred to the scrap, the off-gas temperature will be lower.

It was frequently observed that the heat penetrates more deeply as the scrap heats over the time. Also, as expected, more burner power produces more heating. Based on the off-gas temperature monitoring it can be concluded that heating is more effective (in sense of higher temperature achieved) for smaller size scrap. With large size scrap, the range of pre-heated area compared to the whole charge volume is bigger due to more easy off-gas flow through the scrap layer. This can be confirmed by examples of the heat distribution inside the EAF shell charged with different scrap types (Fig. 9).
At this point, it can be concluded that loading of the scrap bucket with different scrap qualities should be optimized in view of the combustion gas flow through the charge volume and expected pre-heating efficiency, which additionally can be enhanced by the strong chimney effect through air inflow from the slag door to the roof 4th hole.

NON-UNIFORM SCRAP MELTING

Late or non-uniform melting of scrap is a significant problem for the fast operating EAF designed with large shell volume. This usually takes place with melting of large and compacted scrap pieces, such as bundles, crop-ends, ingots, ladle or tundish skulls etc. EAF productivity suffers due to extra superheating time. Extended superheating times are directly reflected in higher energy consumption due to losses to largely exposed area of WC panels. The problem of non-uniform scrap melting decreases with increasing superheat of liquid bath and can also be reduced with increasing efficiency of scrap preheating and proper set-up of the available melting tools.

AUGUST 2015 EAF UPGRADE WITH FURTHER PROCESS OPTIMIZATION

The limited upgrade of the furnace carried out between the 2nd and 18th August, 2015 was focused on partial solving of the problems resulting from the tap weight increase above the original design. The diameter of the lower shell was increased to 8700 mm allowing for 200 t of liquid steel capacity (160 t of tap weight with 40 t of hot heel). The diameter of the roof (8500 mm) has not been changed. The upper shell cage needed to be modified to match the new shell diameter at the split flange level and the existing roof diameter. This modification resulted in a slight inclination of the WC-panels and also modified the angle of the wall injector installation. The installation points for the injectors were maintained the same as with the previous shell design. The new shape of the upper shell caused also some increase of the shell volume up to 330 m³ allowing to operate with single bucket charge with limiting charge density of 0.56 t/m³. Additionally, the new 165 MVA transformer replaced the old one. Furnace reactor and electrode regulation system have not been modified.

EAF Start-up and Trial Testing

The first heat after upgrade was tapped on the 18th August. On the next day the furnace entered into regular production. Optimization of the operating parameters (planned for about 200 trial heats) started at the same time with the furnace gradually reaching higher thermal stability. The initial days were focused on a proper selection of the transformer and reactor settings leading to power on time reduction. This was already achieved more less after 45 heats resulting in a record result of 28 minutes per heat (Fig. 10).
Since that moment, the power on times stabilized at the average level of 30 minutes with the average power above 115 MW. With shorter power on times, the time available for chemical power input decreased as well. The gas, oxygen and carbon flow rates needed to be adjusted continuously to ensure minimum consumptions resulting from calculated energy balances without exceeding the limit of the total oxygen consumption of less than 30 Nm$^3$/t of good billets. As it can be seen, the average oxygen and gas consumption could be maintained at relatively stable levels (Fig. 11).

Simultaneously trials with alternative bucket loading patterns were carried out to find out optimum configuration. The trends for specific energy consumption taken as process efficiency measure are shown below (Fig. 12).

The presented results need to be addressed with regard to observed deviations among the individual heat results.

Yolbulan performance values are related to the actual good billet weight which changes from heat to heat. For instance with the average good billet weight of 157.1 t/heat the minimum recorded weight was 100.6 t/heat, the maximum weight was 180.3 t/heat resulting in a standard deviation of 13.3 t/heat. This variations were caused by so called “billet migration” from one heat to another related to erratic marking with improper heat number.

Low quality of scrap demands to increase lime consumption which actually is definitively higher than the EAF steelmaking average (30 – 35 kg/t). This additional lime increases the specific energy consumption in the range of 20 – 25 kWh/t.

**Long Term Results After EAF Upgrade and Process Optimisation**

After initial process parameter optimization and establishment of stable operational conditions, Yolbulan was continuing optimization of melting process parameters – focused mainly on further improvement of charge yield. Due to this concern the total oxygen consumption was reduced by almost 4 Nm$^3$/t following the rule “less but more efficient”. The yield improvement target was achieved indicating average value of 90.2 % which is an outstanding result for relatively low scrap quality.

Lower oxygen consumption caused a slight increase of the specific energy consumption by almost 8 kWh/t.
The comparison of the EAF performance data before and after furnace upgrade with completed process optimization is presented below.

**Tab. 1 – Single Charge Performance Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Billet Weight t/heat</th>
<th>Energy kWh/t billets</th>
<th>O2 Nm³/t billets</th>
<th>Gas Nm³/t billets</th>
<th>Carbon kg/t billet</th>
<th>Average Power MW</th>
<th>Power On Time min</th>
<th>Output t/h billet</th>
<th>Charge to billet yield %</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEFORE</td>
<td>153.6</td>
<td>394.7</td>
<td>28.4</td>
<td>3.14</td>
<td>15.2</td>
<td>108.6</td>
<td>32.9</td>
<td>213.9</td>
<td>89.8</td>
</tr>
<tr>
<td>AFTER</td>
<td>157.2</td>
<td>386.9</td>
<td>24.6</td>
<td>3.52</td>
<td>17.4</td>
<td>112.0</td>
<td>30.9</td>
<td>225.1</td>
<td>90.2</td>
</tr>
</tbody>
</table>

It should be noted that the furnace operation reached very stable level. The standard deviation of the specific energy consumption was reduced by half from 40 to 20 kWh/t. Optimized melting conditions and reduced caving phenomena drastically decreased the number of electrode breakages from average 8 to 4 times a month. The specific electrode consumption – including the weight of broken pieces remains extremely low in the range of 0.85 – 0.91 kg/t of billets. The percentage of heats with single bucket charge increased from 40 to 54%.

**FURTHER PLANNING**

It has been decided that the future actions focused on the Yolbulan EAF efficiency improvements will concentrate around the following issues:

- Trials with submerged carbon injection for better carbon-oxygen balance control and further yield improvement.
- Trials with lime injection through the shell walls with the aim to decrease lime volume in charging buckets.
- Optimization of the Fume Treatment System aimed on increase of off-gas residence time inside the shell and higher yield of in-shell scrap preheating.

**CONCLUSIONS**

The main conclusions related to the Telescope EAF design and operational features can be expressed as follows:

- The Telescope EAF represents higher efficiency than other single charge furnaces.
- Particular furnace design allowed for partial elimination of negative aspects related to large volume and height of the shell.
- In-shell charge preheating efficiency entirely depends on proper set-up of electrical and chemical energy input parameters.
- The influence of scrap quality on the furnace performance is clearly visible and can be influenced by optimized scrap bucket filling recipes.

**REFERENCES**