Chapter 2
Implementation of New Technology

Abstract Advantages and disadvantages of conveyor and shaft furnaces using the new technology and operating with flat bath are examined. Basic performances of these furnaces are compared with those of modern EAFs. Furnaces with flat bath having a number of important advantages, however, lag behind modern EAFs in productivity and in electrical energy consumption as well. In addition, shaft furnaces have very serious problems concerning environment.

Keywords Conveyor furnaces · Shaft furnaces with fingers · Shaft furnaces with pushers · Flat bath · Comparison of furnace performances · Scrap melting rate in liquid metal · Scrap charging rate · Environment regularities · Decomposition of dioxins and furans

2.1 Predecessors

Technology of continuous scrap charging into flat bath was developed and implemented by J.A. Vollomy who, in the late 1990s, built the first conveyor furnace Consteel [1]. In 2007, G. Fuchs adapted this technology for use in his shaft furnaces by placing the shaft with scrap alongside the EAF and by equipping the shaft with hydraulic pusher [2]. These breakthrough innovations as well as the other innovations have predecessors and very informative history.

In the late 1960s, M.A. Glinkov proposed and tried out continuous scrap charging in 600-t open-hearth furnaces at several plants in Russia and Ukraine. The furnaces operated on metal-charge with about 60 % hot metal content and with intense oxygen bath blowing. The new technology became known as scrap-oxygen process. The scrap was charged, as usual, by molds through the furnace windows after hot metal charging. Under the conditions of open-hearth furnaces, the new process did not demonstrate any advantages, but tremendously hindered production management of the open-hearth shops. That is why the try-outs of this method have been stopped and have never resumed.
In 1961 in West Germany, M. Tring created direct flow recuperative furnace with productivity 10 t/h for semi-finished product melting [3]. The furnace design included the elements resembling some fundamental key features of modern conveyor and shaft furnaces with continuous scrap charging. The scrap was moved by pushers (1) to the melting zone (2), equipped with burners (3) on the sloping stepped bottom (4) of the chamber (5) adjacent to the bath (6), Fig. 2.1. In the process, the scrap was heated by gases being removed from the melting zone (2) through the chamber (5) into the gas duct (7). Air for the burners was preheated in the recuperator. Industrial tests have revealed essential shortcomings of these furnaces and they have not been developed further.

In 1980s–1990s, so called energy optimizing furnaces (EOF) developed by Pains have been operating in Brazil [4]. The freeboard shape of these furnaces resembled that of EAF except for the fact that they did not have electrodes since they used energy of fuel instead of electrical energy. The shaft scrap preheater was placed above the central part of water-cooled furnace roof. The off-gases were removed from the freeboard through this shaft, Fig. 2.2. The shaft was divided from top to bottom into several chambers by the movable water-cooled fingers. A portion of scrap was placed on the fingers in each chamber. The total mass of scrap in all chambers was equivalent to the amount of scrap needed for one heat.

The burners were installed under the lower chamber. These burners provided the additional amount of heat required for high-temperature scrap heating. When the fingers in any of the chambers moved apart, the scrap dropped onto the fingers of the chamber below. The scrap from the lower chamber dropped into the furnace.
The partitioned shaft scrap preheater makes the EOFs quite close analogs of modern conveyor and shaft furnaces. The similarity of EOFs and conveyor EAFs is even stronger due to the fact that the shaft preheater divided into several chambers is, essentially, a kind of the vertical conveyor which enables charging of scrap into the furnace by separate small portions following each other.

The preheater functions in the following manner. When each new heat starts, all the scrap heated during the previous heat is already in the preheater. The scrap in the lower chamber is preheated to the maximum required temperature, whereas in the upper chambers the temperature is decreasing. The scrap in the top chamber has the lowest temperature. The heat starts with discharging scrap from the lower chamber into the furnace. Then the scrap is transferred, in order, from each chamber into the next chamber below. The scrap transferred into the lowest chamber is being further heated there during a certain short period of time, while the empty uppermost chamber is being charged with the cold scrap. As soon as the scrap in the lower chamber is preheated to the maximum required temperature, it is discharged into the furnace, and the next cycle of the scrap transfer from the top to the bottom and charging of upper chamber with a new portion of scrap is repeated. The total required for a heat amount of scrap preheated to the maximum required temperature is charged into the furnace in several cycles, depending on the number of chambers. Concurrently with finishing of charging the scrap into the furnace, the preheater is filled with scrap for the next heat.
For scrap melting and, to a far lesser degree, for liquid metal heating, oxygen-fuel burners were used in EOFs. Oxygen was used not only in the burners, but for bath blowing and for CO post-combustion in freeboard as well. Total oxygen flow rate was 60–80 m³/t. Fuel consumption (expressed in terms of fuel equivalent) was about 10 kg/t. Such low fuel consumption could be explained by scrap preheating to 800–850 °C as well as by high content of hot metal in charge.

Heating of metal to tapping temperatures was carried out mainly by means of physical and chemical heat of hot metal; its content in metal charge was usually 50–60 %. Increasing a share of scrap in a charge to more than 50 % resulted in serious difficulties due to very low effectiveness of heating of liquid bath by burners. There was sharp increase in tap-to-tap time which on EOF usually amounted to about 1 h. The attempts to process in the EOFs a charge consisting mainly of scrap were unsuccessful. Relatively low productivity of the EOFs, a need to use hot metal in large quantities, and some other factors made it impossible for these steelmaking units to compete with EAFs. As a result, they were used to a very limited extent.

More successful was an attempt to implement continuous scrap charging combined with high-temperature scrap heating by off-gases in a BBC-Brusa steelmaking unit. This unit combines an EAF with a rotary tube-type heating furnace forming a single system. The first installation of this kind started operating in the early 1970s (Italy) [5]. In this unit, a 13 m long rotary tube-type heating furnace (1) was installed above a 36-t EAF, Fig. 2.3.

The gases escaping through an opening in the EAF roof are drawn into the tube-type furnace. The scrap is continuously charged into the bath of the furnace through the same opening. When passing through the tube furnace, the gases are heating the scrap coming from a batcher (2) equipped with vibrator (3). At the upper end of the furnace the cooled gases are drawn into a fume hood (4) and are removed for purification.

Fig. 2.3 BBC-Brusa unit (designations are given in the text)
Gas burners (5) are located at the lower end of the rotary furnace. The scrap passes through the furnace for 6–10 min. During this time the scrap is heated up to medium mass temperature of about 1000 °C. This temperature was reached not quite due to off-gas heat but mostly due to the burners which account approximately 73% of all heat coming into the rotary furnace. Rotation of the furnace prevents welding of the scrap lumps despite their high temperature and assures that heat from the refractory lining is being used for scrap heating. This enhances the advantages of countercurrent system of gas and scrap motion which makes gases exit the furnace at low temperature. The thermal efficiency of the rotary furnace calculated for the total heat input reached approximately 45%. Performance of the BBC-Brusa unit equipped with transformer power of 7.2 MW for 3 years of service shows great potentialities and principle energy advantages of high-temperature scrap heating. With natural gas consumption of 30 m³/t, electric energy consumption was cut by 220 kWh/t. Furnace productivity increased up to 100,000 ton per year which at that time was equal to the productivity of a furnace with the same capacity, but equipped with high-power transformer. Continuous charge of scrap assured very quiet arcing and low noise level (less than 80 db). Durability of the refractory lining of the rotary furnace was 1500 heats. Despite the advantages attributed to the high-temperature scrap heating, such units had quite limited use and only for a short period of time. This can be explained by the fact that for the modern high-productivity EAF the dimensions of a rotary furnace required call for really too big size and height of the buildings for EAF's shops. Besides, rotary furnaces can operate only using properly prepared fragmentized scrap. This narrows raw material supply base and increases cost. The units with rotary furnaces also have other significant drawbacks which prevent them from being used. Nevertheless, the impressive results obtained on BBC-Brusa units promoted a search for new options of high-temperature heating a scrap in combination with continuous charging it into the bath. This has resulted in development of modern shaft and conveyor EAFs.

2.2 Conveyor Furnaces

2.2.1 Design and Technological Process

Due to persistent efforts of Tenova company, conveyor electric arc furnaces Consteel designed by J.A. Vollomy have become considerably widespread. On the late 2013, there are over 40 of these furnaces worldwide. This steelmaking unit combines an electric arc furnace and vibratory conveyor (2) consisting of chutes made of sheet steel. A conveyor is adjacent to a side wall window of an arc furnace from the side opposite to a furnace transformer, Fig. 2.4.

Total length of the conveyor is about 100 m. A part of the conveyor is inside of a refractory-lined tunnel (1) adjoining the furnace. The length of this tunnel is about 30 m. The off-gases leaving the furnace are removed through this tunnel. In the
tunnel, the gases move in the opposite direction to the scrap and heat it up. Then the gases are directed through the water-cooled duct (3) into the bag filters for dust extraction. The conveyor chutes located in the tunnel are cooled by water.

Scrap charging into a bath is carried out by special water-cooled chute installed at the end of the conveyor. This chute is filled with scrap at regular intervals, then moved into a freeboard through a window, and the scrap is dropped into a bath. The width of the conveyor depends on furnace capacity and on the 350-t furnaces is about 2.5 m. A furnace roof is opened only during the first heat after a furnace scheduled maintenance before which all liquid metal and slag is tapped from the furnace. During this heat, one basket of scrap is charged into the furnace from the top in order to accumulate on the bottom a sufficient amount of liquid metal to start continuous scrap charging by conveyor. During all other heats, the furnace operates with a hot heel and charging is carried out by conveyor only without opening the roof. This significantly reduces dust and gas emissions into the atmosphere of the shop.

The Consteel furnaces do not impose much stricter requirements to the quality of scrap preparation for the heat in comparison to the conventional EAFs with scrap charging from the top. The rate of scrap charging into the bath is always kept equal to the rate of scrap melting in liquid metal. As a result, the bath remains flat during the whole melting process. During this period, the temperature of metal is kept at a constant level of 1560–1580 °C. Temperature increase above this level is not recommended in order to avoid sharp drop in durability of the refractory lining of the bottom and the banks of the furnace.

The rate of scrap melting in liquid metal is determined by intensity of convective heat transfer from metal to scrap which depends first and foremost on speed of metal streams flowing over the surface of scrap pieces as well as on difference in temperatures between metal and scrap. Amount of heat $Q$, kW/t, transferred from liquid metal to scrap per unit time is defined by the following equation:

$$Q = \alpha \times F \times \Delta t$$  \hspace{1cm} (2.1)
\( \alpha, \text{kW/(m}^2\text{°C)} \) — coefficient of convective heat transfer from liquid metal to scrap.

\( \Delta t, \text{°C} \) — average difference in temperatures between metal and scrap pieces, per melting period.

\( F, \text{m}^2/\text{t} \) — specific surface area of all the scrap pieces submerged into liquid metal.

In Consteel furnaces, electric arcs are constantly submerged into foamed slag. They do not have direct heat contact with scrap and do not affect intensity of heat transfer from metal to scrap. The arcs participate in scrap melting only indirectly by maintaining metal temperature at a required constant level. Given a specific furnace capacity, such melting mechanism precludes the possibility of increasing melting rate by increasing the power of arcs. The latter must strictly correspond to the scrap melting rate which does not depend on the power of arcs. Thus, the power of arcs does not determine scrap melting rate, but, on the contrary, scrap melting rate determines the maximum permissible power of arcs which must not result in overheating of metal. In the EAFs, such a limitation of the electric power does not exist. As the arc power rises, both melting rate and hourly productivity of the furnaces increase.

In the modern EAFs, the scrap melting process may be divided into two periods. During the first period, the main body of scrap pile is melted down with the electric arcs in the furnace freeboard above the hot heel surface. Plasma of the arcs has a temperature of more than 5000 °C and possesses high kinetic energy. The heat energy of the arcs is transferred to the scrap by both radiation and convection. The intensity of these heat transfer processes is much higher than that in the liquid metal where the difference between a temperature of the liquid metal and scrap melting point amounts to 30–40 °C only. The power of the arcs is also higher than that of the Consteel furnaces. Furthermore, the oxy-gas burners and the process gases formed during post-combustion of CO in the freeboard contribute to the heating and melting of scrap. At the first period of the scrap melting process in EAFs, all these factors must ensure the higher melting rate in comparison with that in Consteel furnaces.

During the second period, upon completion of both forming of the flat bath and submerging of the arcs into a foamed slag, the rest of the scrap melts down in the liquid metal. If any, the mechanism of heat transfer to scrap is the same as in the Consteel process. However, just like in the first period, the rate of melting has to be considerably higher. It could be explained by the fact that the scrap lumps before submerging into the melt are heated up to a temperature close to the melting point in the EAF freeboard. Only a small portion of fine scrap placed on the bottom of the basket submerges into the hot heel not being preheated. Increase of melting rate must result in the higher productivity of the moderns EAFs in comparison with the conveyor furnaces. These considerations are confirmed by actual data.
2.2.2 Comparison Between Conveyor Furnaces and Modern EAFs

The key performances of the furnaces were compared: hourly productivity and electrical energy consumption, as well as scrap melting rate which to a large extent determines productivity. The furnaces using hot metal were not considered since their performances are determined by hot metal percentage in the charge rather than by the design features and operating modes of the furnaces, Chap. 1, Sect. 1.2.

Despite the fact that there are more than 40 conveyor furnaces operating worldwide and that numerous articles related to these furnaces have been published by Tenova personnel in such magazines as “MPT International” and “Iron & Steel Technology”, in Proceedings of the European and US conferences as well as in other information sources, data allowing to determine scrap melting rate and hourly productivity are given only for several conveyor furnaces operating without hot metal. Even less data are provided on electric energy consumption. This allows to suppose that published data show the very best achievements of the conveyor furnaces. Therefore, comparison between these furnaces and the state-of-the-art modern EAFs seems to be most objective.

This comparison appears to be the most indicative with respect to estimating the potential of the steel melting units being analysed. All the data corresponding to the above-indicated requirements have been used for the purpose of this comparison. Advertising data not containing the actual performances of the furnaces operation have not been taken into consideration.

The rate of melting was determined by dividing the total mass of scrap and pig iron by melting time. In the cases when the data on composition of the charge were absent, the mass of solid metal-charge was determined using the tapping weight with consideration of the liquid steel yield. The melting time was determined using the power-on time with due correction for the time needed for heating of the melt to the tapping temperature. Despite very poor data used for making a comparison of furnaces the curves plotted based on these data are characterized by an insignificant spread of points which allows to draw the quite definite conclusions.

With the increase in the capacity $M^1$ the scrap melting rate $S$ increases in both furnace types, Fig. 2.5. This could be explained by an adequate increase in electrical power of the furnaces. In the Consteel furnaces, with the increase in their capacity the weight of hot heel grows which allows speeding up the scrap charging rate and, consequently, increasing the power of arcs.$^2$ For the entire range of the furnace capacities from 100 up to 350 tons, the rate of scrap melting in the EAFs

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$^1$ The furnace capacity $M$ was determined by the sum of weights of both the hot heel and tapping.

$^2$ An effect of the hot heel weight as well as other factors on a permissible scrap charging rate, equal to the melting rate, is reviewed in detail in Chap. 3.
is higher than that in the conveyor furnaces by approximately 1.6 times. In addition, the ratio of the melting rate in the modern EAF to that in the conveyor furnace operating under similar conditions at the same region in Russia after reducing them to the equal \( M \) amounts to 1.6 as well, Fig. 2.5.

The Consteel process eliminates times expended on upper scrap charging with baskets which shortens power-off time. Due to this advantage, when replacing EAFs with Consteel furnaces, the total shortening tap-to-tap time and increasing hourly productivity were reached in a number of cases despite reduction in the melting rate. At present, the situation changed. Owing to an increase in the capacity of the new generation furnaces, more and more frequently scrap is charged by a single basket in EAFs of low and medium capacities and by two baskets in EAFs of high capacity. This fact along with speeding-up of crane mechanisms and furnace drives, training of furnace personnel and improving in work coordination has allowed to shorten power-off time in the best EAFs down to a level of that in Consteel furnaces, Chap. 1, Sects. 1.3.7 and 1.5.1. The combination of these achievements with greater scrap melting rate ensures increase in productivity of the EAFs by about 20–25 % on average, as compared to the conveyor Consteel furnaces, given equal capacities, Table 2.1.

Electrical energy consumption in the conveyor furnaces is approximately the same as or even higher than that of the EAFs operating without scrap preheating. According to the data in Table 2.1, it is about 8 % higher. Electrical energy consumption is
closely related to scrap preheating temperature. When Consteel furnaces were being developed, it was expected that scrap on conveyor would be preheated by off-gases up to 700–900 °C. Such preheating could have ensured quite considerable electrical energy savings. However, these expectations were not realized. Scrap preheating in Consteel furnaces proved to be ineffective. Mass average temperature of scrap preheating does not exceed 250 °C on the medium capacity furnaces and is even lower on the 350-t furnaces because of the increased scrap layer thickness (reaching 900 mm). According to energy balance of one of these furnaces, the enthalpy (in other words, heat content) of the preheated scrap $E_s$ is 16.4 kWh per ton of scrap \[18\]. Interpolating between the values of temperature $t_s$ equal to 100 and 150 °C, Table 1.1, Chap. 1, we find that the enthalpy $E_s = 16.4$ kWh/t corresponds to the temperature of scrap $t_s = 125$ °C. Low effectiveness of scrap preheating in the Consteel furnaces is explained by an unsatisfactory regime of heat transfer from gases to scrap in the heated tunnel as well as by insufficient heat power of off-gases flow. These factors are closely examined in Chaps. 3 and 4.

In countries like Russia, Norway, etc., operating the Consteel furnaces during winter time causes considerable difficulties resulting from low scrap preheating temperatures. Getting into conveyor, snow and ice melt in the tunnel heated by gases. Water formed as a result does not have time to evaporate. It flows into the lower part of the conveyor chutes, mixes up with mineral debris contained in the scrap, and forms mud deposits which, along with the water and wet scrap, are charged into the bath of the furnace. This results in dangerous “popping” and intense metal splashing, and, in case of unfavourable combination of circumstances, can even lead to explosions with catastrophic consequences, which is confirmed by the experience of operating the 170-t Consteel furnace, Asha, Russia. Scrap preheating temperature on this furnace is 150–250 °C \[19\]. Due to such low scrap preheating temperatures an amount of dioxins emitting in this case is

### Table 2.1 Performances comparison between EAFs and consteel furnaces

<table>
<thead>
<tr>
<th>Furnace type</th>
<th>Country</th>
<th>Capacity/ tapping weight, t</th>
<th>Power MVA</th>
<th>Tap-to-tap time min</th>
<th>Productivity t/h</th>
<th>Electrical energy kWh/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF</td>
<td>Europe: USA</td>
<td>120–130</td>
<td>150–160</td>
<td>&lt;35</td>
<td>&gt;200</td>
<td>345–355</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>146/128</td>
<td>95</td>
<td>55</td>
<td>140</td>
<td>374</td>
</tr>
<tr>
<td></td>
<td>Turkey [17]</td>
<td>380/320</td>
<td>240</td>
<td>60</td>
<td>320</td>
<td>359</td>
</tr>
<tr>
<td>Consteel</td>
<td>Norway [7]</td>
<td>123/83</td>
<td>75</td>
<td>41</td>
<td>122</td>
<td>384</td>
</tr>
<tr>
<td></td>
<td>Greece [8]</td>
<td>180/130</td>
<td>120</td>
<td>48</td>
<td>162</td>
<td>395</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>168/118</td>
<td>90</td>
<td>61</td>
<td>116</td>
<td>416</td>
</tr>
<tr>
<td></td>
<td>Thailand [1]</td>
<td>300/187</td>
<td>125(^b)</td>
<td>65</td>
<td>173</td>
<td>363(^c)</td>
</tr>
<tr>
<td></td>
<td>Italy [10]</td>
<td>350/250(^a)</td>
<td>209</td>
<td>63</td>
<td>238</td>
<td>–</td>
</tr>
</tbody>
</table>

\(^a\)Tapping weight, expected  
\(^b\)The values calculated per active powers of 95, 34 MW  
\(^c\)For 40 % of pig iron in a charge which reduces electrical energy consumption
insignificant and, therefore, the problem associated with decomposition of dioxins in operating Consteel furnaces did not arise so far.

Along with afore noted shortcomings Consteel furnaces in comparison with EAFs have important advantages thanks to flat bath operating. These advantages are common for all the furnaces operating with flat bath including shaft furnaces as well. Therefore, the latter is examined at the end of the chapter, Sect. 2.4.

2.3 Shaft Furnaces

2.3.1 Furnaces with Fingers Retaining Scrap

The development of shaft furnaces is associated with the name of G. Fuchs. In the first 90-t shaft furnace the water-cooled shaft was installed above the furnace roof and did not have fingers retaining the scrap in the shaft. The scrap was charged into the furnace through the shaft. While the lower part of the scrap pile was located on the bottom of the furnace, its upper part was in the shaft. Gases from the furnace were evacuated through the shaft and heated the scrap located in it. As the scrap melted in the furnace, the entire scrap pile settled down. This created the free space in the shaft, which allowed charging of additional portions of the scrap.

Later G. Fuchs has developed and put into operation at several plants the furnaces with one row of fingers in the lower part of a shaft, Fig. 2.6. The scrap is charged into the furnace by two baskets. At the tapping the scrap of the first basket heated by the off gases during the previous heat lies on the fingers in the shaft. After the tapping the fingers split apart, and the heated scrap is charged into the furnace. After that, the cold scrap from the second basket is charged into the empty shaft. The share of the scrap from the second basket remaining in the shaft is heated by the off gases passing through the shaft. As the scrap melts in the furnace, the scrap in the shaft rapidly caves in and the shaft clears. The fingers are then shut, and the first basket of scrap for the following heat is charged on the fingers. By the tapping time this portion of scrap is already preheated by the off-gases up to relatively high temperature.

With this heating method when gases pass through the scrap from the bottom to the top, the overheating and even the partial melting of the lower scrap layer do not create any problems. The melt and the liquid slag formed flow down into the furnace and do not obstruct splitting fingers apart and scrap discharging. At those periods of the heat when the off-gas temperature reduces, a lack of heat can be compensated by using of burners installed under the shaft. Heating a scrap layer on the fingers with gases passing through the layer is much more efficient than surface heating a scrap on a Consteel conveyor. All this contributes to increasing the average mass temperature of scrap heating and reducing electrical energy consumption. Another advantage of shaft furnaces is that a substantial part of the dust carried out from the freeboard settles down in the layer of scrap. Due to this fact the yield is increased by approximately 1%.
Although there is no reliable data on average-mass temperatures of scrap heating for the finger shaft furnaces, this temperature can be estimated with the help of the heat balance data for one of such furnaces. In accordance with these data for the 135-t shaft EAF with the 120 MVA transformer and tap-to-tap time of approximately 38 min, the first basket of heated scrap introduces 55 kWh/t of steel [20]. The total amount of scrap per heat is 148 tons. Assuming that the first basket contains 89 t (60 %) of scrap, we can find its enthalpy
\[
E = \frac{55 \times 135}{89} = 83.4 \text{ kWh/t of scrap.}
\]
Corresponding to this enthalpy is the average-mass temperature of scrap of 550 °C, Chap. 1, Table 1.1. It can be assumed that only half of the scrap from the second basket, i.e. 30.0 t, is in the shaft and that this additional amount of scrap is heated by the off-gases to the temperature of 550 °C as well. In this case, the average enthalpy of the entire amount of scrap heated by the off-gases will be
\[
\left(89.0 + 30.0\right) \times 83.4/148 = 67.0 \text{ kWh/t of scrap, which corresponds to preheating temperature of 450 °C, Chap. 1, Table 1.1.}
\]
Such a relatively low temperature can be explained by the facts that only a part of the scrap equal to approximately 80 % of its total amount is heated by the off-gases, the duration of heating of the scrap from the first basket on the fingers is short, and also heat power of the off-gas flow is relatively low.

In this case, heating by the off-gases returns to the process
\[
83.4\left(89 + 30\right)/135 = 73.5 \text{ kWh/t of steel. Assuming the electrical energy efficiency coefficient } \eta_{EL} = 0.75, \text{ we will find that reduction of the required useful heat consumption}
\]
by 73.5 kWh/t can reduce electrical energy consumption by 73.5/0.75 = 98 kWh/t. The minimum electrical energy consumption on the shaft furnace under consideration [20] was 285 kWh/t. In comparison with conventional EAFs operating without scrap preheating, the reduction of electrical energy consumption is about 90 kWh/t.

Later design of a finger shaft furnace was persistently improved. The latest variation of the furnace, named Siemetal EAF Quantum, developed by Siemens VAI Metals Technologies, Germany, along with other innovations comprises a new system of shaft charging and improved design of fingers retaining scrap [21].

Scrap is charged into the shaft from above with a special chute moving up and down on inclined elevator rather than baskets with a crane. The chute is loaded on scrap yard and contains one third of the scrap required for the heat. Such a system allows covering the shaft with a hood and considerable decreasing uncontrolled gas-dust emissions from the shaft during the charging of scrap.

As opposite to the fingers shown in Fig. 2.6, in the EAF Quantum the fingers, similar to pitchforks, are introduced into the shaft through its sidewalls. To charge a batch of the preheated scrap into the bath the fingers are pulled out of the sidewalls of the shaft. After charging they are immediately introduced into the shaft to receipt the next batch of scrap. Thus, all the scrap is heated on the fingers what allows increasing its average mass temperature. The prior system, Fig. 2.6, did not enable to close the fingers at once after falling of the first batch of scrap into the furnace freeboard. It was necessary to wait for caving-in of scrap. Therefore, only the first basket of scrap was heated on the fingers.

Designed productivity of a 100-t Quantum furnace with a transformer of 80 MVA is 182 t/h when charging 3 chutes, and when charging 4 chutes is 162 t/h. Expected electrical energy consumption is 280 kWh/t [21]. Since approximately even electrical energy consumption has been achieved at the Fuchs’ finger shaft furnace in the late 1990s [20] it can be supposed that in the new furnace an average mass temperature of scrap preheating with off-gases will not exceed 450–500 °C.

2.3.2 Shaft Furnaces with Pushers

The off-gas heat efficiency when heating a scrap in a shaft is higher by approximately three times than that when scrap is heated on a Consteel conveyor. On the other hand, continuous furnace operation with the flat bath is an advantage of the Consteel process. To combine these both advantages G. Fuchs has developed and implemented real-life shaft furnaces with the continuous charging of scrap into the liquid bath. The design of such a furnace named COSS is schematically shown in Fig. 2.7.

A rectangular shaft (1) is installed on the cart (2) next to the furnace. The shaft is connected to the furnace with a short tunnel (3). A sliding gate (4) opens for charging of scrap into the shaft. The charging is carried out with the power-on and does not interrupt the furnace operation. A gas duct (5) is placed under the sliding
The shaft is lined with the massive steel segments and has no water-cooled elements which could be damaged during the scrap charging. The mass of scrap in the shaft is gauged by the measuring elements on which the shaft rests. This makes it possible to control the rate of charging of scrap into the furnace.

The scrap is charged continuously into the liquid bath with the help of the pusher (6) which is moved forth and back by the well protected hydraulic cylinder. During the entire period of charging and melting of scrap in the liquid metal its temperature is kept by the electric arcs at the constant level of 1560–1580 °C, just like in the Consteel process. All the fundamental features of this method of scrap melting, its advantages and shortcomings are the same as those of the Consteel furnaces. Unlike in the first finger shaft furnaces, in the furnaces with the pushers the off-gases heat all the scrap. This made it possible to expect the higher temperatures of heating. Unfortunately, the reliable data on the temperatures for the furnaces operating without hot metal are absent.

As reported by G. Fuchs, the hourly productivity of the three 140–150-t furnaces put into operation recently was 125–149 t/h with the minimum electrical energy consumption of 300–341 kWh/t on the better days. With regard to productivity, these furnaces are considerably inferior to the modern EAFs.

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3 Presentation: Ekaterinburg, Russia, 2012.
which can be explained not only by the relatively low melting rate of scrap in liquid metal, but by the low power of transformers (80 MVA) as well. The electrical energy consumption does not differ significantly from that of the best results achieved on the modern EAFs operating without scrap preheating during some of the short periods of their operation. Obviously, that the high-temperature scrap preheating has not been achieved in these shaft furnaces either. This can be associated with both the insufficient duration of the heating and relatively low heat power of the off-gases flow in furnaces operating without use of hot metal.

When operating with hot metal, the heat power of the off-gas flow increases sharply what makes it possible to achieve the high-temperature heating of scrap in the shaft furnaces. As an example, let us review the performances of the shaft furnace of 150-t capacity with pusher operating in China [2]. For this furnace, share of hot metal in the charge is 40 %, tap-to-tap time is 35 min, oxygen flow rate is 40 m³/t, and electrical energy consumption is less than 100 kWh/t.⁴ Scrap melting is carried out with low electrical energy consumption, mainly by means of sensible and chemical heat introduced with hot metal, by exothermic reactions of oxidation of C, Si, Mn, and P, and by highly heated scrap which temperature reaches 800–1000 °C. Operating experience proves that the pusher works reliably at such temperatures of scrap. It is worth mentioning that such performances can also be achieved on the EAF without scrap heating if the share of hot metal in a charge is significantly increased.

Elimination of gas-dust emissions when charging scrap into the shaft is one of topical tasks of improving of shaft furnaces operation with continuous scrap melting in the liquid bath. In order to solve this problem an original scrap charging system named EPC [22] has been developed by the Company KR Tec GmbH, Germany. Operating principle of this system is explained by Fig. 2.8.

The main component of the system is a movable hopper (1) with an opening bottom placed in a bunker (2) adjacent to the shaft (3). By means of hydraulic cylinders of the bunker the hopper can be moved into the shaft through an aperture in its sidewall. When the hopper is placed in the bunker its front wall is closing the aperture. When the hopper is positioned in the shaft the aperture is closed with the hopper back wall. At this position the bottom of the hopper is opened and the scrap falls smoothly into the shaft.

In the course of feeding of the scrap into the bath by means of a pusher (4) the scrap caves in inside the shaft and the hopper can be moved backward to the bunker. The hopper is charged there again with the help of a scrap basket (5). A slide gate (6) is opened for a while to charge the hopper only. Thus, during the heat the scrap can be charged into the shaft by separate batches without loss of airtight of the system. Therefore, gas-dust emissions from the shaft into the shop atmosphere are almost completely eliminated.

⁴ This figure seems somewhat understated.
Melting of the scrap starts when the scrap batch preheated in the shaft during the prior heat is feeding into the hot heel. The system allows realizing different variations of furnaces operation. During the heat one or several of scrap batches can be charged into the shaft depend on a furnace capacity, shaft and hopper dimensions. This requires the certain number of hopper movements and charging of the hopper with baskets. Figure 2.8 shows a stage of the heat preceding the next charging of the scrap from the hopper into the shaft. Off-gases passing through the scrap layer heat it and are evacuated via a gas duct (7).
2.3.3 Ecological Problems

During development and implementation of the shaft furnaces, the following problem occurred: personnel and environment had to be protected from highly toxic compounds of halogens and hydrocarbons (usually referred to by the generic term “dioxins”) contained in the off-gases. When the regular grades of steel are produced in EAF, relatively cheap scrap contaminated by plastic, rubber, upholstery materials from car interiors, and oil is used. When such scrap is preheated in shafts by off-gases to temperatures exceeding 400 °C these contaminators burn down with the formation of dioxins. The gases leaving the shaft with temperatures of the order of 400–500 °C are saturated with dioxins. For complete decomposition of dioxins, further heating of these gases by burners in special chambers to approximately 1000 °C and even higher is needed. This involves additional natural gas flow rate of 5.5 m³ or more per ton of steel, which sharply reduces the energy efficiency of the process.

As already mentioned, the Consteel furnaces do not encounter the problem of dioxins only because the scrap on the conveyor is preheated to quite low temperatures at which the formation of dioxins is insignificant. It is known that dioxins are practically absent in case of smelting of alloy and special grades of steel for which clean scrap is used. However, due to economic considerations, for mass production of EAF steel, it is impossible to avoid the use of cheap contaminated scrap as well as to ensure its thorough cleaning.

In North America, Western Europe, and some other countries, the acceptable concentration of dioxins in the atmospheric emissions is limited by legislative regulations and cannot exceed extremely low values of the order of $10^{-10}$ g/m³. Since removal of dioxins from gases involves significant additional power consumption, the shaft furnaces have spread to a limited extent only, mainly in China, Indonesia and other countries, where such strict regulations so far do not exist. However, such an approach to solving this problem is unpromising.

In EAF, dioxins are also formed after charging of each next basket of scrap. However, under the conditions of high temperatures of the freeboard and of the entry part of the gas duct, dioxins decompose completely. Then, the gases cool down as they move through the duct, and at the temperatures below 600 °C decomposed dioxins may reform. This process takes some time and occurs only if the gases cool down relatively slowly. To avoid reforming of dioxins, atomized water is injected into the gas flow downstream. Water evaporates quickly, and the temperature of the gases sharply drops to approximately 200 °C, at which reforming of dioxins is completely avoided. Thus, suppression of dioxins formation in EAF does not require additional power consumption, as opposed to the shaft furnaces.

It is important to emphasize that water injection into the gas duct not only prevent reforming of dioxins, but also completely eliminates possibility of further post-combustion of carbon monoxide CO. Allowable CO emissions into atmosphere are also strictly limited in many countries. Therefore, when water injection
is used, it is essential to achieve complete post-combustion of CO within the duct before the point of injection; this ensures that allowable CO emissions into atmosphere are not exceeded. In modern gas evacuation systems this problem is solved by intensifying the process of mixing of furnace gases flow with flow of the air drawn into duct.

2.4 Results of the Implementation

The principal potential advantage of the technology of flat bath with continuous scrap melting in liquid metal is a possibility to significantly increase productivity and to reduce electric energy consumption, Chap. 1, Sect. 1.6.2. In the modern conveyor and shaft furnaces this advantage has not been realized so far. With regard to both productivity and electric energy consumption, these furnaces significantly trail the modern EAFs using the conventional methods of scrap charging and melting. If this challenge is not overcome, the conveyor and shaft furnaces will not be able to successfully compete with the EAFs, replace them, or to be considered as steel melting units of the future.

In case of equal capacities, the power of transformers of the conveyor and shaft furnaces is considerably lower than that of the EAFs, which allows to install these furnaces in the regions with electrical supply grids of relatively low power. However, this could be considered as an advantage of the conveyor and shaft furnaces only in case of identical productivity of these furnaces with that of the EAFs. Otherwise, the lower electrical power resulting from relatively low melting rate of scrap cannot be considered as advantage because installation of the EAF of the same power ensures higher productivity. However, the furnaces with flat bath actually impose lowered requirements to electrical grids. This advantage remains in case of transformer power equal to that of the EAF. Such an advantage can be explained by the fact that the furnaces with flat bath have a lowered level of electrical interferences generated in the grids due to improving arcing stability.

Almost all the other potential advantages mentioned in Sect. 1.6.2, Chap. 1, have been also realized fully or partially. Furthermore, due to relatively low temperature of metal bath as well as to possibility of slag replenishment during scrap melting stage in the furnaces with flat bath, better conditions for dephosphorization are created as compared to the conventional EAFs. At the same time, increasing the content of FeO in slag is not required, which contributes to an increase in yield. All these advantages ensured quite wide spread of the conveyor furnaces. The ecological problems caused by forming of dioxins hindered spreading of the shaft furnaces, Sect. 2.3.3.

In order to determine the most efficient methods of increasing productivity and reducing electrical energy consumption on the conveyor and shaft furnaces, the detailed analysis of the processes of scrap melting in liquid metal is needed. Chapter 3 addresses this analysis.
References

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