Electric boosting – a technology review

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Electric boosting systems using molybdenum rod electrodes were introduced in the 1950s and the basic technology is well-known and widely used. However, there are still a number of important technical issues that are less well appreciated and some of these are discussed below.

Side wall or bottom electrodes

There are various reasons for installing supplementary electric heating systems (so-called boosters) in conventional furnaces and one of the most common is simply to increase the melting capacity. In such cases electrodes are installed to the rear part of the furnace and the electrical energy is introduced where the glass is melted.

Electric heating systems release the energy directly into the glass bath and this brings two advantages for the melting process. Primarily, additional energy is introduced into the glass bath - a basic prerequisite for increasing the melting capacity. The second advantage is that it may be possible to apply this energy to the lower regions of the glass bath that are not normally heated directly by the fossil heating system.

In melting boosters electrodes can be installed horizontally through the side walls. The typical arrangement in a U-flame furnace has a group of electrodes on each side of the furnace, approximately opposite the normal hot spot, and a further group on the rear wall below the burner ports. The distance between the electrode groups depends almost entirely on the tank dimensions (length and width) and cannot be chosen to suit the booster operation.

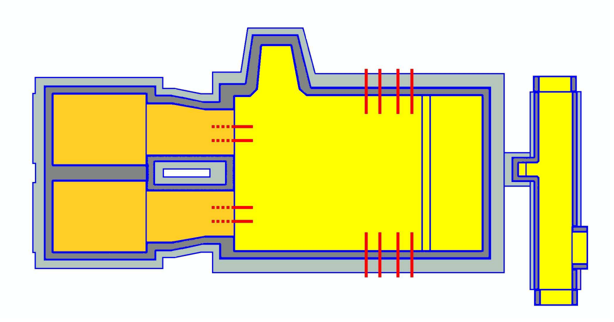

Fig. 1: Typical melting booster with horizontal electrodes

The glass bath is effectively a resistive load, with the distribution of power being dependent on the resistance distribution, which is itself a simple function of the temperature distribution.

Although the distribution of both temperatures and electrical resistances in the furnace are very complex, it is possible to define the following two basic principles:

- the largest electric currents flow along the paths with the lowest electrical resistance,
- the glass temperatures tend to be highest near the glass bath surface.

From this it can be deduced that with electric boosting systems there is a basic tendency for more energy to be generated in the hotter areas near the glass bath surface and comparatively less in the lower, colder layers, which is exactly the opposite of what is really required.

This fact can become important if side wall electrodes are used, and can actually reduce the efficiency of a melting booster installation. The effect is probably negligable in small furnaces, but with larger furnaces the distances between the electrodes can mean that this effect is significant.

The installation of the electrodes vertically through the furnace bottom offers more flexibility in terms of electrode layout than side wall installations. The electrodes can be installed closer together, as there are no restrictions set by the length and width of the furnace, and can be distributed across a section of, or over the complete melting area of the furnace.

As the electrodes can be located relatively close to one another the tendency for preferential heating of the upper layers is significantly reduced and, as a result, the direct heating of the lower, colder layers is improved. A melter booster with bottom electrodes is more effective than a comparable system with side electrodes.

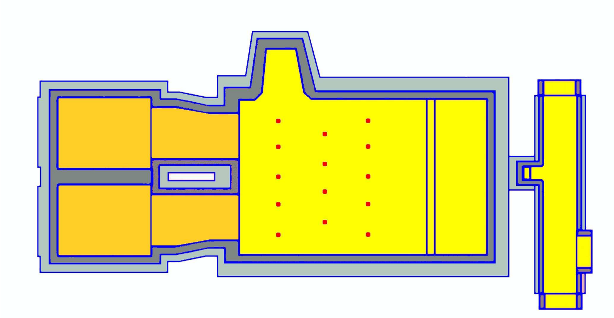

Fig. 2: Typical melting booster with vertical electrodes

There is a difference in the electrode wear pattern between side wall and bottom electrodes. In the case of side wall electrodes there is a greater concentration of current at the electrode tip, whilst the current concentration near the holder is much lower. This leads to the well-known conical wear pattern, and the electrode becomes shorter as the tip wears away.

In the case of bottom electrodes the current distribution along the length of the electrode is more balanced, with a lower concentration at the tip. The wear pattern is more even, with less wear at the tip

The difference in the wear pattern between the side wall and bottom electrodes means that side wall electrodes must be advanced more often than bottom ones, which increases the thermal stress on the electrode holder and the adjacent refractory.

However, there is another decisive factor when considering the use of either bottom or side wall electrodes. Nowadays a high level of cullet is used in many furnaces and unfortunately this often contains large amounts of metal.

This collects on the bottom of the furnace and can form an electrically conductive layer. When bottom electrodes are used a short circuit between the electrodes may occur and cause significant damage.

Therefore, despite their proven advantages, bottom electrodes should only be used in furnaces with a high cullet content if it can be ensured that virtually all metals have been removed from the cullet.

The economic aspects of installing a melting booster

In most countries electricity is a more expensive source of energy than oil or gas so that, despite the higher efficiency of direct electrical heating, fossil fuels are still more economical. However, the installation of an electric booster can still be a viable investment.

A conventional furnace is designed for a particular maximum melting capacity, and when operated at this maximum the furnace can achieve an excellent specific energy consumption. However, if the furnace is operated below the designed maximum melting capacity, the specific energy consumption rises and so do the specific energy costs.

If the expected operating profile of a furnace has an average melting capacity with occasional peaks, it may be advisable to design the furnace for the average capacity and to use a booster to cover the peaks.

In small furnaces the melting booster capacity can be as low as a few hundred kW, and more than 2 MW in larger furnaces (e.g. 300 +/24 h container glass). When a very high power is installed it is better to install two independently operating boosters in order to improve the operational flexibility.

Boosting to improve the quality

A so-called barrier booster may be installed to improve quality without increasing the capacity. Normally a barrier booster comprises a row of bottom electrodes installed across the width of the tank, near the hot spot.

The flow pattern inside the furnace and the temperature of the glass on the furnace bottom are significant factors affecting glass quality. The upward current produced by the electrodes stabilises the hot spot and thus the barrier created between the melting and refining ends of the furnace. Colder bottom glass is borne upwards, where it is heated by the conventional heating system. Simultaneously it is replaced by hotter, surface glass, that raises the bottom temperature.

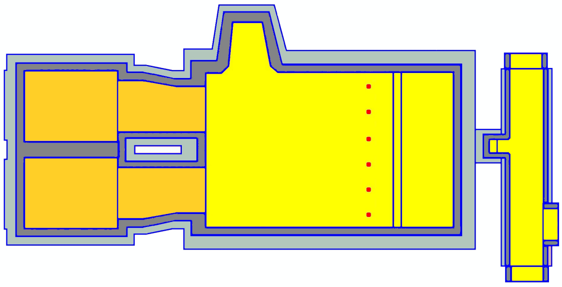

Fig. 2: Typical barrier booster

A barrier booster also strengthens and heats the return convection current that flows from the conventional hot spot towards the doghouse end of the furnace. As a result, more energy is returned to the actual melting area of the furnace and so the melting capacity is slightly, but definitely, increased.

The installed power of a barrier booster system is normally between 500 and 1000 kW.

Direct heating of a particular area

Electric heating can also be used to heat regions of the glass bath that are otherwise very difficult or even impossible to heat directly with conventional heating systems. A typical example of this type of booster is for throat heating – a system that is recommended for all coloured glass furnaces. It is possible to heat the complete area between the throat entry on the melter side and the riser exit on the working end side with 2 or 3 electrodes. This prevents these areas from becoming too cold if there is low or no throughput.

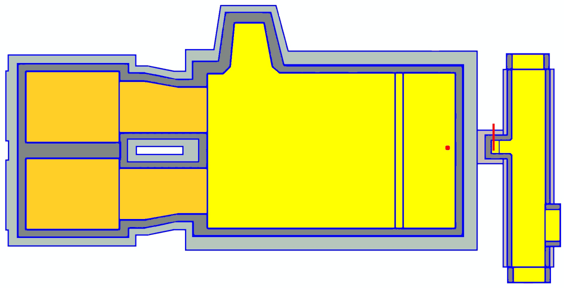

Fig. 3: Typical throat booster

These direct heating systems are also suitable for use in the prevention of devitrification, or for improving the thermal homogeneity in working ends and forehearths.

Specific power requirement

It is difficult to define the specific power required to achieve a particular increase in melting capacity. The theoretical energy requirement for melting glass depends on many factors. The cullet content alone is responsible for reducing the theoretical energy requirement from 605 (0 % cullet) to 448 kcal/kg glass (75 % cullet). However, a booster for soda-lime glass is often calculated on the basis of values between 28 and 30 kW per tonne of additional glass required.

It is sometimes claimed that a particular booster system uses less than the theoretical energy amount per additional tonne of glass, which would be the equivalent of an efficiency level of more than 100 %. This apparently impossible situation is explained by the fact that the influence of the booster on the glass flow can also result in the fossil heating becoming more efficient. Although the resulting increase in the melting capacity is attributed to the booster, it is in fact partly an indirect result of the use of the electric heating. In such cases the “super capacity” of the booster is less a positive characteristic of the electric heating and more the proof of the poor capability of the conventional heating without electrical support.

How much booster power is possible?

There is no easy way of defining how much additional electrical energy can be introduced into a conventional furnace.

Factors such as the ability of the furnace to refine the glass and the wear on refractory materials must be taken into consideration. The more glass that is to be melted, the more energy is required. The additional energy automatically leads to higher temperatures, resulting in increased refractory wear and a reduction in the furnace life.

Practical experience has shown that, in medium and large furnaces for soda-lime glasses, a booster can increase the specific melting capacity to upwards of 4 tonnes per day per m^2 of area. However, it should be noted that such values can only be achieved under ideal conditions.

Owing to their relatively small dimensions the situation is more limited with smaller furnaces, so that the specific melting capacities are normally lower than in larger installations.

Installed power / available power

There is always a difference between the installed and available powers of a booster.

The electrical conductivity of glasses depends on the glass temperature - it increases when the temperature rises and vice versa. Glass temperatures in the furnace alter, particularly when the operating conditions change, and this causes changes in the electrical resistance of the glass. As in the case of a simple electrical circuit, any change in the resistance results in a change of the ratio between current and voltage (Ohm´s law).

A transformer can only be constructed for a fixed ratio between current and voltage, so that the transformer is basically only suitable for one load resistance. If the load resistance changes, either the maximum available voltage is insufficient to produce the maximum power, or the maximum current is reached at a lower power. In both cases the nominal capacity of the transformer cannot be achieved.

In practice the specification of the transformer is increased to allow the maximum required power to be achieved over a range of load resistance values, which results in a difference between the nominal and the available power of the transformer.

The transformer and other booster system components also cause certain losses. However such losses amount to hardly more than 5 % of the power applied.

If the system losses and the difference between nominal and available power are taken into consideration, up to about 20 % of the nominal capacity of the transformer may not always available.

However, there are also some avoidable reasons for large differences between nominal and available powers:

- one or more electrodes are either extremely short or even broken off - this increases the system resistance,
- the glass colour, glass composition or even type of glass has been changed,
- faulty electrical phase distribution,
- use of a transformer that was designed for a different application.

Electrode length

The water-cooled electrode holders used to introduce the electrodes protect the electrodes against oxidation and limit the wear of the refractories around the electrodes. The importance of water cooling is generally accepted, but the significance of the electrode condition itself is often under-estimated. The operation of a booster with short electrodes endangers both the electrode holder and the refractory material near the holder.

There are no direct methods for accurate measurement of the condition of the electrodes, but analysis of the typical operating data can be a good indicator. However, this requires the collecion of the relevant data and the necessary experience in order to carry out the analysis.

A new system development – the SORG® ELM system – provides operating personnel with clear, precise information about the electrode condition. With the ELM system the operating data is analysed and the results compared with reference data based on a specific electrode condition. The result is displayed as a numerical value that represents the electrode length that still exists.

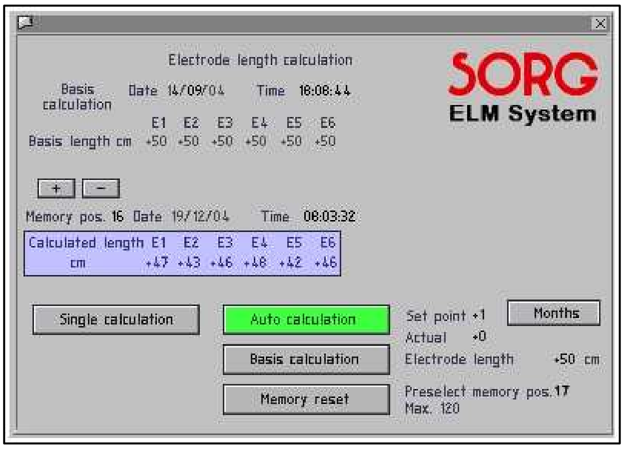

Fig. 4: ELM system – a typical result window

The operators can follow the electrode wear and plan the advancing work in good time, so that disruptions to the furnace operation are kept to a minimum.

The numerical value also indicates clearly to the operator how far each electrode needs to be advanced.

Boosters are often used despite the higher cost of electrical energy compared with that from fossil fuels. However, recent significant increases in the cost of fossil fuels have reduced the cost differential between energy sources in many countries, and make the use of boosting systems even more attractive.

In the case of special glasses that are difficult to melt, such as E glass and Pyrex®, boosters are absolutely necessary. For soda-lime applications there are also compelling technical and, increasingly, economic reasons for their use. With environmental considerations now complicating the equation - for example, the use of electrical energy does not contribute to the CO_2 emissions of the glass factory – each individual case must be considered separately.