Five years of operational experience with the SORG LoNOx® Melter[1])

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Following an operation of $5^1/_2$ years, the prototype of the well-known LoNOx® Melter was shut down in the bottle glass plant at Steinbach am Wald, repaired and then put into operation again. This paper is about the operational experience gained during the time the melter was in operation as well as about the changes made during the repair and their initial consequences.

During the last furnace campaign the tonnage was increased from 165 to a maximum of 220 t/d and the cullet ratio was raised to 95 % at the same time. The specific energy consumption decreased to below 3600 kJ/kg and it was possible to further reduce it to 3300 kJ/kg following the repair. The proportion of booster energy, too, was reduced. The NO_x levels initially achieved were mostly below the target value set by TA Luft (air pollution regulations). At present, the target value can be maintained in a stable way. This type of furnace can be considered to be a good alternative to conventional furnaces with a Denox unit.

Fünf Jahre Betriebserfahrung mit dem SORG-LoNOx®-Melter

Nach $5^1/_2$jähriger Laufzeit wurde der Prototyp des bekannten LoNOx®-Melters in der Flaschenglashütte in Steinbach am Wald gelöscht, repariert und wieder in Betrieb genommen. Es wird über die Betriebserfahrungen der vergangenen Laufzeit berichtet und Angaben zu Veränderungen während der Reparatur und deren ersten Auswirkungen gemacht.

Im Verlauf der Wannenreise wurde der Durchsatz von 165 auf maximal 220 t/d gesteigert, der Scherbeneinsatz dabei auf 95 % erhöht. Der spezifische Energieverbrauch sank unter 3600 kJ/kg und konnte nach der Reparatur auf 3300 kJ/kg gesenkt werden. Auch der Anteil an Boosterenergie wurde verringert. Die erreichten NO_x-Werte lagen anfänglich teilweise unterhalb des Zielwertes der TA Luft. Derzeitig läßt sich der Zielwert stabil einhalten. Nach wie vor wird dieser Wannentyp als günstige Alternative zu konventionellen Wannen mit Denox-Anlage eingeschätzt.

1. Problem of NO_x formation during glass melting

From time immemorial glass has been made under fire. The hotter the fire, the better and the clearer the glass will be. Conventional high-duty glass furnaces as they are operated for economically producing container glass in particular must have temperatures of more than 1500, or even more than 1600 °C, in the fired heating chamber in order to achieve the desired glass quality at high levels of performance and energy efficiency. The development of good refractories allowed this trend to be developed, which led to furnaces melting 200 to 300 t/d at overall efficiencies of more than 50 %.

This development is, however, restricted by the fact that an increasing intensity of the melt does on the other hand lead to an increasing emission of contaminants. At flame temperatures of more than 1600 °C as they exist in the glass furnace, for instance, nitric oxide (NO) is generated in several ways which gets into the atmosphere via the waste gas, is subsequently oxidized to NO_2 and is one of the causes of the "acid rain". Combustion with excess oxygen as well as a high preheating temperature of the combustion components, both of which are economically beneficial factors, increase the tendency to NO formation. Depending on the type of fuel, on the combustion conditions and on the dwell time at peak temperatures, 1 to 5 g NO, calculated as NO_2, may be generated per cubic metre of waste gas in standard state [1].

In addition, there are some other emissions which occur during glass melting. These are:

a) NO_x (NO, NO_2) from the dissolution of sodium nitrate which is added to the glass batch to act as refining or oxidizing agent;

b) dust generated by the evaporation from the melt (alkali oxide, boron trioxide, borates, lead oxide, fluoride etc.);

c) dust carried over from the input material in the turbulent flame;

d) sulphur oxides from the sulphur contents of the fuel (especially in the case of heavy fuel);

e) sulphur oxides, chlorides and fluorides from the material used (refining agent Na_2SO_4, contaminations of the batch raw materials and the cullet, the latter of which accounts for 95 % of the raw materials used).

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[1]) Extended version of a paper presented in German to the Technical Committee VI of the German Society of Glass Technology (DGG) on October 20, 1993 in Würzburg (Germany).

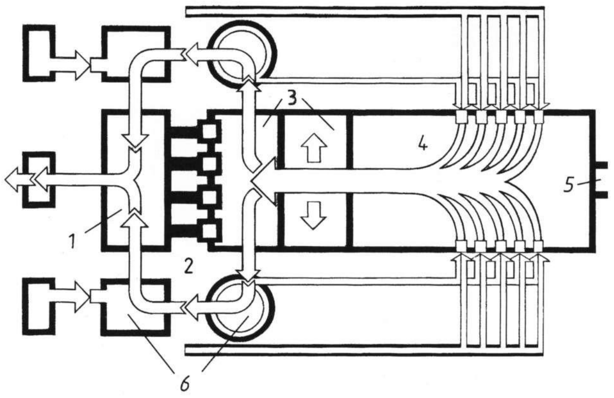


Figure 1. Scheme of the LoNOx® Melter. 1: cullet preheater, 2: charger, 3: premelting zones, 4: melting zone, 5: throat, 6: recuperator.

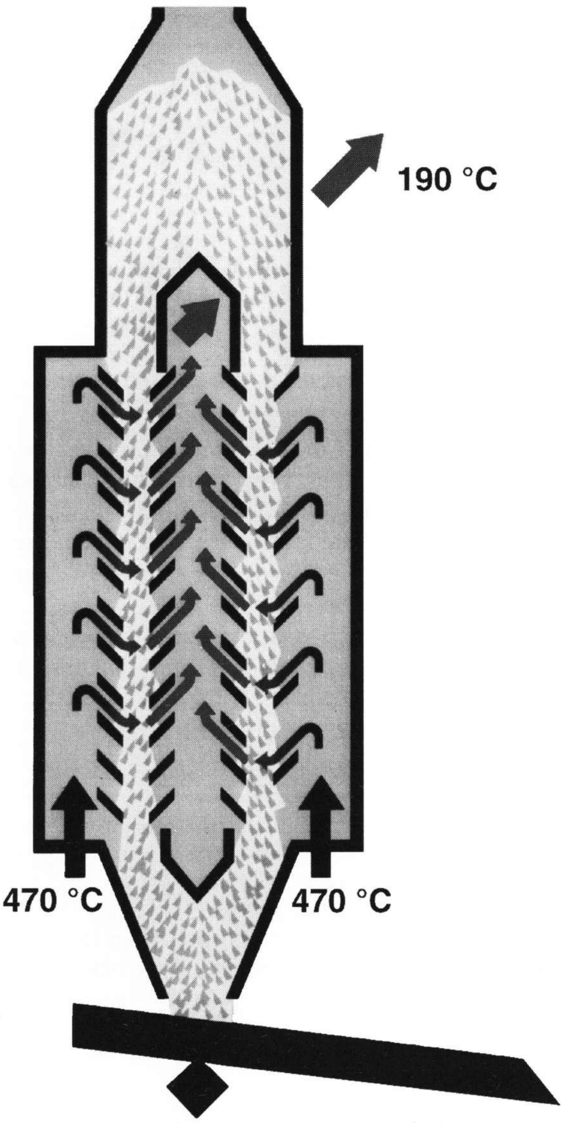


Figure 2. Scheme of the cullet preheater.

2. Objective

In order to close the increasingly irreconcilable gap between economy and ecological harmlessness of the glass melting process without having to take efforts to subsequently treat the waste gas, the company SORG worked out a new furnace concept where the melting conditions were directed towards an emission of contaminants at the lowest possible level. As the main intention was the reduction of NO_x, which was difficult to separate in other ways, the new furnace was named LoNOx® Melter ("Low NO_x").

Hence, assuming ratings (200 t/d at minimum) and an energy efficiency comparable to good end-fired furnaces, the objective was to reduce the emissions of contaminants to such a degree that the target values set by the TA Luft (air pollution standards) would be reached. Having in mind all the experience made so far, this type of task seemed to be like trying to square the circle, especially with regard to the NO_x target value of 500 mg/m^3 waste gas related to 8 % O_2 in the waste gas.

3. Concept of the SORG LoNOx® Melter

Figure 1 shows the concept of the LoNOx® Melter which has already been presented several times in the past [2]. This concept assumes that a combustion with slight air preheating strongly diminishes the formation of NO_x. In accordance with this, the waste gas temperature in the furnace itself is heavily reduced by conveying the heat to the charged material in the counter flow. The remaining heat which is no longer used in the subsequent recuperator is transferred in a cullet preheater to the cullet. The threefold benefit gained from using heat of the furnace, of the recuperator, and of the cullet preheater ensures low heat consumption levels despite limited air preheating to approximately 700 °C and moderate furnace peak temperature. As per the concept, the furnace has a long shape with several furnace chambers behind one another and with increasing temperature level.

Apart from the Deep Refiner area, the largest bath depth of the furnace is in the charging area. Here, the heat is transferred particularly from below via the hot backflow of the glass to the charged material, supported by a charging booster system. The lowest bath depth is to be found in the hot area. Backflow and homogenization are here supported by a bubbler system. The known Deep Refiner for settling down and cooling down the glass is adjoining.

The cullet preheater (figure 2) consists of two parallel cullet flows, which vertically move downwards and are held by louver-like supporting plates. Hot waste glass flows through the spacings of the supporting plates directly through the cullet bed and conveys its heat to the cullet resulting in preheated cullet being sent to the charger.

4. Installation and first operational experience made at Wiegand Glas

The prototype of such a melting aggregate was set up and put into operation at the Bayerische Flaschen-

Glashüttenwerke Wiegand & Söhne GmbH & Co. KG in Steinbach in 1987. The main data can be seen from table 1.

Table 1. Main data of the initial LoNOx® Melter

total area	113 m^2
preheating area	63 m^2
melting and refining area	50 m^2
planned throughput	200 t/d
glass type	amber container glass
designed specific heat consumption	3600 kJ/kg
cullet preheating temperature	≥400 °C
air preheating temperature	≤700 °C

The furnace is heated with natural gas (H), but it can also be heated with heavy oil. The booster efficiency in the melting area was 900 to 1000 kW according to approximately 10 % of the total energy supply. Following set-up and commissioning of the furnace in mutual cooperation of Sorg and Wiegand Glas, it turned out that some changes would be necessary. These were in particular:

a) No gas-preheating system (failures through problems with materials, too few benefits in energy consumption);

b) rebuild of the convective part of the recuperators (too susceptible to failure by strong cakings of dust);

c) use of new chargers because the old ones led to excessive formation of dust in the furnace as a result of a very large height of fall (designed for a good heat transfer). This led to a high degree of furnace corrosion in the superstructure;

d) change in number and arrangement of the bubbler nozzles in the refining bench area (transition from area bubbler to 2 discrete bubbler rows);

e) alteration of the connection and arrangement of the booster electrodes (concentration of the booster energy to the charging area).

Following these changes a normal production operation was possible on the furnace. Initial measurements of the furnace emission yielded an NO_x level of 412 mg/m^3 waste gas with 8 % O_2, i.e., a level that is below the one targeted by the TA Luft.

A level of 503 mg/m^3 waste gas was measured for SO_2, which is a level that is just a result of the removal of gas from the batch or of the cullet reactions since natural gas H is virtually free from sulphur.

The contents of dust with a level of 250 mg/m^3 waste gas was far above the limit set by TA Luft, i.e., the objective of a dust-free glass melt without precipitation is not achievable. However, with the unit being connected to a waste gas purification system (dry sorption with $Ca(OH)_2$, electric precipitator), the contents of dust, Cl^- and F^- did not pose any problems in the end. There are several reports available on the initial operational experience [2 and 3].

5. Operational experience following a continuous operation of more than 5 years

The furnace was put into operation in December 1987 and was shut down in May 1993. The operational time of $5^1/_2$ years can now be summarized as follows.

a) Furnace efficiency

It was possible to increase the tonnage continuously during the furnace campaign (figure 3). Daily peak levels were around 220 t/d. Consequently, the specific energy use decreased to levels of below 3600 kJ/kg. This was possible by permanently optimizing the furnace operation (charger, bubbler, booster, burner settings, etc.). Another conductive factor was the permanently increasing ratio of cullet, which was 95 % at the end of the furnace campaign. It was not possible to reduce the proportion of electric energy to below 10 % because otherwise melting problems were to be faced.

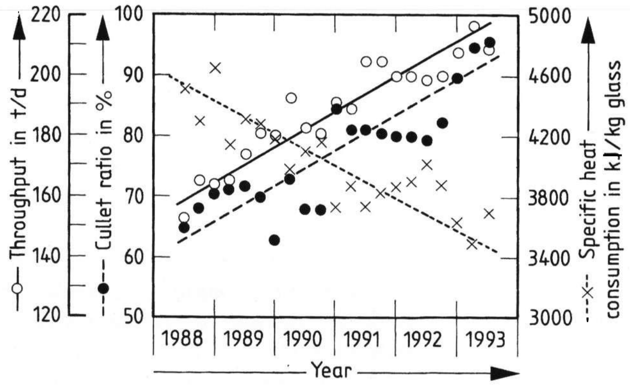


Figure 3. Throughput, amount of cullet and specific heat consumption during the furnace campaign.

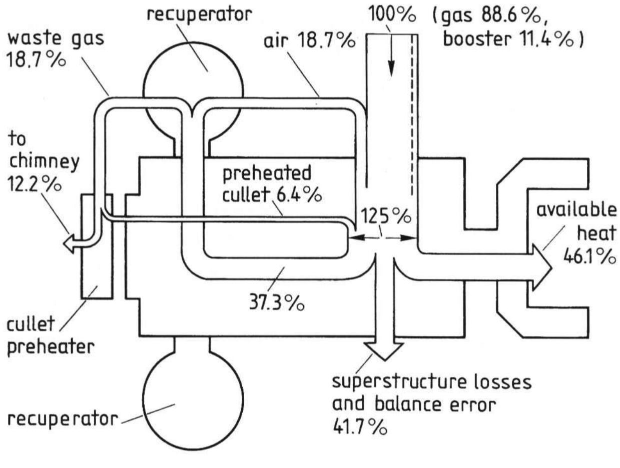


Figure 4. Estimated heat balance (in %) of the LoNOx® Melter; throughput: 200 t/d, amount of cullet: 95 %.

b) Glass quality and glass flows

Regarding seediness the furnace produced satisfactory results. The stones were mostly undissolved porcelain fragments from the recycled cullet. Due to the high cullet ratio and the low superstructure temperature, the amount of stones was slightly higher than in other furnaces.

c) Heat balance

The heat balance of the furnace was calculated from the operational data assuming a tonnage of 200 t/d at a cullet ratio of 95 % (figure 4). In this regard it must be pointed out that this cannot be considered to be a detailed balance and, therefore, contains any errors that are involved in the temperature measurement of flowing gases and preheated cullet, for instance. If one assumes the total energy input (booster 11.4 % and the rest gas) to be 100 %, then the waste gas losses amount to only 12.2 % as a result of the multistage utilization. The available heat and hence the overall efficiency are 46.1 %, which is a level that can be considered to be good. The balance item of "superstructure losses" seems to be high, but does contain the balance error. However, considering the relatively large furnace body (the specific melting rate is only about 1.8 $t/(m^2 \cdot d)$ in total, while the specific melting rate in the melting and refining area is 4.4 $t/(m^2 \cdot d)$, a slightly higher loss in the superstructure is to be anticipated despite a very good heat insulation.

d) Cullet preheater

As already reported [4], the cullet preheater caused relatively few problems. From its heat balance it can be seen that approximately 1/3 of the remaining waste gas heat will be transferred to the cullet after having passed through the recuperators. Initially, dark colour streaks occurred in the glass from time to time, which was the result of a local over-reduction caused by fine and carboniferous deposits of smouldering remnants in the preheater. This problem was eliminated by periodical automatic cleaning and by going over to washed cullet.

The heat transfer from the waste gas to the cullet is to be considered very good because the cullet almost takes on the waste gas inlet temperature. This continued to be the case even after a considerable tonnage increase of the cullet preheater from initially 120 to a maximum of 210 t/d. At this high efficiency, the cullet dwell time in the preheater is approximately 11 h, with the cullet being about half of this time in contact with the waste gases. The amount of waste gas was heavily increased by air leakage through the charging side of the preheater, which resulted in high suction efficiencies of the forced-draught fan, the fan wheel and housing of which had to be frequently repaired or even renewed due to the abrasive effect of the glass dust.

The maximum proportion of fine grain <3.15 mm initially set by the company SORG was 10 %. The resulting amount of fine grain sieved was therefore used on other furnaces. Because this caused some trouble in the long term, the fine grain was added to the cullet during the last six months. By doing so, the dust contained in the raw waste gas increased, which was indicated by an increase in the SiO_2 contents in the filter dust from 7 to 15 %. No significant increases in the wear of the fan were experienced, although the fan speed was slightly raised. There were no dust deposits in the pipings which could have lead to failures. There was very little wear in the area of the guide plates of the preheater. However, some distortions occurred in the steel construction, which were caused by temperature changes and had to be eliminated during repair.

e) Recuperators

The recuperators arranged in pairs consist of a radiation zone with a cage in counter-flow operation and a convective zone connected behind on the waste gas side. The cage in the radiation zone showed moderate-to-low deposits which did not markedly hinder the heat transfer. The convective zone had to be freed from loose deposits at regular intervals of 4 weeks despite the rebuild to wider waste gas conducts mentioned in section 4. This very laborious hot work also led to short-time malfunctions in the furnace operation because the air and cullet preheating were disrupted.

f) Furnace control

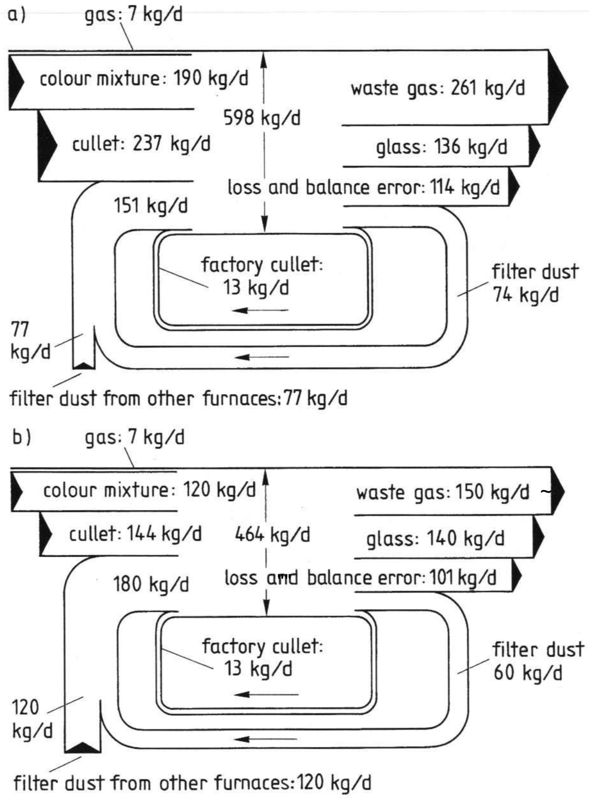
As a result of the slower operation of the furnace, new experience need to be gained in the furnace control and the operators are required to be more foresighted. Bubbler intensity, boosting, and burner settings had to be defined anew for each throughput. The furnace operation became more stable as the cullet ratio increased, which was evidenced by the low tendency to foam formation in the furnace, by a quicker melting of the batch piles in front of the bubbler area and by an improved colour stability. It was possible to influence the working end temperature, which occupies a particular central position in furnaces with working ends of low volume and high pull rates, by means of the bubblers; however, an increase in the bubbler air volume first led over a certain threshold to a temperature decrease in the working end and then gradually to a temperature increase. This is considered to be caused by increasing the speed of the glass flow at the bottom of the furnace, which in the longer term leads to an increase in temperature.

g) Emissions

A question of very high interest is that of the development of the emissions of the LoNOx® Melter. Initial intentions to run the LoNOx® Melter with the cullet preheating system without arranging for any further waste gas purification but to rely on SO_2, HCl, HF and dust being bonded to such a degree that one would fall below the limits set by TA Luft had soon to be abandoned. Though there is indeed a certain absorption for acid gas components, the balance of NO_x, HF and HCl is shifted to the glass side, which means that these components are slightly reduced in the waste gas. As for dust, there naturally occurs an even stronger loading because the cullet is covered with dust, even after having been washed. As already mentioned, the waste gas is

Table 2. NO_x measurements on the LoNOx® Melter

date	output in t/d	NO_x, standardized to 8 % O_2, in mg/m³ waste gas	
21/07/1988	162	412	
11/05/1989	177	421	
16/05/1991	207	755	modified burner operation
10/06/1992	200	664	
27/02/1994	220	430	



Figures 5a and b. Sulphur balances (in kg/d) of the LoNOx® Melter for an amount of cullet of 80 %, a) in August 1991, b) in August 1992.

purified later and satisfies the TA Luft regulations with regard to the limits of dust, SO_x, HCl and HF.

The NO_x values obtained from initial measurements were 412 mg/m³ waste gas (8 % O_2). As already described, the furnace efficiency and hence the load on the combustion chamber as well as to a low degree the temperature, too, were steadily increased. As a consequence, the NO_x values were slowly raised. Measurements which were carried out by the authors showed decreased values in between times. The results of the most recent official measurements are shown in table 2.

Figures 5a and b show sulphur balances calculated for various times. It can be seen that a certain amount of SO_2 can be added by using filter dust from other furnaces.

h) Furnace wear

Following the shutting down of the furnace after a campaign of 5¹/₂ years, the wear pattern can be briefly depicted as follows:

- Basin (ER 1681 or 1711 of various qualities)
  - almost no attack in the cold area;
  - normal attack on the metal line in the hot area, this part could have been run for another 4 to 5 years or a total of 10 to 12 years without paving.
- Superstructure (silica, insulated)
  - severe attack and melting in the cold area caused by initial strong dusting and alkali condensates; gable wall and doghouse arch were severely attacked, zone separating arches were fully away.
- Hot area almost pristine, only small areas of corrosion existed in connection with other materials.

To a high degree, these damages were caused as early as in the first year of operation. A detailed description of the wear pattern is to be found in [5].

Following a summing up of the total operational experience made so far, the partners Wiegand and Sorg mutually agreed and implemented the following constructional changes:

- enlargement of hot area (increase of the furnace efficiency, 5 instead of 4 pairs of burners) and at the same time reduction of the preheating area,
- new burners (generation of a luminous flame in order to improve the heat transfer),
- no intermediate arch in the primary melting zone of the furnace,
- constructional changes of the arches,
- reduction of the bath depth in the charging area (reduction of dead volume, less need for boosting),
- flatter and shorter threshold (wall-type shaping),
- arrangement of bubblers in front of the wall in the deep area (acting as the driving force of the backflow),
- simplification of the charging technique (conventional charger with eccentric troughs designed for low dust charging,
- structured superstructure for improved radiation,
- new recuperator system (larger radiation part, smaller convective part with wide conducts, changeable registers and good accessibility),
- redesigning of the infeed and outfeed of the cullet preheater (reduction of false air and hence less output and slighter wear of the blower),
- improved insulation in several areas,
- use of unwashed cullet including a proportion of fine grain.

6. Starting up following general repair – Estimation of the future changes of the LoNOx® Melter

After putting the furnace into operation again subsequent to the general repair, efforts had to be made to gain new experience in order to optimize the furnace operation. This work cannot be regarded as finished yet. The following statements can, however, already be made:

- The planned increase of efficiency to 220 t/d is achieved. Peak values are not known yet.
- The use of dry processed cullet has not caused any drawbacks so far.
- The total amount of energy used could be reduced to approximately 3300 kJ/kg (peaks of 3200 kJ/kg).
- The proportion of electric energy could be reduced to approximately 3 %.
- Regarding refining and dissolution of stones, the operation is more favourable than with the old furnace.
- Stable glass colouring.
- The contents of O_2 in the waste gas decreased from 11 to 7.5 %, i.e., the system draws a markedly lower amount of false air; the fan speed and the level of wear decreased.
- The flame is luminous and comes out well on the camera image.
- The wear of the superstructure in the preheating zone seems to be strongly reduced.
- The cleaning of the convective recuperator requires considerably less work than it did before.
- Cullet ratios of 90 to 95 % can still be used, provided that the cullet is of good quality.
- By specifically influencing the combustion process in the furnace a stable operation of the furnace with NO_x contents <500 mg/m^3 waste gas, standardized to 8 % O_2, is possible.

The current overall assessment of the system is based on the assumption that the system produces top thermic values. It equals most advanced end-fired furnaces with material preheating. Regarding primary NO_x formation, a level has been reached which other systems are not able to achieve permanently. It is possible to steadily fall below the target value set by the TA Luft. But an operation without a waste gas purification system (dust, acid contaminants etc.) that is connected behind is not possible.

A colour change in the furnace has not been implemented by SORG yet. In the old furnace state, this was considered to give some reason for concern and therefore a colour change (high dead volume) was not carried out. Following the implementation of the changes to the furnace a colour change should be possible over a period of 3 to 4 d, but is not planned at the moment.

Positive experience with regard to glass quality, energy consumption and low emission levels has meanwhile been gained by the company SORG on the FlexMelter® which is similar to the concept of the LoNOx® Melter. As to their present state, the LoNOx® and the FlexMelters® are a real alternative to the conventional melting units which use a Denox system.

7. References

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