

Comparison of ecological and economic aspects of a modern regenerative end-fired furnace and the second generation Sorg LoNOx[®] Melter¹⁾

Helmut Pieper, Thomas Platzter and Jürgen Becher
Nikolaus Sorg GmbH & Co. KG, Lohr (Germany)

All cost parameters which affect the economic viability of a glass melting furnace have been compiled and assessed in the present comparison. Ecological aspects have joined the previously valid economic aspects causing higher operating costs in the case of conventional furnaces. An economic comparison between an end-fired furnace and a second generation LoNOx[®] Melter, with and without cullet preheating, was made, whereby all furnaces have a melting capacity of 250 t/d with an amount of 90% cullet in the batch. The most important value for the operator ultimately is the value of the furnace-dependent costs per tonne of glass at the end of two furnace campaigns. It turns out that this value for the second generation LoNOx[®] Melter with cullet preheating is about 19% lower than in the case of a high-performance end-fired furnace. In addition, an oxygen-fired LoNOx[®] Melter has been included in the assessment to complete this comparison.

Ökologischer und ökonomischer Vergleich zwischen einer modernen U-Flammenwanne und der zweiten Generation des Sorg LoNOx[®] Melters

In dem vorliegenden Vergleich werden alle Kostenparameter, die die Wirtschaftlichkeit einer Glasschmelzwanne beeinflussen, zusammengetragen und bewertet. Zu den bisher gültigen ökonomischen Gesichtspunkten haben sich ökologische Gesichtspunkte gesellt, die bei herkömmlichen Wannen zu höheren Betriebskosten führen. Es wird ein Wirtschaftlichkeitsvergleich zwischen einer U-Flammenwanne und einem LoNOx[®] Melter der zweiten Generation mit und ohne Scherbenvorwärmung angestellt, wobei alle Wannen eine Schmelzleistung von 250 t/d, bei einem Scherbeneinsatz von 90%, erbringen sollen. Der Wert, der letztlich die größte Aussagekraft für den Betreiber hat, ist der Wert der ofenabhängigen Kosten für die Tonne Glas am Ende von zwei Wannenreisen. Es zeigt sich, daß dieser Wert bei der zweiten Generation des LoNOx[®] Melters mit Scherbenvorwärmung um 19% niedriger als bei einer Hochleistungs-U-Flammenwanne liegt. Zusätzlich wurde noch ein sauerstoffgefeuerter LoNOx[®] Melter in die Bewertung aufgenommen, um den Vergleich abzurunden.

1. Introduction

In the past furnaces were judged on campaign length, energy consumption and investment cost, but today tightening environmental regulations have led to increased emphasis on the ecological aspects of modern glass furnace operation. This paper draws a comparison between an end-fired furnace and a second generation LoNOx[®] Melter, with reference to ecological and economic parameters.

Campaign length, energy consumption, refractory material costs and therefore the investment cost, and the costs involved with any auxiliary equipment that may be required, such as DeNOx equipment, are the main factors which exert a significant influence on the economics of a furnace. The main ecological factors cover NO_x emissions, reduction of the mass flow and other emissions.

The glass sector is one of the branches of industry with the highest NO_x emissions. At the present time relatively high concentrations of NO_x in the waste gases are permitted in the glass industry. However, these NO_x

limits are subjected to a dynamic clause, which states that the current state-of-the-art technology must be applied to reduce emissions. In glass melting furnaces the main source of NO_x is the flame. The high flame temperatures, the oxygen content in the immediate reaction zone and the residence time in the high-temperature environment of the furnace superstructure are the main factors which influence the amount of NO_x produced.

In practice these factors depend on a number of operating parameters; such as the amount of excess air provided, the preheat temperature of the combustion air, the flame temperature, the type of fuel, the mixing of fuel and combustion air, various burner parameters, intensive slow mixing of the combustion gases and the furnace chamber dimensions. It is widely known that minimization of the excess air in order to achieve nearly stoichiometric combustion will significantly reduce the NO_x emission level. A considerable reduction can also be obtained by a decrease in the combustion air preheat temperature. This effectively suggests a change to recuperative glass melting furnaces.

In order to compensate for the higher energy consumption of recuperative furnaces compared with regenerative end-fired furnaces, Sorg has developed the LoNOx[®] Melter.

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Table 1. Comparison of technical data for three furnace types. The basic data for all furnaces are: melting capacity = 250 t/d, green container glass, amount of cullet in the batch = 90%

	furnace type		
	LoNOx [®] Melter without cullet preheating	end-fired furnace	LoNOx [®] Melter with cullet preheating
melting area in m ²	130	85	118
electrical energy in kW	450	390	450
electricity ratio in %	4.0	3.6	4.8
specific energy consumption	930 kcal/kg glass (≈ 3906 kJ/kg glass)	900 kcal/kg glass (≈ 3780 kJ/kg glass)	770 kcal/kg glass (≈ 3234 kJ/kg glass)
batch charging	4 chute chargers	2 pusher chargers	4 chute chargers
bubbler	1 bubbler row	1 bubbler row	1 bubbler row
air preheating	1 recuperator	1 single-pass chamber	1 recuperator
air preheat temperature in °C	650	1280	650
cullet preheating	none	none	400 °C
expected NO _x values in mg/m ³	ca. 440	ca. 800 with Sorg [®] Cascade Heating System	ca. 440

2. Comparison

The melting capacity was set at 250 t/d for green container glass, with an amount of 90% cullet in the batch, for the two furnace systems, whereby one of them is examined both with and without cullet preheating.

Two of the main features of the LoNOx[®] Melter are the internal raw material preheating on the glass bath and the integration of cullet preheating within the process. Experience has shown that the specific heat consumption achieved is significantly lower than with conventional recuperative furnaces. A comparison of the most important technical details of both furnace systems is shown in table 1.

A specific melting rate of approximately 2.94 t/(m² d) is used for the regenerative end-fired furnace. In comparison the LoNOx[®] Melter with cullet preheating attains a specific melting rate of 2.12 t/(m² d). The melting area of the LoNOx[®] Melter without cullet preheating must be somewhat greater to compensate for the lack of energy from the hot cullet. A specific melting rate of 1.92 t/(m² d) is the basis taken for this furnace. However, a comparison of the specific melting rates in this form has no meaning. If only the area actually heated were taken into account, the LoNOx[®] Melter would achieve a specific melting capacity of approximately 3.5 t/m².

The amount of electrical energy used on both systems is approximately 4%. The air preheat temperature is taken as 1280 °C for the regenerative end-fired furnace and 650 °C for the LoNOx[®] Melter. Preheating the cullet to approximately 350 to 400 °C, and a number of other measures have a significant influence on the energy consumption. An energy consumption of approximately 3780 kJ/kg glass (= 900 kcal/kg glass) is achieved by the regenerative end-fired furnace, whereas the LoNOx[®]

Melter with cullet preheating reaches a value of approximately 3234 kJ/kg glass (= 770 kcal/kg glass). For the LoNOx[®] Melter without cullet preheating a value of approximately 3906 kJ/kg glass (= 930 kcal/kg glass) is obtained.

The LoNOx[®] Melter, with or without cullet preheating, achieves NO_x emission values in the waste gases of approximately 440 mg/m³, compared with 800 mg/m³ for the end-fired furnace. All values are corrected for 8 vol.% oxygen, dry waste gas, 273 K and 1 bar. The NO_x emission value for the end-fired furnace is only achieved with the installation of a Sorg[®] Cascade Heating System. Based on these values the LoNOx[®] Melter discharges about 45% less NO_x than the regenerative end-fired furnace.

The energy consumption and energy costs for both furnace types are shown in figure 1. The energy costs are based on prices of DM 180.00/t for oil and DM 0.136/kWh for electrical energy. The respective costs for the LoNOx[®] Melter with cullet preheating are DM 19.25/t glass, and DM 22.22/t glass without cullet preheating.

An energy consumption of ≈ 3780 kJ/kg glass (= 900 kcal/kg glass) was calculated for the end-fired furnace. The energy consumption of the LoNOx[®] Melter with cullet preheating is approximately 14.4% lower than that of the end-fired furnace, whereas without cullet preheating, the energy consumption of the LoNOx[®] Melter is approximately 3.3% higher than that of the end-fired furnace.

The low energy consumption of the LoNOx[®] Melter with cullet preheating is a result of the low waste gas temperature of approximately 1050 °C at which the waste gases enter the recuperator, and of the energy returned

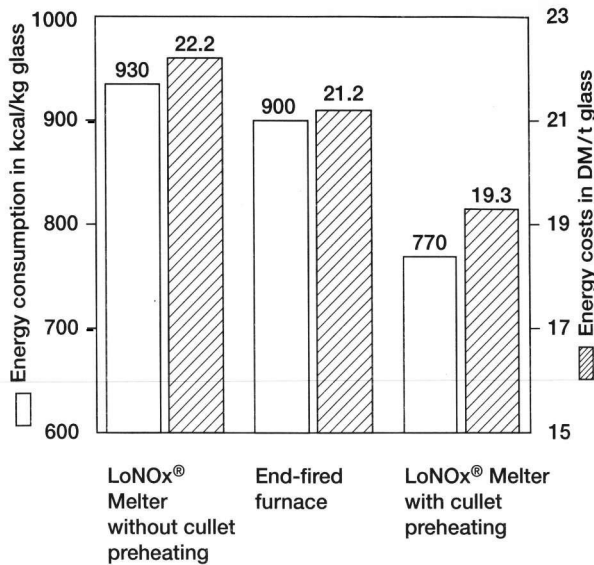


Figure 1. Energy consumption and energy costs for the three furnace types. Energy consumption for: LoNOx Melter without cullet preheating = 930 kcal/kg glass (\approx 3906 kJ/kg glass), end-fired furnace = 900 kcal/kg glass (\approx 3780 kJ/kg glass), LoNOx Melter with cullet preheating = 770 kcal/kg glass (\approx 3234 kJ/kg glass)

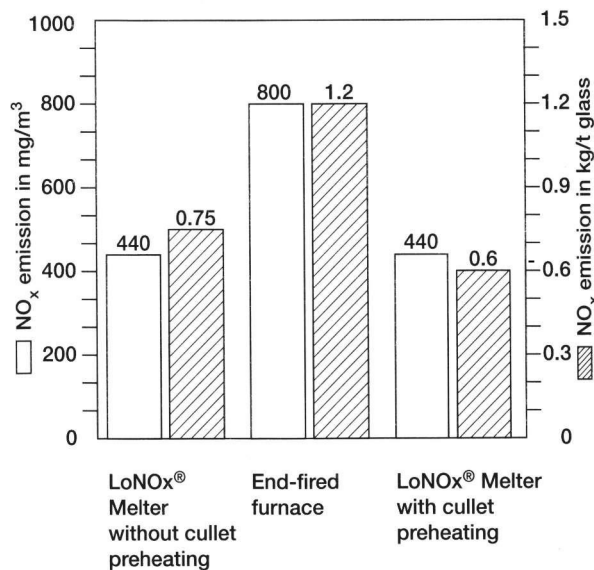


Figure 2. NO_x emissions of the three furnace types.

by the preheated cullet. The cullet preheating introduces approximately 800 kW of energy into the furnace. The LoNOx[®] Melter with cullet preheating saves up to DM 174 000.00 in energy costs annually compared with a regenerative end-fired furnace.

The German TA Luft emission regulations define limit values for NO_x emissions in mg/m³ of waste gas. However, in some published works the NO_x emissions are quoted as mass-related values, i.e. in kg/t glass. In figure 2 the volume-related NO_x emissions in mg/m³ are compared with the mass-related emissions in kg/t glass.

As can be seen in the diagram, the NO_x emissions from the LoNOx[®] Melter are approximately 45% lower

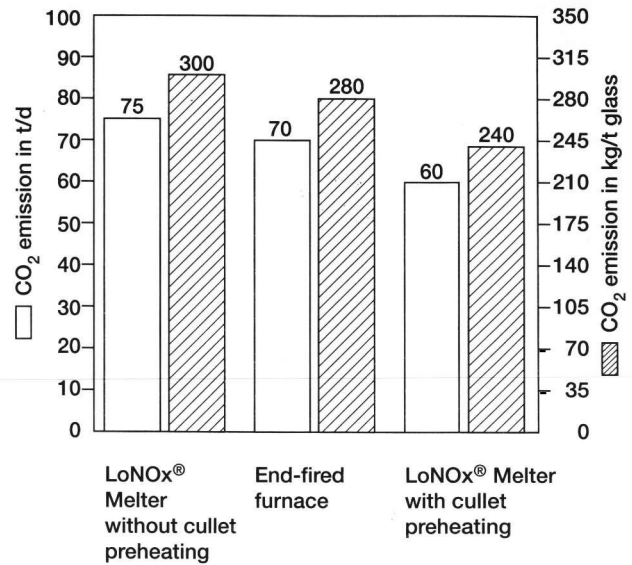


Figure 3. CO₂ emissions of the three furnace types.

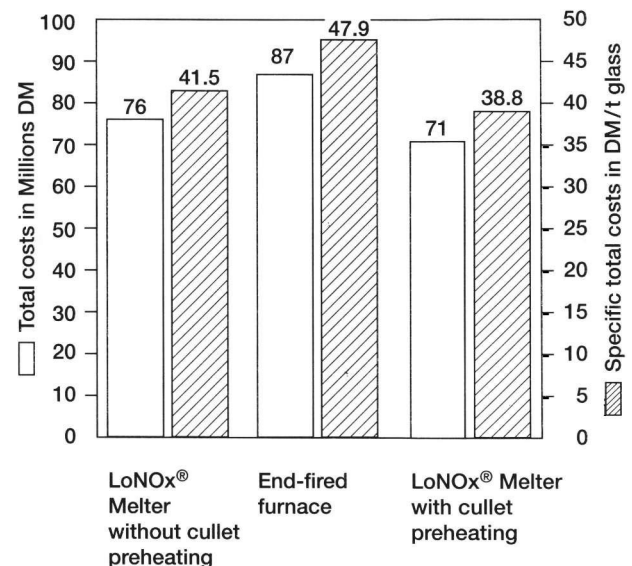


Figure 4. Total costs and specific total costs over an operating period of 21 years for the three furnace types.

than from the end-fired furnace. Values of 440 mg/m³ have been measured on a LoNOx[®] Melter, whereas the figure of 800 mg/m³ was measured on an end-fired furnace with the Sorg[®] Cascade Heating System. NO_x emissions of approximately 0.3 to 0.4 kg/t glass are quoted in the literature when oxy-firing is used. With a mass flow of 0.55 kg/t glass the LoNOx[®] Melter achieves values very similar to those of an oxy-fired installation.

There are currently discussions about the application of a CO₂ tax, possibly at a level of DM 35.00/t. It is therefore interesting to consider the CO₂ content in the waste gases as part of the economical/ecological review.

Figure 3 shows a comparison of the CO₂ emission in t/d and kg/t glass from the three furnace types. As a

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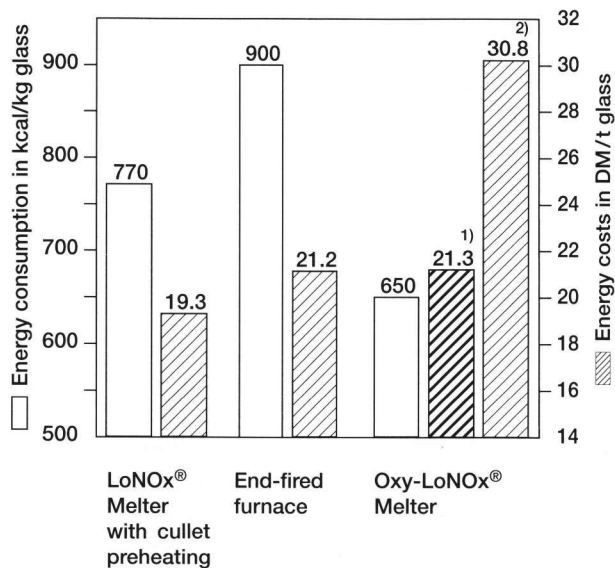


Figure 5. Energy consumption and energy costs of an Oxy-LoNOx[®] Melter compared with the LoNOx[®] Melter (with cullet preheating) and the end-fired furnace. The oxygen costs for the Oxy-LoNOx[®] Melter are based on two prices: 1) DM 0.06/m³, 2) DM 0.12/m³.

result of the low quantity of waste gases produced the CO₂ emission from the LoNOx[®] Melter with cullet preheating is lower than from the end-fired furnace and from the LoNOx[®] Melter without cullet preheating. If the CO₂ emission tax were actually levied at a rate of DM 35.00/t, these results would give annual savings of DM 128 000.00. This is definitely a sum worth saving if the CO₂ tax should become reality.

3. Results

The decisive factors when comparing different furnace systems are the specific costs in DM/t glass over the complete furnace campaign, including all furnace-dependent costs. Figure 4 shows the total costs for both furnace types over an operating period of 21 years. Two intermediate repairs are included for the end-fired furnace, with a 7-year campaign length being assumed, whereas the LoNOx[®] Melter is assumed to have a campaign length of 10¹/₂ years, and therefore to require one intermediate repair. The total costs were obtained from the sum of the investment costs, the energy costs, the repair costs, the maintenance costs and the interest on the capital.

This results in total costs of approximately DM 71 mill. for the LoNOx[®] Melter with cullet preheating, approximately DM 76 mill. for the LoNOx[®] Melter without cullet preheating, and finally approximately DM 87 mill. for the regenerative end-fired furnace. This means that the total costs for the LoNOx[®] Melter with cullet preheating are DM 17 mill. lower than those for the end-fired furnace. This is equivalent to a saving of 19%.

The specific total cost, calculated as the sum of all furnace-dependent costs divided by the melting capacity

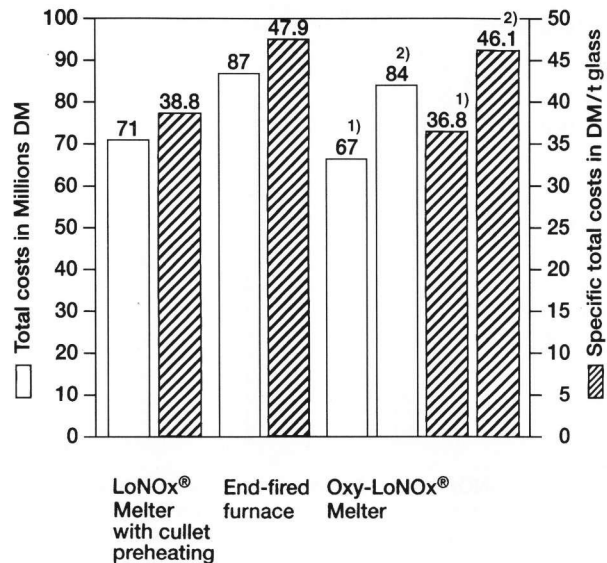


Figure 6. Total costs and specific total costs of an Oxy-LoNOx[®] Melter compared with the LoNOx[®] Melter (with cullet preheating) and the end-fired furnace. The costs for the Oxy-LoNOx[®] Melter are based on two prices for oxygen: 1) = DM 0.06/m³, 2) = DM 0.12/m³.

amounts to approximately DM 39.00/t for the LoNOx[®] Melter with cullet preheating and approximately DM 48.00/t for the regenerative end-fired furnace. This gives a difference of DM 9.00/t glass. If DeNOx equipment must be installed on the end-fired furnace, then the total costs for this furnace are increased by a further DM 3 mill.

The specific total cost is calculated from the energy costs and the specific additional costs. For the LoNOx[®] Melter, with and without cullet preheating, the energy cost proportion amounts to approximately 50% of the specific total costs, whereas a proportion of approximately 44% is reached with the end-fired furnace.

4. Additional comparison with the use of oxygen

The application of oxy-firing is finding increased interest in the glass industry. The use of oxygen can be expected to lead to the following advantages. The melting capacity will increase by about 15 to 20%, there will be a reduction of the NO_x emission, and the energy consumption will be reduced as a result of the low waste gas volume.

Figure 5 shows a comparison between a LoNOx[®] Melter with cullet preheater, an Oxy-LoNOx[®] Melter using oxygen, with cullet preheater and a conventional end-fired furnace. The diagram shows energy consumption values of ≈ 3234 kJ/kg glass (= 770 kcal/kg glass) for the LoNOx[®] Melter with cullet preheating, ≈ 2730 kJ/kg glass (= 650 kcal/kg glass) for the Oxy-LoNOx[®] Melter with cullet preheating and, as already mentioned, ≈ 3780 kJ/kg glass (= 900 kcal/kg glass) for the end-fired furnace. This means that when oxygen is

Table 2. Advantages of the Sorg LoNOx[®] Melter

ecological advantages	economic advantages
NO _x values <500 mg/m ³	campaign length 10 to 12 years
higher cullet amount in the batch, maximum 95%	energy consumption <800 kcal/kg glass (≈ 3360 kJ/kg glass)
cullet preheating >350 °C	waste heat recovery within the process without loss of efficiency due to the cullet preheating
lower primary dusting	
reduction of organic particles in the cullet	
reduction of the mass flow and emission	through dried cullet: - constant redox factor - better refining - lower foam formation - more stable glass colour - good homogeneity
lower temperatures make it simpler to dedust waste gas after cullet preheating	lower operating costs
	lower entry temperature in working end (good glass workability due to long residence time in the melter)
	higher flexibility at load changes

used in the LoNOx[®] Melter the energy consumption decreases by about 16 %, and the energy consumption is 28 % lower than that of the end-fired furnace.

However, the high energy costs for oxygen heating must be set against the low energy consumption. Based on oxygen prices of DM 0.12 or DM 0.06/m³, the energy

costs for the Oxy-LoNOx[®] Melter are approximately DM 21.30 at an oxygen price of DM 0.06 or DM 30.80 at an oxygen price of DM 0.12/m³.

A comparison of the total costs and the total specific costs of the LoNOx[®] Melter with air combustion, an Oxy-LoNOx[®] Melter using oxygen, and a conventional regenerative end-fired furnace is shown in figure 6.

Depending on the oxygen price used as a basis, the total costs of the Oxy-LoNOx[®] Melter over the comparative time period vary between DM 67 mill. and DM 84 mill. If these figures are divided by the melting capacity, the Oxy-LoNOx[®] Melter will give melting costs of DM 36.80/t at an oxygen price of DM 0.06/m³ or DM 46.00 at an oxygen price of DM 0.12/m³. This means that at an oxygen price of DM 0.12/m³ the specific total costs of the Oxy-LoNOx[®] Melter are lower than those of the end-fired furnace, which are DM 48.00/t glass. Therefore, the LoNOx[®] Melter and the end-fired furnace have similar costs when oxygen costs DM 0.12/m³.

However, in order to achieve the same cost level with the Oxy-LoNOx[®] Melter as is obtained by the normal LoNOx[®] Melter with cullet preheating, the oxygen price should not exceed DM 0.054/m³. It is unlikely that this price level will be achieved.

Nevertheless, a LoNOx[®] Melter which is completely or partially operated with oxygen can be a viable alternative, if the investment costs should be reduced to the detriment of the operating costs, or if there is insufficient room to build the larger furnace with air and cullet preheating. In conclusion the ecological and economic advantages of the LoNOx[®] Melter are shown in table 2.

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