Glass Melting
RECENT DEVELOPMENTS OF BATCH AND CULLET PREHEATING IN EUROPE—
PRACTICAL EXPERIENCES AND IMPLICATIONS

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ABSTRACT
Batch & Cullet preheating itself is not new. First installations in the glass industry go back until the early 80ies of the last century. But, even after first successes and significant energy savings (~14-18%), the demand was not increasing, due to low energy prices, investment costs, risk aversion of decision makers, and also certain shortcomings of existing systems. However, in the last years the request for this technology increased significantly and the first new installations were made. One major challenge in first generation systems was the evaporation of batch moisture in the preheater, which resulted in batch clogging and maintenance efforts and restricted the application to batch with cullet ratios above approximately 50 per cent.

In order to improve the existing technology, Ziepe undertook considerable R & D activities and finally initiated a pilot project, together with a major European container glass producer and a leading company in furnace design to test and prove the superiority of the modern, 2nd generation system. In the meantime, in 2010, also another batch & cullet preheater (350 mt/d) was installed and first results are available. The paper will deal with these new experiences made and shall elaborate under which circumstances modern batch preheating shall be taken into account to save energy and therefore energy costs.

ENVIRONMENTAL CONTEXT
The productivity of the glass industry underwent significant improvements in the last decades. Compared to 1970, productivity in Germany approximately tripled and grew from 17,100 € to 54,800 €. While it seems that a lot has been done to improve efficiency, there are still potentials and also necessities for further improvements. In 2005 the EU implemented the so called ETS (Emission Trading Scheme) that comprises all 27 member states and forces energy intensive industries (in total 12000 production plants) as the glass industry - to focus on CO2 emissions. Each company that is listed in the national allocation plan (Nationale Allokationsplan) needs to disclose their yearly emissions which are then compared to a given and approved target. From the next trading period on in 2013, the values will be compared to reference glass factories with BAT (Best Available Technique). While also considering eventual already realized improvements, the factory is given a target emission, for example 510 kg CO2/m² of flat glass that needs to be fulfilled. This target is reduced in certain periods such that the factory is obliged to undertake further efficiency improvements. If the factory emits more

1 The combined research project "PRECIOUS" started in 2006 and was supported by the German Environment Ministry (Deutsche Bundesstiftung Umwelt). The theoretical research was done in cooperation with a major German technical university. The tests are accompanied by a reputable research organisation.

2 The start of the "PRECIOUS" project was already presented by Dr. Ann-Kathrin Glüsen: "Preheating Devices for Future Glass Making, a 2nd generation." 67th Conference on Glass Problems, Columbus Ohio, 30th Oct.- 1st Nov.


Defined as gross value added per employee per year (€).

1 Nationaler Allokationsplan Deutschland from 28.06.2006, obtained from (28.07.2010):
CO₂ than foreseen for free allocation of CO₂ permits, it needs to purchase so called CO₂-certificates which are traded at the European Energy Exchange in Leipzig, Germany. The prices in May 2010 fluctuated between 15 and 16 €/ton CO₂. Prices are expected to increase significantly in the next years, especially after the beginning of the next trading period, starting in 2013, when the quantity of certificates will be shortened, the benchmark values will be tightened and more of the certificates will also be auctioned. The aim of this market-based instrument is to enforce efficiency improvements by implementing incentives to firms to invest in pollution-minimizing (CO₂-lean) technologies. The incentives for firms are twofold. In order to avoid the necessity to purchase CO₂ certificates, firms may invest in emission-reducing technology, such as waste heat recovery systems. Furthermore, if a firm reduces its greenhouse gas emissions, it is allowed to sell non-needed allowances on the market which means an additional incentive to invest in "green technology."

Energy prices remain a concern for the European glass industry. Between 2005 and 2009, the gas prices for industrial users in the EU-27 raised from 6.0 to 9.4 €/GJ, which constitutes a price increase of almost 57%. In 1998 the respective price in the EU-15 was at level of 4.0 €/GJ.\(^4\) In Germany— the biggest glass market in the EU— prices in 2007 remained at a level of more than 12 €/GJ and only slightly decreased in 2009 to about 11 €/GJ.

Graph 1: Gas price development in the EU (€/GJ) for industrials users

These high prices and also the expectation of further increasing prices in the future, emphasized the necessity of the glass industry to invest in energy efficient technologies. However, for the melting of glass with today's technology, there are physical limits, which are almost reached.

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Table 1: development of key figures of the glass melting process

<table>
<thead>
<tr>
<th>year</th>
<th>1928</th>
<th>1968</th>
<th>1990</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>specific heat demand (kWh/int)</td>
<td>5600</td>
<td>2600</td>
<td>1550</td>
<td>1100</td>
</tr>
<tr>
<td>throughput (t/m²·d)</td>
<td>0.2</td>
<td>1.1</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>furnace lifetime(d)</td>
<td>300</td>
<td>2100</td>
<td>3000</td>
<td>4500</td>
</tr>
<tr>
<td>melting temperature(°C)</td>
<td>1370</td>
<td>1450</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>recycling ratio (%)</td>
<td>10</td>
<td>20</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>CO₂ emission (kg/int)</td>
<td>1240</td>
<td>700</td>
<td>400</td>
<td>270</td>
</tr>
</tbody>
</table>

The specific energy demand for 1 ton glass is today about one fifth than it was in 1928. Also the throughput and the furnace lifetime increased dramatically. The emissions are today about one fifth compared to the beginning of industrial glass making with regenerative melting furnaces around 1928. Through increased utilization of cullet as a batch ingredient, energy can be saved. As commonly known, through the additional input of 10%, approx. 2-3% of melting energy can be saved. However, in Europe, the additional utilization of cullet is limited in many countries, since recycling ratios are already on a high level and the availability of reusable cullet constricted. Respective ratios in Switzerland are at about 95%, in Germany at about 90%.

Taking into consideration calculations from CONRADT, the theoretical process heat demand - which constitutes the minimal possible heat demand - is reached at a value of 920 kWh/t. Looking at an industry average value of about 1000 kWh/t in 2003, it can be seen that potentials in glass melting for saving energy are limited, as the efficient frontier with today’s technology is almost reached.

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Recent Developments of Batch and Cullet Preheating in Europe

Graph 2: development of heat demand for glass melting process

Thus, to improve the energy efficiency in the glass industry to a reasonable and considerable extent, there need to be other starting points.

In the following, an overview of the energy flow of an existing container glass furnace in Europe can be seen. This furnace was taken from a best-practice-study and shows one of the most energy-efficient furnaces. At a cullet level of 84 per cent, the specific energy consumption amounts up to 3.62 GJ/ton. About 23 per cent of the total energy is needed as reaction energy, and about 45 per cent as heat content for the glass melt. Also the wall losses of about 17 per cent are considerable. However, the impact of additional insulation is limited. Thicker and stronger insulation would make the construction of the furnace more complicated and also have disadvantages concerning safety and operation of the furnace, as it would make the surveillance and the control of critical parts more difficult. As wall losses of the regenerator and the energy needed for water evaporation are of minor quantity and can hardly be changed, it seems obvious to focus on the energy losses via flue gases after the regenerator, which account for about 30% of the total energy consumption.

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Fig. 1: energy flow of a typical container glass furnace

The flue gas temperatures after the regenerator may vary, depending on furnace type, age, regenerators etc., between 370 and 600°C.

In case of oxy-fuel furnaces the gas temperatures are even higher through the lack of regenerators. This energy is usually lost via the stack and constitutes the starting-point for batch- and cullet preheating.

HISTORY AND TECHNOLOGY OF BATCH- AND CULLET PREHEATING

Batch & Cullet Preheating is not new. Already decades ago, glass technology professionals saw the necessity to recover the waste heat. The advantage of batch & cullet preheating are twofold. On the one hand, a significant amount of energy can be saved (holding pull constant)- on the other hand, also the furnace pull can be increased in the same range as the energy consumption of the furnace decreases. When holding the pull constant, the furnace lifetime can be increased due to lower melting temperatures in the furnace, as some pre-reactions of the batch have been replaced into the preheater (such as water evaporation)\(^6\). Usually the optimum operating level will be a trade-off between these two parameters. Practical experiences have shown that the best results are obtained when also the melting rate is increased- thus batch preheating for future installations may be seen as an integral part of the whole production system.\(^7\)

To make use of the waste gas, different concepts existed, such as using boiler systems, or usage of the heat for any other application, like heating buildings. Because of high investment costs and lower efficiency of boiler systems and limited application possibilities for direct heating of buildings etc., other concepts had to be found.

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\(^7\) As a result of the lower gas consumption, volume flows in the furnace can be reduced and such heat losses minimized.

\(^8\) With pull increase, energy savings up to 20% are possible. Beerlens, Ruud, TNO. 1 October 2008 NCNG-Senter Novem-TNO workshop. 69th Conference on Glass Problems Columbus OH 3. & 4. November 2008.
Basically, there were two batch preheating systems which were both developed in the early 1980ies and were adopted by the market to some extent. One is the so-called Nienburger-type direct batch & cullet preheater, which was designed for applications with high cullet content (> 50%).

![Diagram of Nienburger-type batch & cullet preheater]

Figure 2: The Nienburger-type batch & cullet preheater

The basic concept of this design follows the direct-principle, meaning, there is a direct contact between flue gases and the batch. The flue gases are directed in a cross-counter-flow manner through so-called roof-elements, which are open at the lower side and such create a hollow space under these roofs. The material is moving vertically downwards and is while having direct contact with the gases being preheated. The flue gas enters the preheater at the lower part with a temperature of 400–450°C and leaves the preheater in the upper part with a temperature of about 250–325°C.

As the gas channels are open at the bottom side, acid components in the flue gases HCl, HF, SOx and SeO, are partly absorbed by the earth-alkali compounds in the batch (soda, limestone, dolomite). Thus, the preheater partly also works as a scrubber.

Due to the direct contact of batch and flue gases, dust emissions are increased significantly and thus the technology requires appropriate filter systems, such as large electrostatic precipitators or bag house filters. Measurements from the operation show an increase of dust concentration before the preheater from 96.5 mg/m³ to 1675 mg/m³ after the preheater. Behind the precipitator, a dust concentration of 22.4 mg/m³ was measured— a value comparable to furnaces without batch preheating technology.

Taking this into consideration, the use of an electrostatic precipitator becomes a must when applying

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11 There were also the PRAXAIR, Endress, and the SORG system. However, these systems were designed for the application with very high cullet content of 85-90% and are therefore also called "cullet preheaters". Other patents were filed for example by OWENS-CORNING 1994, "Method of Preheating Glass Batch". This method utilizes a rotating drum for the heat transfer at a commercial level, this system has not been put through.

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this technology. Latest modifications of this system aimed at reducing gas velocities in the preheater and reducing carry-over. Five of such systems have been built in the 80ies and 90ies, three of them are still running. The others stopped because of general glass production capacity reductions. The overall energetic results of the system show savings of about 15% with batch and cullet preheating at 300-325°C.13

THE LATEST INSTALLATION IN EUROPE

Lately in 2010 a new installation of this type for a 350 mt/d container glass U-flame furnace in the Netherlands has successfully been installed and put into operation.14

Figure 3: the latest batch preheating installation in Europe in 2010 (Copyright: Zippe Industrieanlagen GmbH)

A large European container glass producer decided to integrate a batch preheating system at an existing furnace. The new add-on-system starts at the existing pre-furnace-silo. Through a Y-section below the silo, the material is fed to a vibratory tray feeder that conveys the batch to the elevator and thus to the top of the preheater. Over another vibratory tray feeder, the material is brought into the preheating system. The outlet of the system is guaranteed by in-line screw feeders that transport the batch to the collecting screw feeder. Finally, the batch is conveyed to the existing batch charger and brought into the furnace. In case of maintenance, a bypass is foreseen and the normal way through the pre-furnace silo is taken. The flue gases are taken from the existing waste-gas pipes though a bypass. In case of need, the whole system can be bypassed and the normal production process would be applied.

13 Details of this systems are not be elaborated here - they might be found in Barklage-Hilgendorf, Hamburg, “Batch Preheating on Container Glass Furnaces,” 69th conference on Glass Problems November 4-5, 2006, Columbus, Ohio.
14 System supplied by ZIPPE Industrieanlagen GmbH.
A few key facts characterize the system:

- furnace type: regenerative U-flame, 1 doghouse
- throughput: ~350 mt/d
- flue gas inlet temperature: max. 450°C
- flue gas outlet temperature: 220-230°C
- total weight: ~320 mt including steelwork and batch filling
- dimensions: 4700mm x 5400mm x 13000mm

The system was put into operation in July 2010 and first measurements show significant energy savings. As the last preheater-installation was implemented around 1996, this installation represents the latest one in 15 years.\(^\text{15}\)

Another type is the so-called Zippe-type indirect batch preheater. Four of such systems have been built in the 1990s, the latest one was installed 1996 at a container glass furnace and has stopped its successful operation in 2010 because of a furnace shut-down.

![Figure 4: The Zippe-type Batch preheater (Copyright: Zippe Industrieausrüger GmbH)](image)

The main difference with this system is that there is no direct contact between the batch and the flue gases. The preheater is being fed with batch in the upper inlet zone and the material is moving down by gravity with approximately 1–1.5 m/s. The waste gas enters the system at the bottom part and is being led upwards in a cross-counter flow and exits the system at the upper part with about 190–240°C. De-vaporizing modules were designed and installed between the single modules to let the moisture exit the system. In the top section, the vapours have to be released without condensation and can be added to the hot flue gas.

\(^{15}\) It is not known of any big-scale installation in Europe in the glass industry during that time.
Due to non-existing direct contact between batch and flue gas, there is no increase in dust concentration and no chemical reactions between substances of the flue gas and the batch can occur. Preheat temperatures also practically remain at a level of 250–325°C. In combination with an increased pull, energy savings of 15–20% have been found in the installation in the Netherlands. Also with this preheater, in case of usage of electric boosting, the need for boosting is lowered and the comparable more expensive electric energy can be saved—leading to a reduction of energy costs higher than the relative savings of energy.

The following table shows the results of such a preheater installed in 1996.

Table 2: results of indirect preheater in the Netherlands, installed 1996

<table>
<thead>
<tr>
<th>Betriebsverfahren: Scherben- und Gemengevorwärmung PLM Dongen</th>
<th>Practical Experience: Cullet and Batch Preheating at PLM Dongen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rauchgasenlritt/Waste gas inlet:</td>
<td>480 °C</td>
</tr>
<tr>
<td>Rauchgasaustritt/Waste gas outlet:</td>
<td>270 °C</td>
</tr>
<tr>
<td>Schmelzguteintritt/Batch input:</td>
<td>15 °C</td>
</tr>
<tr>
<td>Schmelzgutaustritt/Batch outlet:</td>
<td>280 °C</td>
</tr>
<tr>
<td>Gemengedurchsatz/Batch throughput:</td>
<td>15.5 to/h</td>
</tr>
<tr>
<td>Scherbenanteil/Cullet ratio:</td>
<td>65%</td>
</tr>
<tr>
<td>Erdgaseinsparung/Saving of natural gas</td>
<td>7.8 %</td>
</tr>
<tr>
<td>Stromeinsparung/Saving of electric energy</td>
<td>62.2 %</td>
</tr>
<tr>
<td>Gesamte. Energieeinsparung/Total Energie savings</td>
<td>14%</td>
</tr>
<tr>
<td>Energiekosteneinsparung/Saving of energy costs:</td>
<td>27%</td>
</tr>
<tr>
<td>Erdgaseinsparung/Saving of natural gas</td>
<td>4.390,000 m³/year</td>
</tr>
</tbody>
</table>

The batch, including 65% cullet, is being heated up to 280°C at a throughput of 15.5 m³/h while using a temperature delta between 480°C waste gas inlet and 270°C waste gas outlet temperature. Total energy savings remain at a level of 14%. As more costly electric energy could be saved as a result of reduced electric boosting, a total saving of energy costs of 27% was achieved.
Recent Developments of Batch and Cullet Preheating in Europe

So the question arises, why batch preheating systems have not been adopted widely in the glass industry—given its significant energy saving potential. One point surely is that it is a substantial capital investment, roughly between 1.2–1.8 mil. Euro (1.5–2.3 mil. $) for a complete system that needs to be justified. Also, relatively cheap energy prices prolonged return on investments. Furthermore, some improvements in the design of such systems had to be done.

Shortcomings of former preheating devices were:

- chemical batch reactions due to water migration (condensation, evaporation)
- fatigue of preheater material because of corrosion and exposure to high-temperature
- charged bulk behaviour of cold and preheated batch
- charging and junction of cold and hot cullet/batch and carry-over in the furnace
- odour nuisance through burning-off of organic compounds from the cullet
- maintenance requirements and poor accessibility of batch preheating aggregates
- restrictions in cullet content (min. 50%)
- restrictions in batch moisture

While other shortcomings of these first generation systems could be solved, especially the maintenance effort due to occasional clogging of material in the indirect batch preheater had to be reduced significantly. Due to the physical batch moisture of appr. 3–4%, and also the chemically bound water content of the soda, from about 104°C on, evaporation starts and the physical and also the chemically bound moisture has to leave the preheating system. As, in a completely indirect system, there is no contact between flue gas and batch material, and thus moisture cannot be taken out by the waste gas stream, it has to leave the system in another way. Since, in the 1st generation system, the de-vaporization units were still not optimal, another solution had to be found.

To overcome these shortcomings of existing systems, ZIPPE has initiated a new R&D project in 2006. Partially, these results are now available and will be presented below.

THE NEW DEVELOPMENT OF THE 2ND GENERATION “ADVANCED BATCH PREHEATER” SYSTEM

The new system constitutes a hybrid between indirect and direct preheating systems. In many inhouse-tests, combined with theoretical modelling, the chemical behaviour of soda at different temperatures had to be studied as an essential starting point.

When heating up batch, a key reaction that is taking place is the release of moisture during the different phases of the soda transformation.

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16 The indirect characterisation however surely prevails.
Table 3: the different soda phases at different temperatures

<table>
<thead>
<tr>
<th>Phase</th>
<th>Formula</th>
<th>Water (% by weight)</th>
<th>Transition temperature into lower phase (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>free of water</td>
<td>Na₂CO₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>monohydrate</td>
<td>Na₂CO₃·H₂O</td>
<td>14.5</td>
<td>&gt; 107</td>
</tr>
<tr>
<td>heptahydrate</td>
<td>Na₂CO₃·7H₂O</td>
<td>54.3</td>
<td>&gt; 35</td>
</tr>
<tr>
<td>dekahydrate</td>
<td>Na₂CO₃·10H₂O</td>
<td>62.9</td>
<td>&gt; -2</td>
</tr>
</tbody>
</table>

Pure soda holds 62.9 weight percent of water. Usually, in the glass industry, calcined soda (Na₂CO₃) is used. However, this soda is highly hygroscopic and is being enriched depending on the ambient temperature and humidity with water and transformed to monohydrate (Na₂CO₃·H₂O) or, in the worst case even into the heptahydrate. After exiting the batch mixer, it may surely be assumed that the soda is at least in the state of a monohydrate by this point of time meaning that there is still a minimum of 14.5 weight percent of water enclosed.

This effect was known from theory before, however, the magnitude of the practical relevance needed to be verified. In a small-scale preheater, batch with 50% cullet and 1.5% moisture was heated up by two burners with 600°C.

Graph 3: the effect of the soda transformation when heating up batch

Firstly, a rapid increase of batch temperature can be seen. However, even with the relatively low moisture content, at about 107°C, the effect of the water migration becomes obvious—the temperature
remains at this level for a remarkable long time before the transformation has taken place and the temperature is rising again. Also, considerable clogging occurred in the aggregate. So the goal for a new system was to find a system that is able to bring out the moisture from the system reliably, especially at the point of time when the main amount of water is being set free. Also, the first generation system had so-called de-vaporization modules- located every 1000mm between the preheating modules- that were designed to withdraw the condensate by suction into the waste gas pipe. However these modules, depending on batch moisture and cullet content, tended to clog and regular cleaning was necessary. Also, these modules guaranteed a de-vaporization only section-wise, thus a continuous process had to be found.

In the following a schematic drawing (cross-section) of a module of the new developed batch preheater (ABP) is shown.

The flue gases enter the system at the lower part and stream upwards in a counter-flow manner while being directed by deflectors.

Especially in the drying section, a continuous devaporation needed to be guaranteed. Thus, especially laid-out slots were constructed that were able to let the moisture exit the system. To improve the heat conductivity, the flue gas channels were fully integrated into the system. This system was completed with a pre-drying unit at the top and a mechanical anti-agglomeration device for applications with cullet contents below 30 per cent. As in the previous system, the batch moves down vertically in the batch channels by gravity and heat-transfer is secured by convection through the channels.

Figure 5: concept of the new ABP (Copyright: Zippe Industrieanlagen GmbH)

Some characteristics show the differences between the first generation systems and the ABP:

| Table 4: comparison between old and new batch preheater type ABP |
|------------------|------------------|------------------|
|                  | Old type         | ABP              |
| Working principle| cross-counter flow | cross-counter flow |
| Construction     | modular           | modular           |
| Heating mode     | indirect          | Indirect/semi-indirect |

17 In this case for about 40 mins.
18 ABP refers to the "Advanced Batch Preheater" Concept and will also be used in the following.
19 Patent registered.
20 Patent registered. Not shown on this drawing. This device mechanically loosens the batch in the pre-drying zone at the top of the preheater to avoid any sticking.
21 Patent registered.
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<table>
<thead>
<tr>
<th>Waste gas conduction</th>
<th>internal / external</th>
<th>completely internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam discharge</td>
<td>yes</td>
<td>yes, improved</td>
</tr>
<tr>
<td>Max. waste gas</td>
<td>600 °C</td>
<td>650 °C</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. batch humidity</td>
<td>max. 0.5%</td>
<td>tested &gt; 5%</td>
</tr>
<tr>
<td>Min. cullet value</td>
<td>min. 60%</td>
<td>tested &lt; 20%</td>
</tr>
</tbody>
</table>

The new type is mainly based on the indirect system, however, with now small openings in the flue gas channels for removal of the evaporated water from the batch & cullet. It is a modular system that is adapted to the needed capacity. Also the cross counter flow was maintained as it guarantees favourable degree of efficiency. The main improvement and benefit is the applicability of this system with low cullet percentages.

PRACTICAL TESTS OF THE ABP

Even though a considerable level of experience in batch preheating was achieved through the last decades, a practical test on a glass melting furnace under real conditions had to be performed to prove the superiority and the practical safety of a new system. An in-house test, in whatever size would never reflect reality and would not give security and confidence high enough for future installations in glass furnaces under real conditions. For this, a cooperation with an European container glass producer was formed and also a leading furnace specialist and an international and reputable glass research institute were integrated into the project. As batch preheating technology must be seen as a system, it was regarded as valuable that different companies in a related sector would exchange know-how.

A long-term test of the new system at a container glass furnace was planned and performed. The project endured for about 2 years.

The basic data of the furnace were:

- tonnage of 320 tpd
- regenerative U-flame
- 2 doghouses
- 17% cullet addition
- 3% batch humidity
- 4450 MJ/ton actual energy consumption
- 8% electric boosting

Thus, it can be said that this shows an example of a typical European container glass furnace- however with a very low cullet percentage. So the conditions were a challenging test for the new system, as with existing systems, an operation with such low cullet content would have not been possible and would have resulted in severe clogging and caking problems that finally would have stopped the material flow and the whole system.

To guarantee a significance of the results, the test preheater was laid out for a capacity of 1/3 of the total tonnage, for about 40 tons per day.

The general layout is shown in the following:

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33 In a small scale preheater, tests with cullet contents below 10% were successfully conducted.
The aggregate is installed next to the existing pre-furnace silo, where an additional outlet is foreseen. Through a vibratory tube feeder, the material is charged via an elevator to the top of the preheater. To guarantee a homogeneous and even distribution into the preheater, a so-called anti-agglomeration device\(^{23}\) is installed at the top of the system. The sink speed of the batch is approx. 1 m/h. At the outlet, a screw feeder conveys the preheated material to the existing batch charger and into the furnace.

The average flue gas inlet temperature was at about 375°C, the outlet temperature at about 230°C. So the available waste gas temperature was lower than typically, resulting in lower preheating temperatures. The material preheat temperature was at about 210°C. In case of higher flue gas inlet temperatures, higher preheating temperatures would have been achieved.\(^{24}\)

RESULTS OF THE TEST SYSTEM
A major goal of the test was to verify that the system allows a reliable operation with low cullet contents, so the cullet content had to be reduced gradually. It was started with 70% cullet and 3.2% moisture. The furnace pull was about 30t/d and throughput of the preheater was about 36m³/d. A preheating temperature of above 200°C was achieved, which was lower than planned, due to the lower flue gas inlet temperature of about 360°C. Each test sequence was performed for a period between 1 and 3 days. The following table sums up the major results.

\(^{23}\) Patent registered.
\(^{24}\) The relation between flue gas inlet temperature and material outlet temperature is almost linear.
Table 5: main test results

<table>
<thead>
<tr>
<th>% Cullet</th>
<th>Moisture</th>
<th>Furnace</th>
<th>Pull</th>
<th>Preheater Throughput</th>
<th>Operation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>3.2%</td>
<td>Furnace</td>
<td>Pull</td>
<td>305 t/d,</td>
<td>No clogging, safe operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 36 t/d</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>3.2%</td>
<td>Furnace</td>
<td>Pull</td>
<td>302 t/d,</td>
<td>No clogging, safe operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 50 t/d</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>3.2%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>Some clogging in a few material clots</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 40 t/d</td>
<td></td>
</tr>
</tbody>
</table>

Modification of surface area of the preheater, change in material charging and distribution

<table>
<thead>
<tr>
<th>% Cullet</th>
<th>Moisture</th>
<th>Furnace</th>
<th>Pull</th>
<th>Preheater Throughput</th>
<th>Operation Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>3.2%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>No clogging, safe operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 40 t/d</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>2.5%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>No clogging, safe operation, higher dust concentration in flue gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 36 t/d</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>2.5%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>No clogging, safe operation, higher dust concentration in flue gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 36 t/d</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>2.5%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>No clogging, safe operation, higher dust concentration in flue gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 40 t/d</td>
<td></td>
</tr>
<tr>
<td>&lt;20%</td>
<td>2.5%</td>
<td>Furnace</td>
<td>Pull</td>
<td>310 t/d,</td>
<td>No clogging, safe operation, higher dust concentration in flue gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preheater throughput 40 t/d</td>
<td></td>
</tr>
</tbody>
</table>

Modification to lower under-pressure in system and thus lower dust concentration

The results of these tests have clearly shown that it is possible to preheat batch with cullet contents below 20% and maintain a safe operation. These tests were performed over a period of several months at an existing glass furnace in operation. These positive results represent a novelty for the glass industry. The next trials have the aim to lower the dust concentration in the flue gases and are planned for the fourth quarter in 2010. In case of the expected positive results, it can be said that a sustainable concept of batch preheating has been found for a wide range of applications.

**Ideal Preconditions for Installation of a Batch & Cullet Preheater**

Although theoretically, a batch & cullet preheater can be installed at almost every furnace, there are factors that promote an installation. Typically, these devices are installed at container glass furnaces only. These furnaces are run with a higher amount of cullet and also the batch charging area makes an integration of a preheater and also the charging of hot and dry batch easier. Often, green glass furnaces are run with high cullet percentages and also a high amount of electric energy which favours the benefits of a preheater. If the furnace is operated with electric boosting, even higher energy cost savings can be obtained through the substitution of the relatively more expensive electricity. When applying a preheater at a furnace with a high pull rate, relative investment costs will be lower and also the relative energy savings will be higher and thus the payback time shortened.

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25 At the point of time, the author has no knowledge of any preheater installed at a float-glass plant.
With the new ABP, also applications with low outlet percentages of about 20% and lower are possible according to the latest practical tests. These may enlarge the potential fields of operation significantly. Also, when taking into account an indirect system, large filters, or even additional filter equipment are not necessarily needed. Thus, lower investment cost may lead to better economic feasibilities.

Furthermore, there are of course constraints in space that have to be considered when integrating a preheater as an add-on.

**SUMMARY AND FUTURE OUTLOOK.**

Modern batch preheating offers significant energy saving potentials and is suitable for many furnaces, and also applications with less cullet availability. Tests have shown that the latest generation is able to handle batch with less than 20% cullet.

Long-term experiences show a safe operation of preheaters. Rising energy prices and tightening regulatory constraints increase the necessity to invest in such systems. As about 30% of the melting energy is still lost through the flue gases, batch preheating represents the starting point with the highest potential.

Future improvements will have to focus on the eventual carry-over in the furnace. As all batch preheaters deliver very dry batch, the batch charging situation must eventually be adapted. Although existing systems run reliably with regular batch chargers, to decrease dust formation in the furnace, regenerators, and also nearby the doghouse, eventual modifications of the batch charging must be taken into consideration when installing a batch preheater. This especially for end-port fired furnaces, where the batch is almost directly exposed to the gas flows from the flames.

Taking into account the latest experiences and also economical and ecological frameworks surrounding the glass industry, preheating technology may be considered more than ever seriously for new greenfield furnaces and existing furnaces with favourable conditions.

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