Possibilities of Energy Consumption Reduction in the Course of Glass Annealing

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Introduction

In the manufacture I was engaged in problems of glass annealing related to the energy consumption for more than 20 years (1979 – 2001). However almost everything has been described in literature, e.g. in the book Glass Annealing by F. Schill [1] it is difficult and time demanding to apply the theory into practice. It is namely necessary to convince the glassworks management about the advantageousness of changing the technological annealing process, investing into adjustments of the annealing lehr, conveyors, receivers, burners, control systems, product loaders, insulation etc. According to the evidence of the glassworks Crystalex Nový Bor it is possible to save 50 – 80 % energy costs, i.e. for the electric or gas heating of lehrs. At the same time it is also possible to reduce the breakup rate sometimes arising at the entrance or exit of the annealing lehr.

The process of the energy saving solution

In the easiest way the process can be documented in simple pictures. Both the initial and the final situations of individual solutions have been described.

Annealing curves

Changes of the temperature settings at the beginning of tests in 1980 and the final situation in 2001 is best documented in the picture 1 (machine production) and picture 2 (hand production). The original specification claimed heating of 10 heating sections when heated even the 10th zone permanently (the demanded temperature was 400°C). A detailed specification of temperatures is given in the tables 1 and 2. Nowadays the 1st – 4th zones are heated permanently, the 5th - 6th zones have usually a higher temperature than demanded (due to the heat radiation from products). Heating of the zones is done just in case of the empty annealing lehr without products (when heating the annealing lehr for hand production at shiftwork, when changing the assortment of the machine production, mould changing, failure etc.).

The annealing temperature has been chosen as high as possible with respect to the annealed production in order to prevent bending of thin-walled products and/or a chain marking of thick-walled ones. The highest possible temperature allows a faster elimination of strain in products after their forming.

The annealing curve of the machine production differs for various products: for the thick-walled ones it is located higher and the annealing is slower (the line L 7) than at the stemware lines.

The temperature in the 1st zone is actually adjusted lower than in the original specification. Continuous pyrometers proved a considerably lower temperature of the atmosphere in the vicinity of products in the 1st zone than specified even in case of permanent heating of the 1st and 2nd zones (the annealing lehr entrance wasn’t
equipped with a cowling).

**Heating of the lehr**

The originally electrically heated annealing lehrs were adapted for heating by natural gas (see picture 3). The most loaded sidewalls of the lehr at the heating electrical coils were more expanded (dished) in the 1st and 2nd continuously heated zones and it was necessary to repair the arised cracks during the complet overhaul of the tank.

Now, gas heated burners in the sidewall of the lehr burn into a metal tube installed under the roof that – together with the circulation blower – are heavily loaded by heat. The metal tube is opened in its lower part. In case of an insufficient cowling of the lehr entrance it can even occur a deflection of roof parts after a long-term heating.

The changeover of the heating from electricity to gas was based on economical principles (cheaper heating) and substantially better heat convection from flame to products. The gas medium radiation is given mainly by the volume of carbon dioxide and water vapours.

**Pressure conditions in the annealing lehr**

Picture 4 shows the influence of flame on its surrounding. Waste gases generate an overpressure released to sides, i.e. in the direction of the entrance and exit of the lehr. The overpressure decreases the amount of the air drawn in through the loading opening and distributes heat via ducts to its surrounding (to the adjacent zones).

Another regulation of pressure conditions can be easy influenced by counter-flowing blowing-in of air on products behind the exit from the covered part of the lehr.

**Gas lehrs with indirect heating (muffle lehrs)**

Previously frequently used indirect gas heated lehrs showed significantly worse economical results of heat transfer through the inner lining refractories (see picture 5). The consumption moved from 20 - 50 m$^3$ h$^{-1}$, now at gas heated turbulent atmosphere lehrs (and after further modifications) 5 - 10 m$^3$h$^{-1}$.

**Loading of machine made products**

The original loading with 2 jaw type feeders onto the free uncovered conveyor belt (see picture 6a) was gradually replaced during complete tank overhauls with pushing in of a range of products by a push-in arm (rake). The difference in loading is visible from the picture 6b (see the position of the feed cylinder). The jaw type feeders loaded individual pieces far from the entrance to the 1st heated circulation zone and due to it the pieces got considerably cool. Neither the lower boosting of the conveyor belt with products using two tube burners brought an improvement.

Loading using the rake shortened considerably the trajectory of products to the annealing lehr. The transverse band situated before the feed cylinder was gradually cowled including the rake. Heatings under the rake and the conveyor belt could be
removed thanks to improved insulation and closing of the receiver as even the rake was warm enough so that not to cause fine cracks in contact with pushed-in products.

A problem is still the trajectory of pushing-in of the product range (see picture 6c). The programmed rake movement includes its lifting over products after pushing-in. In between they travel along the transverse band, the lifted rake moves back and goes down to the starting position. In the way, products can’t reach the beginning of the 1st heating zone as recommended by the annealing theory because of blocking by the inner door in front of the 1st zone lowered as near as possible to products (movement of products in turned position - upside down).

Pushing of the range to the beginning of the 1st zone would be possible provided that the rake would reverse after pushing the product range and return back to the starting position not before its lifting over products.

If the product enters the annealing lehr earlier its annealing time would be shortened with following energy savings resulting from its reheating.

The insulated receiver needs no further additional heating but the temperature is observed by the pyrometer in the roof of the receiver.

**Loading of hand-made products**

The initial situation is shown at the picture 7a. The conveyor belt was opened, the entrance opening of the lehr limited in its height just by the door position in front of the 1st zone given by the height of products. The first simple cowling using uninsulated plates is visible at the picture 7b, including opening, the last version of cowling at the pictures 7c and 7d.

The position of the tube burner was changed, originally it was situated under the conveyor belt where it could have impaired the belt because of uneven burning (resulting from choking of tube holes). It was moved above the conveyor belt tightly at the 1st zone (under the door), its flame inclined into the lehr (at angle of about 45°) forming a thermal barrier. In the way it was allowed to move the feed cylinder to the 1st zone (attachment of the feed cylinder shaft directly on the front of the 1st zone) and to reduce the receiver dimension.

The cylinder shaft bearings are situated outside the cowling, the lower part of the cowling allows tilting down (removal of cullet), the entrance opening divided, hydraulics controlled by pedal switches. When loaded each product must be loaded behind the tube burner, the conveyor belt is covered before the burner. Each opening of the lehr entrance results in a bending of the tube burner flame down to the conveyor belt (a proof of the intense suction of air into the lehr).

**Pressure conditions at the entrance to the belt lehr resulting from the atmosphere circulation and from the forced annealing of product by air**

Picture 8 shows the suction of cold air from the vicinity of the belt lehr into it and in the same time the leakage of heated air through the upper part of the entrance opening. That is why the cowling of the reversible and transport belts, the feed cylinder shaft and the feed cylinder itself must be as perfect as possible.

The influence of fans with uniform dextrorotatory rotation is visible from the picture 9. Fans influence and with the same direction of rotation even support each
other. It results in suction of air at the left side of the belt in the direction of its movement and in a deformation of the temperature field. The influencing of temperatures was confirmed by temperature measurements using continuous pyrometers Thermophyl Stor at the left side of the belt, in the middle and at the right side 10 cm above the belt. If there is a breakup at the belt as a result of an undercooling at the entrance of the belt lehr (when starting a new shape, after longer operation interruptions, etc.), its appearance is most likeliest in the right outer row.

If there are ventilation pipes situated in the 11th to 14th zones used for annealing of machine made products at the end of the belt lehr, it is necessary to take their one-sided influence into consideration (they are not situated in the middle of the belt lehr, the influence of fans is not sufficient for reaching of an uniform influence - picture 10a).

Fans situated at the end of the belt lehr across the uncovered conveyor belt, individually controlled and tilted as necessary (picture 10b) are the most suitable solution. For the thick-walled products it is possible to use even more ramps. The installation of fans on a ramp will allow a precise control of pressure conditions at the entrance of the belt lehr.

From the economical point of view there is a counter-flow effect (so-called drift), giving the least consumption of the heating energy. A higher drift enhances the consumption as well as a lower drift does (allow suction of more air). The drift radically influences the temperature of products at the end of the belt lehr as it takes their heat away which is recovered to ones at the entrance of the lehr. It also influences the situation of the maximum annealing temperature moving it in the direction of the lehr mouth. For any machine made product there is therefore an optimal adjustment of pressure conditions given in its adjustment sheet.

A more moderate effect arises with ventilation stacks (picture 10c). For the hand production with a short annealing belt lehr it is not possible to use the direct air blowing of the most demanding products (vents in the ramp), good proved are the uncovered roof part (picture 10d) and wrapping of products in paper (closed blown products especially the cased ones leave the belt lehr quite hot liable to breaking in the point of the blowing pipe cracking-off).

The air counter-flowing (so-called drift) can’t be used with hand carrying of products to the belt lehr also because of heat negatively influencing the carry-in boys.

**Thermal losses of the annealing lehr**

The thermal losses of the belt lehr are visible from the picture 11. The surface temperature shouldn’t go over 40°C, in fact it is much higher. In the roof part of belt lehrs the temperature is even over 100°C in the vicinity of fan shafts in the heated part. The highest temperature of belt lehr walls is in the vicinity of burners, commonly about 60°C. Higher temperatures than the recommended 40°C can be found also in the lower part of the belt lehr (under the bottom above the reversible belt). It is therefore necessary to replenish insulating materials in the annealing belt lehr during the tank general overhaul, especially in the roof part around fans and burners. Also an appropriate reinforcing of the roof insulation in the heated part and/or in the lehr walls can be useful.

At the entrance and exit of the circulation part of the belt lehr it is necessary to use height regulated doors moving top-down hold close above the belt during heating
the lehr and close above products during annealing. When heating up the lehr or after a longer shut-down the doors can be hold close above the belt.

The cowled receiver is at least as important as the heated parts of the belt lehr from the heat radiation point of view. It is advantageous for insulation to apply plates sibral with their min. thickness of 10 cm including walls, in the roof part even thicker (allowing the movement of the inner door according to the height of products). All openings of the receiver above the transverse band have to be minimized, their size regulated according the annealed product size with orifice plates. This is valid even for the opening above the rake arm.

**Conveyor belt**

The once used conveyor belts were quite dense, heavy and hard permeable for the turbulent atmosphere (picture 12). The belts were sometimes even heavier than the annealed products (hand made stemware). A high volume of heat was used for re-heating of the belt during its way out from the annealing lehr in the uninsulated receiver. At the exit of the belt lehr the dense and heavy belt lost slowly its temperature as well as the products put on it did as the convection over them was insufficient.

The belt must be as thin and light as possible, at the same time with sufficient loading capacity and belt heat stability by some 100°C higher than the annealing temperature. The belt speed should be selected as low as possible, the complete belt surface covered with products (some 5 cm from its edge).

In order to anneal perfectly even hand-made thick-walled products it is necessary to exploit all circulation fans available at the belt lehr. In the moment of switching-off the circulation the continuous pyrometers indicate a lower temperature in the vicinity of products, the product itself gets cold more slowly and is endangered by breakage at the end of the belt lehr due to the temporary strain.

**The distance between the belt lehr and forming machine**

It can be assumed that the shorter distance from the belt lehr to the forming machine the warmer a product loaded in the annealing lehr (picture 13). Cool products need not only time and energy for re-heating to the annealing temperature but even longer time and energy for removing of permanent strain inside of them. Therefore all annealing lehrs were provided with two circulation heating zones at the entrance (2 m added). In the way the transport band was shortened. The band length moves from the shortest of 2 m to 6 m, so it is possible to assume a further possible cutaway (feed of the belt lehr). The shortest band is now used for tumblers or big pieces, in this case the thick-walled bottom visibly shines (the temperature over 600°C) and the temperature in the receiver is the highest. However the surface layer of products is annealed by the mould in such a degree that there is no deformation of products.

**The implementation of the transport band**

The transport band is now partly cowled from three sides. The side oriented to the forming machine operator is covered just partly in order to allow checking products visually and handling them (picture 14). Surface temperatures of the
transport band cowl go over 40°C, it would be therefore useful to reinforce the insulation. The side heating of products and band by tube burners haven´t been optimised yet.

A possibility of covering the band side from operators by transparent technical glass was tested but it crackled. Another solution must be found.

The cowling roof height has now been chosen according to the highest product to be transported. A possibility of adjusting of the roof part position as necessary can be considered. A side wall tilting up of the transport band cowling can be solved by the movement of the wall upright up-down.

The implementation of the transverse band

The quality and operating lifetime of the transverse band dramatically influence the annealing economy. It is the most heat stressed part of the traffic road from the forming machine to the band lehr itself.

The transverse band delivers products from the outer side of the belt lehr to the receiver which is a part of the annealing lehr. It comes through the receiver carrying away broken parts of products (in case of their breakup) and returns back again.

Outside the band lehr the temperature is about 20 – 30 °C, inside in the closed receiver it moves in the range from 300° – 500°C depending on the product shape. The transverse conveyor is under a serious stress due to thermal shocks whereas it is necessary to reach its operating lifetime at continuous operation similar to one of the melting furnace (some 5 – 7 years).

In many industries (e.g. technical glass, container glass, glass tiles etc.) no covering of the transverse band has been done because of bad experience (deformation and following destruction of the conveyor). The question is if the conveyor suitable e.g. for the machine manufacture of household glass by the same manufacturer was tested eventually under what conditions the failure happened.

Conclusion

The lecture has shown possibilities of cost savings at heating of annealing belt lehrs both in hand and machine production of household glass. Many lehrs haven´t been optimised yet and it would be possible to assume savings at least 50 % of the initial energy consumption for annealing. The return of costs of investments is quite fast. Nevertheless it is necessary to find suitable workmen for the solutions and allow them a long-term monitoring and implementation of gradual small steps to the savings.

The annealing process constitutes a problematic part of all glass manufactures and results available in the household glass manufacture can be applied in the whole glass industry. Savings are brought by co-operation and taking-over of experience of technologists from similar branches.
References


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**Appendix - Tables:**

**Table 1:** Technological specification for annealing of machine made household glass (Linkuž).

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**Note.:**

The original specification was valid for the electric heating in 10 heating zones, loading of products at the uncovered receiver using 2 pieces of jaw type feeders.

Settings of temperatures in annealing lehrs with quite different forms of products are compared. In 2001 big products at the annealing belt lehr of the L 7 machine line and stemware of the L 2 machine line were annealed in gas heated lehrs, pushed-in with a rake into the insulated receiver.

The proved heating consumption saving in annealing of stemware amounted 75 % (difference in 1980 and 2001). In 1980 the big products hadn’t been manufactured yet and according to the original technological specification of temperatures it wouldn’t have been possible (products wouldn’t have been annealed at the belt lehr with total length of 20 m, would leave the covered part of the band lehr too hot, an intensive annealing would bring breakup). A longer annealing belt lehr couldn’t be employed because of space reasons.
Table 2: Technological specification of the hand made household glass annealing (Nový Bor)

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<tr>
<th>zone</th>
<th>original specification in 1980</th>
<th>belt lehr of narrow belt lehr of tank °C</th>
<th>specification in 1995</th>
<th>pot annealing kilns</th>
<th>gas heated belt lehr in 2006</th>
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**Note:**

Because of using of a six-position plotter and according to the original specification from 1980 pyrometers were situated in the middle of the 1\(^{st}\) and 2\(^{nd}\) zones, the third one at the end of the 3\(^{rd}\) zone, the fourth at the end of the 5\(^{th}\) zone, the fifth at the end of the 7\(^{th}\) zone and the sixth pyrometer at the end of the 9\(^{th}\) zone. It is evident that according to the original specification virtually all zones must have been heated (according to the installed load), anyway they were not able to reach the specified temperatures.

The annealing lehrs with heating in the 1\(^{st}\) – 6\(^{th}\) zones have been adjusted for heating of the zones 1 – 4 during work of glassblowers. The resting 5\(^{th}\) and 6\(^{th}\) zones heat mainly during the starting heating of the annealing lehr and/or after a longer working break (empty belt). If worked in two shifts it is - due to the consumption - useful to switch-off the belt lehr and then re-heat it again.
1. Specification of temperature settings of the annealing belt lehr for the machine production of household glass in 1980 and in 2001 for L 7 (big products) and for L 2 (stemware)

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10. výstup z podkovy
10 a) leží
10 b) chladíčel
(stranový 
řešený)

11-14 zóna

10 c) odsunovací koníčky

10 d) odkrytí části strana
(slučení v.)
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13. Vědět moc pásovky ve stavebních stropů
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vyhod ptačí

molot těžení