POSTER 1

LOW-E GLASS TEMPERING

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ABSTRACT

It is problematic to heat up Low-E glass in a traditional radiation type furnace, because the glass will bend during the heating cycle which leads to different problems such as viscoelastic changes, coating distortion, surface defects, uneven bending etc.

If we add forced convection to radiation furnaces it becomes possible to temper Low-E glass with the current manufacturing methods on the market. However, the emissivity requirements will be lowered in the future and for this reason we need new manufacturing solutions. One such solution is the use of convection in tempering furnaces.

This paper will give you an idea about the latest developments and test results in this field.

INTRODUCTION

I shall use the case of tempering Low-E glass for the purpose of describing the application of convection in a demanding process for a product growing in popularity.

Before the 90's, furnaces were mostly designed for the tempering of clear glass. For this reason, the main focus at the time was on even application of radiation heating in the furnace. This was quite understandable, because clear glass has high emissivity and it absorbs heat very well. When the new low-emissivity glass products hit the market at the end of the 80's and early 90's, great difficulties in tempering of this kind of glass were initially experienced.

Most of the problems resulted from the unsymmetrical emissivity of the coated glass.

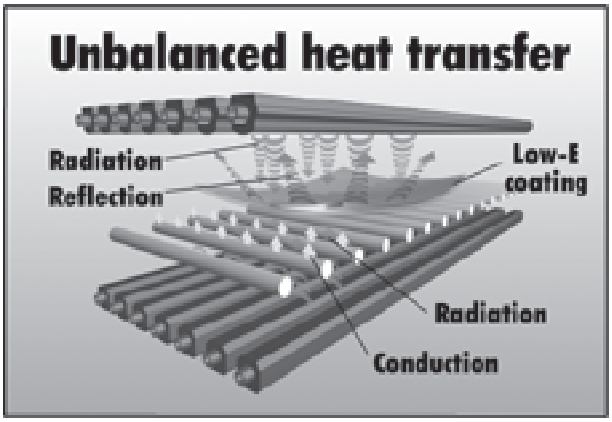

Figure 1: Unbalanced heat transfer

The bottom of the glass displayed high emissivity and absorbed heat effectively, the coated side with low emissivity reflected heat radiation. This unsymmetrical behaviour led to the bending of the glass in the furnace, as the uncoated bottom of the glass heated up more quickly.

The situation could have been helped by placing the coated side against the rollers, which would have resulted in less curving. This method has not, however, been used in Europe, because it causes defects to the coating.

UNBALANCED HEAT TRANSFER - A REASON FOR PROBLEMS

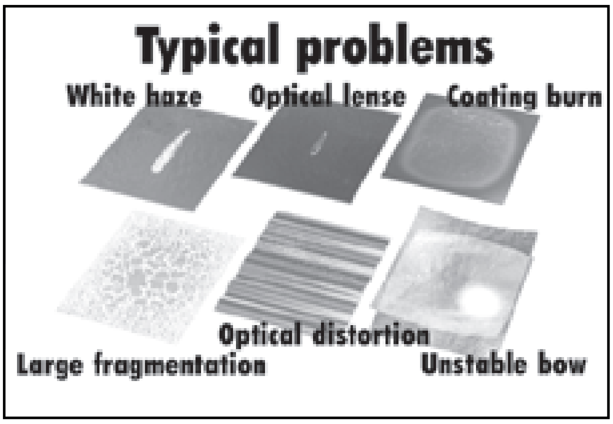

Figure 2: Typical problems

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When the coating is on the top of the glass, the curving causes the following typical problems as displayed in figure 2.

1. White haze
2. Optical lense
3. Coating burn
4. Large fragmentation
5. Optical distortion
6. Unstable bow

Low-emissivity glass has been available on the market since the 80's. Its emissivity was, however, rather high by today's standards. It was not until the late 80's and early 90's that toughenable Low-E glass with an emissivity of 0.1 - 0.23 became available.

The demand for Low-E glass is expected to grow very quickly in the future. A typical indication of the preference put on this product is found in German legislation, where the requirements to save energy are so tough that Low-E glass is practically always required in window structures. The same trends are also visible in other European countries.

HEAT TRANSFER

The design of the heating section in a tempering furnace requires that the heat transfer process between the glass plate and the furnace environment is understood. This is also necessary when the furnace behaviour is adjusted for different types of glass. In order to understand the importance of different heat transfer processes, the conduction in glass, radiation, convection and conduction from the rollers must all be considered.

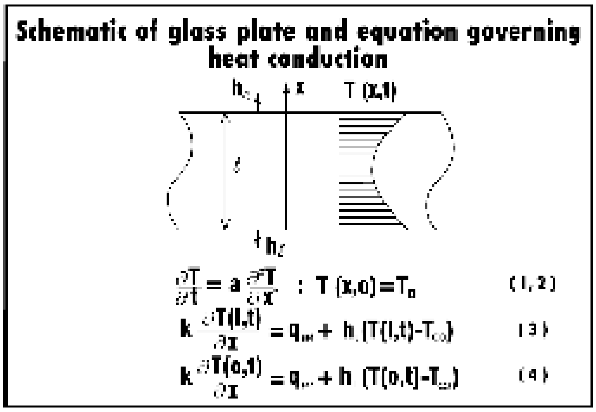

Figure 3: Temperature distribution

The temperature distribution of a glass plate as in figure 3, is governed by the well-known heat conduction equation:

$$\frac{\partial T}{\partial T} = \alpha \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

where T is the temperature of the glass, t and x stand for time and space and a is the thermal diffusivity.

In order to solve equation (1), initial and boundary conditions have to be fixed. Using the notations of figure 3 they are:

$$T(x,0) = T_o \qquad (2)$$

$$k \frac{\partial T(l,t)}{\partial x} = q_{rad} + h_u(T(l,t)-T) \qquad (3)$$

$$k \frac{\partial T(0,t)}{\partial x} = q_{rad} + h_l(T(0,t)-T) \qquad (4)$$

In the equations above, q_{rad} is radiation heat exchange between the furnace and the glass, h_u and h_l are convective heat transfer coefficients of the upper and lower surfaces respectively. h_l also includes conduction heat transfer from the rollers. k is the thermal contactivity of the glass. T_o is the glass temperature before it goes into a hot furnace.

The solution to equation (1) is straight-forward with a numerical method if the boundary conditions (3) and (4) are known. According to equations (3) and (4), heat transfer from the top and bottom surfaces should be the same and uniform. For instance, if the emissivity of the glass to be heated is changed, it affects the radiation heat transfer q_{rad}. In order to keep the heat exchange from the top direction constant, convective heat transfer should be changed by applying forced convection.

In order to control the heat transfer process of tempered glass, theoretically, the spectral radiation properties of the glass should be known. The understanding of convective heat transfer is most difficult. It has been approached with numerical simulations as well as experimental measurements. Heat transfer from the rotating rollers on the bottom side of the glass is also all but understood.

FORCED CONVECTION HEATING METHODS - THE SOLUTION TO TEMPERING LOW-E GLASS

In this context, convection is defined as heat transfer by a flow of air.

Glass can be heated or cooled by applying convection. When glass is heated, the heat is transferred to the surfaces of the glass by means of air flow. The heat then penetrates the glass through conduction.

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The coefficient which denotes the speed of heat transfer is called alpha. It expresses the rate of speed at which heat can be applied to the surface of an object and conducted into it.

When heat is transferred by convection, the efficiency of the process depends mainly on the speed of the air flow and the temperature difference between the glass to be heated and the surrounding air.

A cold glass sheet to be heated in a furnace is affected by different types of heat transfer phenomena which are shown schematically in figure 4.

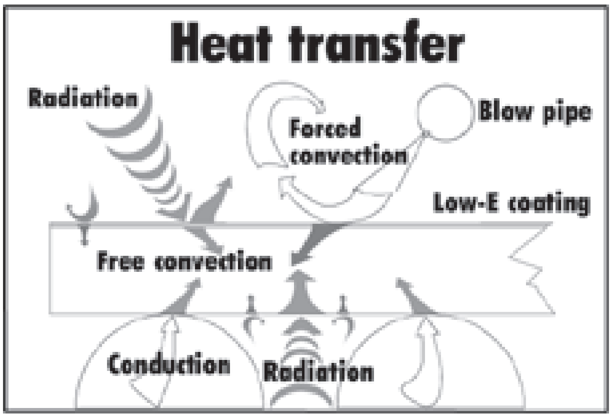

Figure 4: Heat transfer

Traditionally, radiation heating from hot, electrically heated resistance elements in the ceiling of the furnace is used.

When dealing with coated glass, however, this technique is not suitable because coated glass does not absorb radiation as effectively or as symmetrically as clear glass. In addition to radiation, we always have the presence of natural convection from the top and bottom surfaces of a glass plate. The heat transfer is not uniform, but rather results in a large temperature variation.

In order to avoid temperature non-uniformities in a radiation-type furnace, forced convection heating has been applied. Tamglass's first patent in this area is actually from 1980. Forced convection is applied by arranging small jets, from which air is injected in order to create a forced flow. The design of a jet configuration which leads to a uniform heat transfer coefficient is a complex problem .

Another heat transfer mechanism, in addition to those mentioned above, is the heat conduction from the rotating support rollers. That in turn, depends on the material properties of the rollers and on their geometry.

CONVECTION HEATING METHODS IN THE GLASS INDUSTRY

Convection has certainly been applied in a number of different ways in different types of processes. Convection has always been used in autoclaving. Convection is applied for the first stage in which the glass sheets need to be heated up to 130°C and cooled down again before any pressure can be released.

Or as to windscreen production, in the pre-pressing stage of the production hot air is circulated around the glass pair while maintaining vacuum between them. In this way the glass panes and the PVB couple together before autoclaving.

Since 1985 convection has been applied to bending in windscreen processes as well. Convection is used in the front end of the furnace to cool down glass which has already been bent. The energy released is transferred to the pre-heating stage of the glass.

Convection is not used just to transfer heat energy from the glass to be cooled to the glass to be heated. This process also ensures that the low-emissivity stainless steel mold heats up simultaneously with the pair of glasses. It is a well known fact that emissivity is of no consequence in the convection heating method. The new solutions apply to the use of forced convection.

Flat laminating lines also utilise convection. The PVB is first heated up by short-wave radiation before the first pressing. The short-wave radiation penetrates the glass and is absorbed into the PVB. After the pre-pressing stage, forced convection is applied. Achieving a uniform temperature is vital when laminating Low-E or multiple-layer glass applications.

FORCED CONVECTION IN TEMPERING TECHNOLOGY

Flat tempering furnaces have used forced convection since 1980. That coincides with Tamglass's first patent in the area. The method was later modified to meet today's needs. Forced convection, so called "Heating Balance", is used to compensate the heat transfer flow and to make the top and bottom surfaces of the glass heat up at the same speed. As a result, the glass remains flat during the heating process (Refer to figure 4 - heat transfer). This is of particular importance in the case of Low-E glass.

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It is well known that keeping glass, particularly Low-E glass, flat during the first half of the heating cycle is most difficult. To avoid the problems in this area there are four different possibilities:

1. the use of a one-stage radiation furnace and forced convection

2. the use of a two-stage radiation furnace with forced convection
   The principles of one- and two-stage furnaces were explained earlier.

3. the use of a one-stage high-convection furnace (see figure 5), or

4. the use of a two-stage convection system (see figure 6).

HIGH CONVECTION SINGLE CHAMBER FURNACE

A high convection furnace is a very compact roller hearth furnace. The furnace design is modular and the top and bottom furnace shells are symmetrical.

The inside nozzle system generates a high convection heat transfer to both surfaces of the glass panels with reduced pressure loss of the circulating hot air and a high air exchange rate. The uniformity factor of the temperature distribution inside the furnace is very high due to the special nozzle tube system.

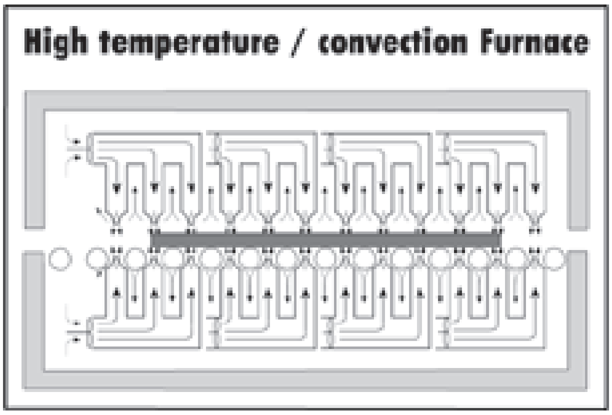

Figure 5: High temperature/convection furnace

The glass charge is heated up to the tempering or bending and tempering temperature in such a way that non-uniformities of heat transfer for top and bottom of the glass sheets (i.e. reflective layer of Low-E glass and thermal conduction between ceramic rollers and the lower glass surface) are compensated for by the control of the top and bottom furnace ventilators. The thermal shock, especially for thicker glass (10 mm and more) is also eliminated by reduced heat transfer during a certain time at the beginning of the heating cycle. The optimal operating point of the top and bottom hot air ventilators can easily be reached by the continuous and accurate control system.

For this reason, the larger sized glass panels of more than 4 square metres can be kept very flat in the furnace during the whole heating process. The mechanical distortions of the lower surface are minimised for each glass thickness and thus for the weight of the glass sheet.

The phenomenon of anisotropy can be positively influenced by reduced furnace temperatures without any significant reduction of productivity.

Independent of the kind and type of glass (coated, tinted, structural or clear), the heating time will be shorter because the asymptotic heat-up curve has a steeper gradient at all times in comparison with the heat-up curve of glass heated in a radiation furnace.

TWO STAGE CONVECTION FURNACES

In a two-stage high-convection furnace, the temperature of the first furnace would be 350 - 450°C and the heating method would be high convection produced by blowers.

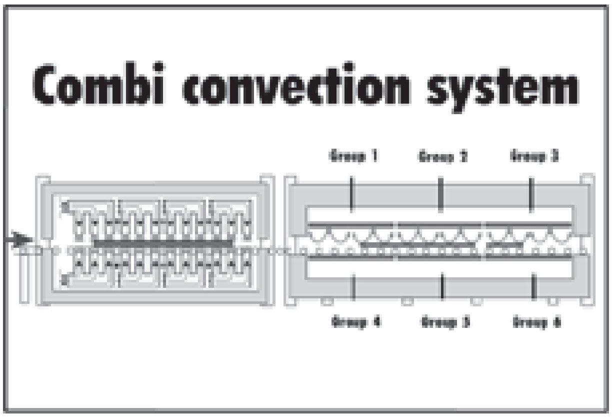

Figure 6: Combi Convection System

In a low-temperature convection furnace, the glass is pre-heated by convection in what is known to be the most difficult part of the process.

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It is natural that the control of temperature and air flow are easier at lower temperatures. The proportion of radiation has been minimised by lower temperature.

Once the glass sheet has been heated up in the first chamber it is moved into the second furnace. In this chamber heating is applied by convection and radiation. The key point in this part of the process is that we can focus heat by radiation and a sophisticated heating system on the middle of the glass sheet which is necessary in order to heat up a large glass surface evenly.

An important point is that this works well for both thin and thick glass, such as 3 - 19 millimetres can be processed without difficulty in this kind of process.

This way we can also be sure that the glass does not break inside the furnace and we can send this evenly pre-heated glass to the second furnace where convection and radiation are used.

Whatever the application of convection, the soul of the process always remains the furnace itself. Even if we use high-convection in the furnace, radiation is a factor which must be considered. The structure of the cooling section is also very important because it influences the tempering glass quality.

I should mention here that our experiences of how to temper Low-E glass are based on the products listed in figure 7.

TOUGHENABLE Low-E glass

	EMISSIVITY	MANUFACTURERS
K-glass	~ 0,16	Pilkington
Comfort now	~ 0,16	Glaverbel
Planitherm II (off line) Eko Plus	~ 0,1 ~ 0,16	Saint Gobain Saint Gobain
Energy advantage	~ 0,2	LOF
Performance Plus. HT™ (off line)	~ 0,12	Guardian
Sungate 500	~ 0,2	PPG

Figure 7: Toughenable Low-E glass

When new coating materials are introduced, we usually carry out the first test runs at our factory in co-operation with the manufacturers. From time to time, we also get involved directly in the setting of process parameters with our customers.

CONCLUSIONS - 4 MM LOW-E

	Radiation furnace	High-convection	Two-stage convection system
Heating time/batch	200 sec ± 5%	125 sec ±5%	100 sec ±5%
Top temperature	675 - 695°C	680°C	350/695°C
Tempering pressure	+10…25%	+10…25%	10…25%

In summary, our findings are that successful tempering of Low-E glass requires even and proper control of the heat transfer during the heating cycles where convection plays a very important role.

REFERENCES

1 R. Gardon: Thermal tempering of glass, Glass Science and Technology, edited by D.R. Uhlmann and N.J. Kreidl, Academic Press 1980.

2 Karvinen, R., Kumola, V. and Kunttu, H: Simultaneous natural convection from upward and downward surfaces of a horizontal plate. The 9th International Heat Transfer Conference, Jerusalem, August 17th-24th, 1990.

3 Tamglass patents.

4 Taskinen, P. and Karvinen, R: Numerical simulation of forced convection in a tempering furnace, Report, Tampere University of Technology, 1995.

5 How to temper Low-E glass, J. Vitkala, Tamglass Engineering Oy, R. Karvinen, Tampere University of Technology, Society of vacuum coaters meeting - 2-7, April 1995, 38th Annual Technical Conference Proceedings, pages 261-267

6 Forced convection heating methods, J.Vitkala, Tamglass Engineering Oy, Glass Processing Days 17 - 19.9 1995

7 Forced convection - the solution to tempering Low Emissivity glass, J. Vitkala, Tamglass Engineering Oy, International Symposium on Glass Problems - Istanbul September 4-6, 1996, page 435-442.

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