TREAMENT OF TRANSIENT RADIATIVE HEAT TRANSFER IN GLASS TEMPERING PROSESS

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INTRODUCTION

In a glass tempering process glass is heated up to 650°C and then cooled very rapidly. As a result of tempering compression stress is created in a glass surface. Tempered glass stands large loading and if broken small crumbs are formed, which do not cause incision wounds. In a glass lamination process two or more glass plates are glued together by placing a plastic film between them and heating a glass-plastic bundle up to 80°C. Temperature of heating resistors can be over 1000°C. There are also other glass processes, where radiative heat transfer plays an important role and temperature of the glass is below 700°C. In the paper a simplified method is presented, in which radiative heat transfer in a glass plate can be taken into account accurately enough in practical applications, where convection, conduction and contact heat transfer must be treated simultaneously with radiation.

THERMAL RADIATION IN GLASS

The simplest method to take radiation into account is to assume glass opaque. This kind of simplification can cause notable errors, when temperature of glass and heater are high. Radiation behaviour in a glass is a very complex phenomenon. In Fiq.1 the behaviour of incident radiation hitting the glass surface is shown schematically. The amount of reflected radiation depends on the angle of incidence and wavelength. Reflection dependence on wavelength is of minor importance when normal soda-lime glass is handled. The rest of radiation travels in a glass plate. If the glass surface is coated also absorption at the surface must be taken into account.

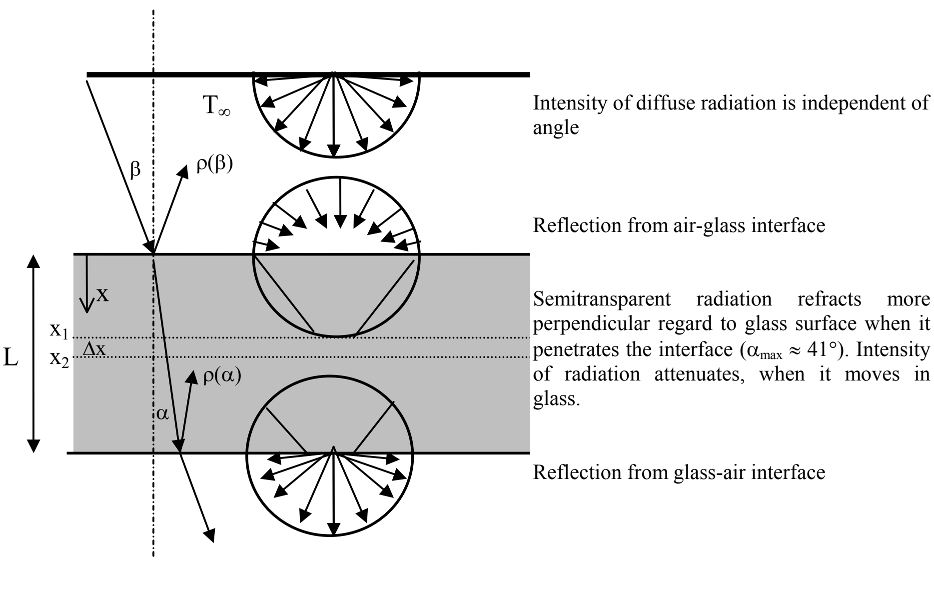

Figure 1. Behaviour of incident radiation in glass

Because of absorption, the intensity of radiation attenuates in glass. The attenuation of radiation is dependent on the wavelength, because absorption in glass is spectrally selective. There are a number of good literature sources where all the equations that are needed to solve the thermal radiation in the glass are presented[1,2,3]. Unfortunately, solving of those equations leads to complex mathematical problems, especially if other transient phenomena have to be solved simultaneously.

SIMPLIFIED TREATMENT OF RADIATION

In the flux-method used in the paper radiation heat transfer between the glass layer and the surroundings is divided in two parts: absorption of external radiation from the surroundings and emission of the glass layers out of the glass. That part of internally emitted radiation, which stays inside the glass and acts almost like thermal conduction because of reabsorption, is ignored. In Eq.2 the absorption of a glass layer is handled as a difference between intensities before and after the layer. In the modelling of a soda-lime glass the integration over wavelengths has been considered so that spectral absorption has been approximated with k wavelength bands with mean absorption coefficient $a(\Delta\lambda_i)$. In the method the integration over the angle is also eliminated by using mean values. Reflections in the surfaces of glass and the direction of propagation in a glass plate have been taking into account as mean values for diffuse radiation. The mean reflectivity ρ_m of a glass surface is 0,09 and mean propagation angle $\alpha_m = \sin^{-1}(\sin\beta_m/n)$. The mean angle in which external diffuse radiation energy hits a glass surface is 45°, but when an angle dependent reflectivity is considered by using Fresnel's equations β_m is 43° and α_m is equal to 27°. When the glass is heated symmetrically on both sides, the net radiation source term S in energy Eq.1

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + S \tag{1}$$

for volume layer Δx in Fiq.1 can be written as

$$S \approx \sum_{i=1,j=2}^{i=k,j=k+1} \left\{ \begin{aligned} &\left[F_b(\lambda_i,\lambda_j,T_\infty)\sigma T_\infty{}^4 - F_b(\lambda_i,\lambda_j,T)\sigma T^4\right] \frac{(1-\rho_m)}{1-\rho_m e^{-a(\Delta\lambda_i)L/\cos\alpha_m}} \\ &\left[e^{-a(\Delta\lambda_i)x_1/\cos\alpha_m} - e^{-a(\Delta\lambda_i)x_2/\cos\alpha_m} + e^{-a(\Delta\lambda_i)(L-x_2)/\cos\alpha_m} - e^{-a(\Delta\lambda_i)(L-x_1)/\cos\alpha_m} \right] \end{aligned} \right\}. \tag{2}$$

If glass is heated unsymmetrically, then reflections must be considered separately. In actual practice only the first one of the reflections inside the glass is needed. In Eq.2 σT^4 is the blackbody emissive power and $F(\lambda_i, \lambda_j, T_\infty)$ is the fraction of radiative energy of a black body spectrum between the wavelengths λ_i and λ_j in the ambient temperature T_∞.

RESULTS

In Fiq.2 the results of the method above have been compared with those in the literature[1,2], where more sophisticated approach is used. Field & Viskanta[1] studied cooling of a glass in the laboratory ambient theoretically and experimentally. Gardon[2] solved the heating problem in a radiation furnace. In the cases studied initial conditions were the same as in the literature examples.

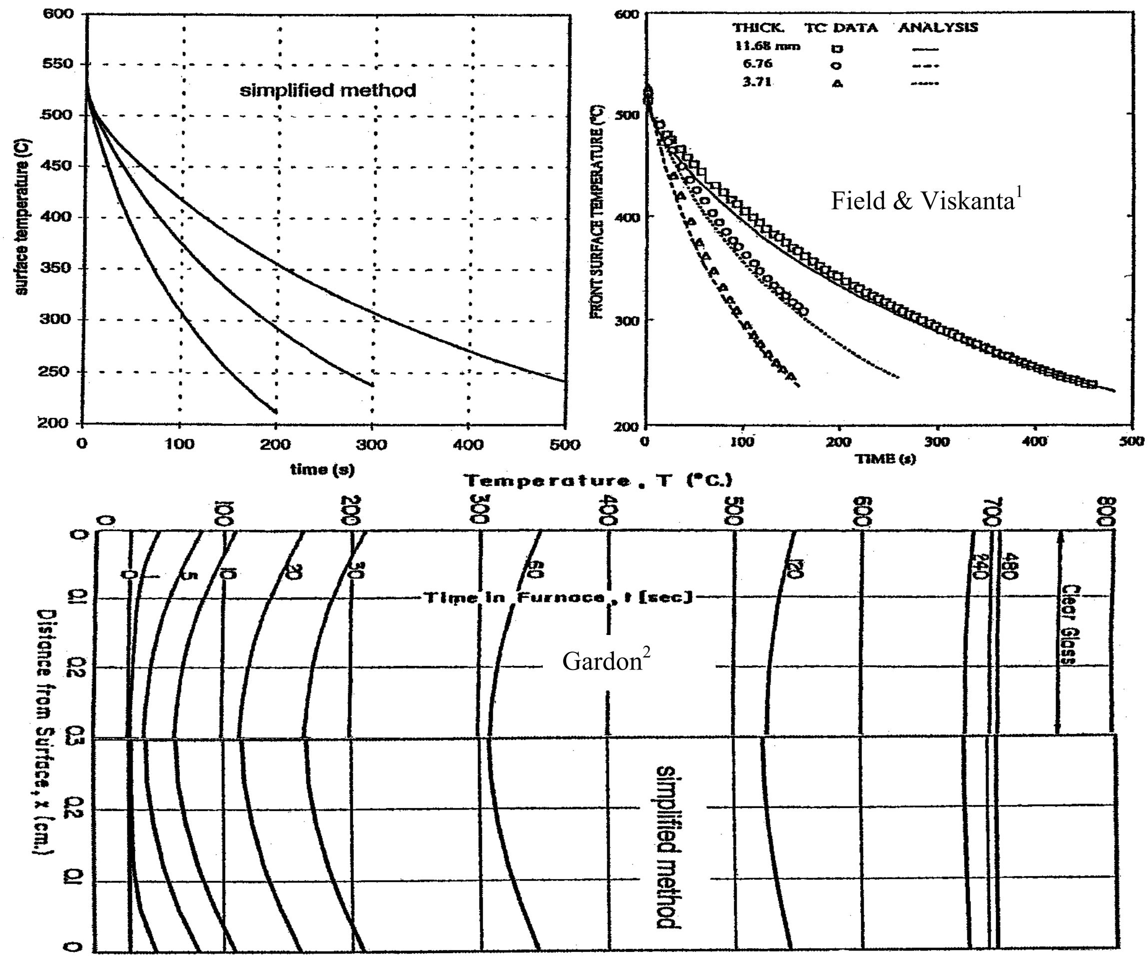

Figure 2. Results of simplified method and comparison with results in literature[1,2].

It can be seen that the results of the simplified method are good.

CONCLUSION

The simplified method above takes radiation into account in glass tempering heat transfer process where glass temperature is below 700°C. The method is convenient to use and boundary conditions of actual practise can be easily handled with it. The simplified method has been used to model radiative heat transfer in glass tempering, lamination and bending processes. The method can be applied in coupled problems, in which also other heat transfer phenomena have to be dealt simultaneously.

1. Field R.E., Viskanta R., Measurement and Prediction of the Dynamic Temperature Distributions in Soda-Lime Glass Plates. Journal of American Ceramic Society, 1990, 73, 2047-2053.

2. Gardon R., Calculation of Temperature Distribution in Glass Plates Undergoing Heat Treatment. Journal of American Ceramic Society, 1954, 44, 305-312.

3. Viskanta R., Jorgensen K.D, Transient Heating of Opaque and Semitransparent Materials by Radiation During Processing. Heat and Mass Transfer 36 (2000) 413-421.