THE EFFECT OF THE GLASS THICKNESS ON THE HEAT TRANSFER BETWEEN GLASS AND MOULD

تأثير سمك الزجاج على معدل انتقال الحرارة من الزجاج

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ABSTRACT

In the manufacture of glass containers and pressed ware, heat is extracted from the glass by bringing it into contact with the surface of the metal mould (steel), the temperature of which is considerably lower than that of the glass. Many factors determining the rate of heat extraction interact in a complicated way. These factors include: the initial temperature difference between the two surfaces, the thermal resistance of the glass-metal interface, the thermal properties of the soda-lime glass and the metal, and the thickness of the glass. This paper investigates the effect of the soda-lime glass thickness on the rate of heat loss during the initial mould contact stage. Simulations are carried out for different thicknesses and the results are compared with previously published work. As the thickness of the glass reduces the surface contact temperatures decrease. The rate of heat lost from the glass during the contact of the glass and the mould is increases.

1. INTRODUCTION

In the manufacturing process of glass containers and pressed ware, heat is extracted from the glass by bringing it into contact with the surface of a metal mould, the temperature of which is considerably lower than that of the glass. The many factors determining the rate of heat extraction interact in a complicated way and they include the initial difference between the temperatures of the glass and the metal surfaces, the thermal properties of the glass and the metal, and the radiation absorption, emission properties of the glass, and the thickness of the glass. This interface has been investigated by

Gardon [1] has shown that, in the tempering of soda-lime glass plates 6 mm thick, radiation plays an important role in terms of heat loss. On the other hand, according to McGraw [2] Babcock [3] in the pressing of a parison radiation is seen to have little influence. The effect of glass thickness on the glass surface temperature during 4 seconds of glass-mould contact time is observed through simulation. The flux induced through the glass-mould interface is also observed over the 4 second period for varying glass thickness.

McGraw [2] used laboratory investigations to measure the heat transfer in glass during pressing and casting, by taking deferent glass thicknesses, these results were then used to develop numerical methods for computing surface heat fluxes for deferent thicknesses. These numerical methods assume an initial uniform temperature distribution over the mould. However, in many forming operations the mould is not at an initially uniform temperature and the analysis of mould temperature data to calculate heat fluxes is extremely difficult. Simulations will be performed to show the effect of the glass thickness temperature on the heat transfer from the glass surface over a 5.0 second contact time and initial mould temperatures of 490 C^{o}. The surface temperature of the hot glass drops faster as the glass thickness decreases.

Babcock [3] studied the heating and cooling of the glass sheets: analysis of radiative heat transfer is so fundamental that it can be applied directly to glass forming problems by changing the sheet glass thickness. The work shows that the glass thickness is very important in terms of the level of the heat transfer from the glass to the mould because of the large temperature gradient. As the thickness of glass decreases the flux increases during a 4 sec time.

In This paper three glass thicknesses are investigated, 10, 25, 50 mm, with the same initial conditions applied in each model as given in Table (4).

A summary of the results is given in Tables In each case simulation for different glass thickness has been performed and comparisons made with previously published works.

2. MATERIALS AND METHODS

2.1 The discrete ordinates radiation model (DO)

The discrete ordinates DO radiation model solves the radiative transfer equation for a finite number of discrete solid angles, each associated with a vector direction $\vec{s}$ fixed in the global Cartesian system (x, y, z). The DO model spans the entire range of optical thicknesses, and allows a range of problems to be solved, from surface-to-surface radiation to participating radiation in combustion problems Curran [4]. It can also provide solutions to radiation in semi-transparent media such as glass Kawasaki [5] Bauer [6]. The non-grey implementation in the software is intended for use with participating media with a spectral absorption coefficient (α), which varies in a stepwise fashion across spectral bands, but varies smoothly within the band Liu [7] Carvalho [8]. Glass, for example, displays banded behaviour of this type. For the purposes of the current investigation, this will allow the anisotropic semi-transparent nature of the model to be included in the simulation. However, the non-grey implementation assumes a constant absorption coefficient within each wavelength band.

Table 1: Types of models used and settings

Parameter	**Setting**
Space	2D
Time	Unsteady, 1st-order implicit
Viscous	Laminar
Heat Transfer	Enabled
Radiation	Discrete ordinate model

Table 2: **Solver control equations**

Equation	**Solved**
Flow	No
Energy	Yes
Discrete ordinates	Yes
Numeric	Enabled

Table 3: Bands of wavelengths and absorption coefficients, used by Shetterly [10]

Band	**Absorption coefficient (α) m^{-1}**	**Wavelength (μ)**
Band-1	23	0.8 - 2.25
Band-2	45	2.25 - 2.75
Band-3	100	2.75 - 4.3

Table 4: Properties and temperatures of glass and mould (steel) as used by McGraw [2]

Property	**Units**	**Glass (fluid)**	**Mould steel (solid)**
Density	(kg/m^3)	2500	8000
C_p (Specific heat)	(J/kg K)	1350	500
Thermal conductivity	(W/m K)	1.45	200
Heat transfer coefficient	$(W/m^2 K)$	-	1500
Absorption coefficient	(m^{-1})	23-45-100	-
Refractive index	-	1.0	-
Temperature	(°C)	1050	490
Thickness	(mm)	10, 25, 50	100
Time	(Seconds)	4	4

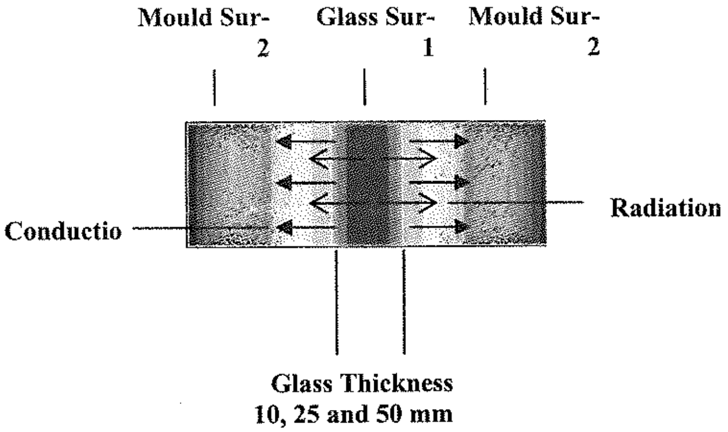

Figure 1: The press stage conduction-radiation, deferent glass thicknesses.

3. SIMULATION RESULTS

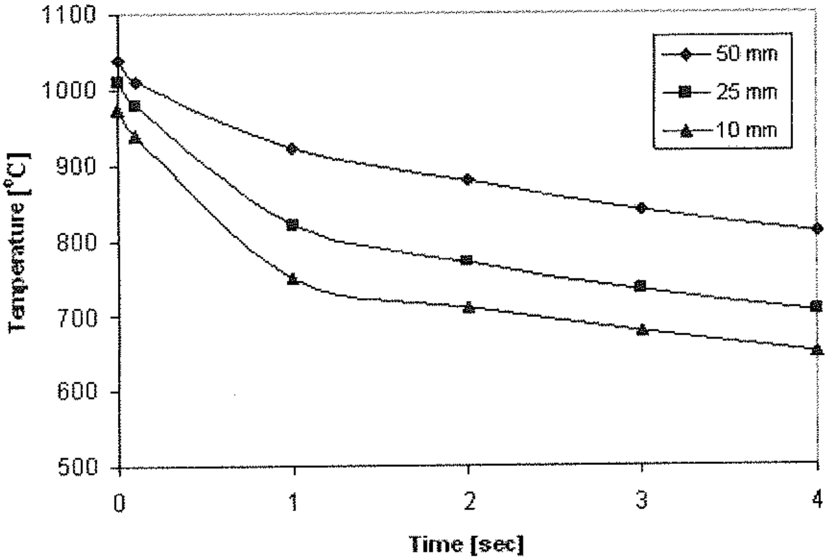

Figure 2: Effect of deferent glass thicknesses on the surface temperature.

Investigating the change of glass thickness effect on surface temperature and flux during the glass-mould press

Figure (2) shows the effect of the thickness of the glass on the fall in surface temperature over 4 seconds of glass-mould contact time. It can be seen that as the glass thickness reduces the glass surface temperature lost during the 4 seconds increases and more heat is transferred from the glass to the mould i.e. as the thickness of the glass reduces the surface contact temperatures decrease,. A summary of the results is provided in Table (5).

Table 5: Surface temperature drop against glass thicknesses during 4 seconds of cooling

Time (sec)	***0***	***0.1***	***1.0***	***2.0***	***3.0***	***4.0***
Surf. Temp. (°C) At (50 mm Thick)	1040	1010	920	880	840	810
Surf. Temp. (°C) At (25 mm Thick)	1010	980	820	770	735	705
Surf. Temp. (°C) At (10 mm Thick)	975	940	750	710	680	650

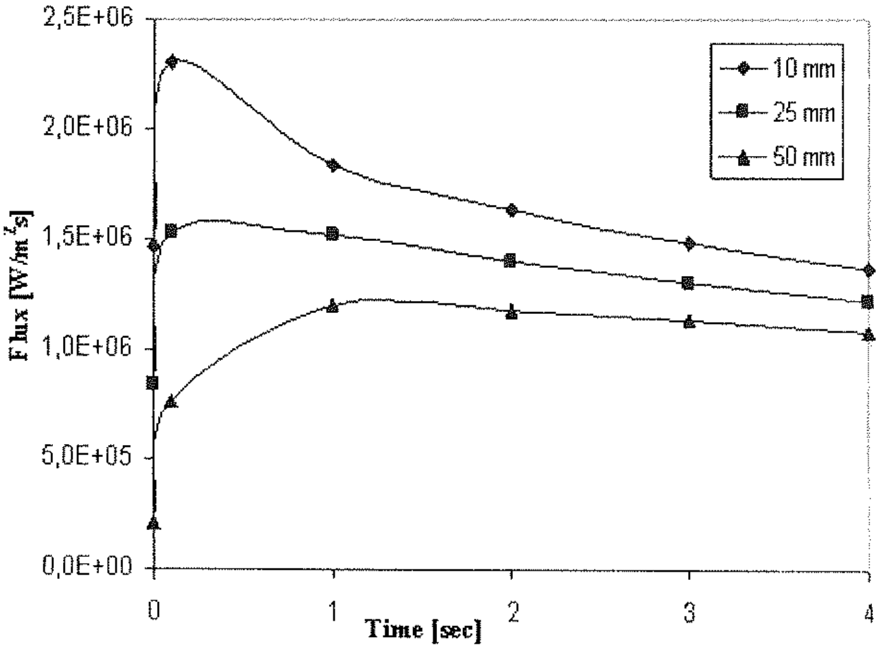

Figure 3: Effect of glass thickness on the surface heat flux during 4 sec.

Figure (3) shows the effect of glass thickness on the heat flux through the contact line between the glass and the mould. From Figure (2) it has been seen that as the thickness reduces the glass surface temperature decreases and more heat is transferred from the glass to the mould. This is also corroborated by the flux over the 4 second period shown in Figure (3) in that, as the thickness of the glass reduces the significance of radiation increases. This confirms the results produced by McGraw [2] Babcock [3]. As the glass thickness decreases the rate of heating and cooling increases .Table (6) provides a summary of the flux characteristics shown in Figure (3).

Table 6: Results of glass surface heat flux of deferent thicknesses during 4 seconds cooling

Time (sec)	**0**	**0.1**	**1.0**	**2.0**	**3.0**	**4.0**
Surf. Flux (W/m^2s) At (10 mm Thick)	**1,47E+06**	**2,31E+06**	**1,84E+06**	**1,64E+06**	**1,49E+06**	**1,37E+06**
Surf. Flux (W/m^2s) At (25 mm Thick)	**8,45E+05**	**1,53E+06**	**1,52E+06**	**1,41E+06**	**1,31E+06**	**1,23E+06**
Surf. Flux (W/m^2s) At (50 mm Thick)	**2,16E+05**	**7,63E+05**	**1,20E+06**	**1,18E+06**	**1,13E+06**	**1,08E+06**

4. DISCUSSION OF RESULTS

Figure (2) shows the effect of different thicknesses of soda-lime glass (10, 25, and 50 mm) on the glass surface temperature during mould glass contact over a period of 4 seconds. As the thickness reduces the centre temperature drops and more heat is transferred from the glass to the mould, the same occurs with the flux in Figure (3), and as the thickness of the glass reduces the significance of radiation increases. In McGraw [2] Babcock [3] it is shown that the glass thickness has a great influence on the heat transfer from the centre of the glass to the surface. As seen from Table (3), when the glass thickness is 10 mm, more heat is transferred from the centre to the surface in comparison to a thickness of 50 mm. The greater the temperature drops the more heat that is transferred from the glass to the mould. Also the centre temperature drops faster for smaller thicknesses of glass, as the high transfer of heat between the glass and the mould causes a high temperature gradient, and high heat flux Pchelyakov [11] and Capurso [12].

5. CONCLUSIONS

After contact with the mould different glass thicknesses of 10, 25, 50 mm are seen to cool at different rates. As the thickness reduces the glass centre and the surface temperatures decrease faster and more heat transferred from the glass to the mould.

Reducing the initial mould temperature at the time of contact, causes a higher temperature gradient and results in greater heat transfer, reducing the glass surface temperature and increasing the heat flux. The dominant period of heat loss from the glass is over the initial 0.1 seconds, at which time the temperature gradient has reduced due to the increased mould and decreased glass temperatures.

المستلخص

أثناء عملية الضغط في تصنيع الزجاج تنتقل كمية كبيرة من الحرارة أثناء ملامسة الزجاج الساخن لقالب السباكة الذي تكون درجة حرارته أقل من الزجاج الساخن، تتوقف كمية الحرارة المنتقلة على عدة عوامل ، منها المقاومة الحرارية بين القالب والزجاج وفرق درجة الحرارة بين قالب السباكة والزجاج الساخن ، الخواص الحرارية للقالب ، وكذلك الخواص الحرارية للزجاج ، ومعامل الامتصاص والإشعاع للزجاج ، وسمك الزجاج المستعمل. من ذلك يمكن تحري تأثير سمك الزجاج على معدل الفقد الحراري من الزجاج أثناء التصاقه بالقالب الذي يكون عند درجة حرارة ابتدائية معروفة . في هذه الورقة البحثية تمت الدراسة بواسطة برنامج (Fluent) حسابات الموائع المتحركة لمحاكاة انتقال الحرارة من الزجاج الساخن إلى القالب بواسطة التوصيل لثلاثة نماذج من الزجاج ذات سمك مختلف. كلما نقص سمك الزجاج تقل درجة حرارة الزجاج عند التصاقه بقالب التبريد. أي يزيد معدل الفقد الحراري من الزجاج إلى القالب

وبذلك تقل درجة حرارة الزجاج الملاصق للقالب . وجميع هذه النتائج وضعت في جداول وتمت المقارنة بالدراسات السابقة .

6. REFERENCES

[1] Gardon R., "A review of Radiant Heat Transfer in Glass" Journal of American Ceramic Soc. Vol.44 no. 7July (1961)

[2] McGraw D.A.: "Transfer of Heat in Glass during Forming," ibid.44 7 353-363 (1961)

[3] Babcock C.L., McGraw D.A. "Treatment of Radiative Transfer in Glass" in proceeding of IV th International Glass Congress. Imprimerie Chaix. Paris, pp.164- (1957)

[4] Curran R. L. Ihab H. Farag: "Modelling Radiation Pyrometery of Glass during Container Forming Process" Glastech Ber 61 No.12 (1988)

[5] Kawasaki H., Motoichi Iga, Isao Satoh," Numerical Simulation of Deformation and Residual Stress for Press-formed Glass" Extended Abstracts, Edinburgh, Scotland, Volume 2, 1-6 July (2001)

[6] Bauer R. Peters, H. Muysenger, F. Simons: "Advanced Control of Glass Tanks by Use of Simulation Models" Proc Forth Int. Conf. "Advance in Fusion, and Processing of Glass". Wuzburg P. 31-8 (1995)

[7] Liu H.P., J.R. Howell: "Scale Modelling of Radiation in Enclosures with Absorbing / Emitting and Isotrpically Media" J. Heat transfer, Vol. 109, no. 2,pp. 470-477(1987)

[8] Carvalho M. G., M. Nogueira: "Modelling of Glass Melting Industrial Progress"
J. De Physique, IV, 3, 1357-66 (1993)

[9] Fellows C. J., Shaw F.: "A laboratory Investigation of Glass to Mould Heat Transfer during Pressing" Glass Technology, 191, pp 4-9 (1978)

[10] Shetterly D.M., N.T. Huff: "Glass to Metal Heat Flow during Glass Container Forming". Journal of non- Crystalline Solids 38, pp.873-878 (1980)

[11] Pchelyakov S. K., Yu Guloan: "Heat Transfer at the Glass-Mould Interface" State Scientific-Research Institute of Glass, No. 9, pp. 14-15, September, (1985)

[12] Capurso T. J. Petopoulos: "Heat Transfer through Glass and Mould during the Glass Forming Process" Glass International Sep. (1979)