Transient temperature behaviour in blank and blow molds during normal container production on IS-machines

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Three-dimensional finite element (FE) modelling techniques have been used to predict transient temperatures within blank and blow molds from the start up of glass forming machines through to the dynamic equilibrium of continuous production. Starting with a preheated mold, repeated gob loading and glass forming cycles are modelled until dynamic equilibrium conditions are reached.

The time dependant models incorporate an insulating gap of around 20-micron thickness between glass and mold materials to simulate the thermal resistance at glass/mold interfaces. The models predict temperature fluctuations at the cavity surface of the mold, inside the mold, at the outer surface of the glass and within the glass. The transient effects of disturbances caused by swabbing molds, diverting gobs and temporary suppression of mould cooling can also be simulated. The models have been applied to BB and NNPB forming processes where major differences have been found. The results of numerical modelling have been directly compared with temperature measurements obtained from field trials.

Description of the Transient Model

To describe the transient temperature behaviour in blank and blow molds a finite element model is used. The necessary thermal properties for cast iron, aluminium bronze and glass are listed in Table 1. Furthermore, to simulate the non-perfect glass/mould contact, a thin isolating layer is being introduced into the model. Assuming thermal properties for this layer close to hot air, realistic heat flux values could be derived.

All molds are cooled down during standard operating conditions by compressed air, either blown to the outer surface – or more economically – passing through axial cooling holes inside the molds themselves. A complete description of the modelling technique, including the calculation procedure for all needed boundary conditions could be found in [1].

The enhancement in thermal conductivity for glass due to radiation is one problem. It was found that an effective thermal conductivity of 3.0 W/(m K) works well to describe the blank side, and λ =2.2 W/(m K) to describe the blow side.

Temperature in °C	Material	Thermal conductivity λ in $\frac{W}{m \cdot K}$	Specific heat c_p in $\frac{J}{kg \cdot K}$	Density ρ in $\frac{kg}{m^3}$	Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p}$ in $\frac{m^2}{s}$
200	Cast iron	40.8	569	7080	0.0000101
300	Cast iron	39.6	616	7080	0.0000091
400	Cast iron	38.2	662	7080	0.0000082
500	Cast iron	36.7	713	7080	0.0000067
200	Bronze	58.0	376	7800	0.0000198
300	Bronze	66.0	418	7800	0.0000202
400	Bronze	73.0	585	7800	0.0000160
500	Bronze	78.0	752	7800	0.0000133
300	Air	0.0441	1046	0.6072	0.0000694
400	Air	0.04996	1067	0.5173	0.0000905
500	Air	0.05564	1093	0.4502	0.0001131
600	Air	0.06114	1116	0.3986	0.0001374
500	Glass	2.0 (without radiation)	1129	2500	0.00000071
700	Glass	2.0 (without radiation)	1170	2500	0.00000068
900	Glass	2.05 (without radiation)	1200	2500	0.00000068
1000	Glass	2.05 (without radiation)	1212	2500	0.00000067
1100	Glass	2.1 (without radiation)	1233	2500	0.00000068
1200	Glass	2.2 (without radiation)	1254	2500	0.00000070

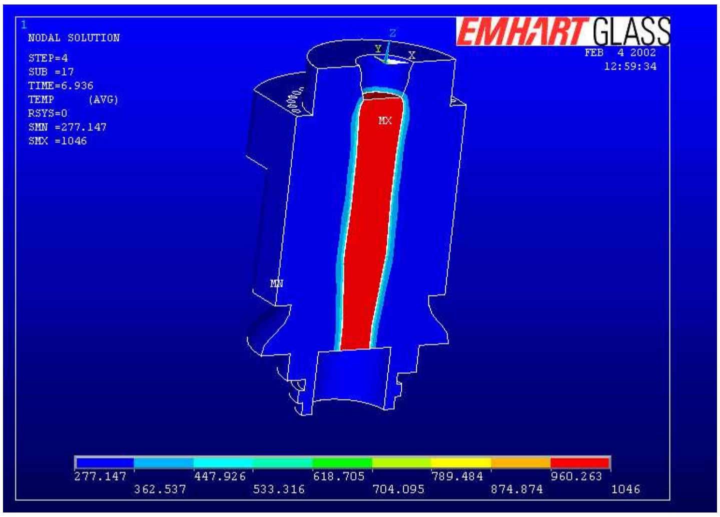
Table 1: Material Properties Used in the Model

Performing a transient heat analysis of blank and blow molds, only the listed temperature depending material properties have to be taken into considerations. No further assumptions are necessary. In Table 2 all major timing events which were needed from the process itself are noted.

Blank Side		Blow Side
NNPB	BB	
Cycle time	Cycle time	Cycle time
Baffle down	Baffle 1 down	Start final blow
Plunger up	Start settle blow	Vacuum on
Mold open	Start counter blow	Mold open
Mold cooling on	Mold open	Mold cooling on
Mold cooling off	Mold cooling on	Mold cooling off
	Mold cooling off	

Table 2: Timing Data Used in the Model.

Starting the transient analysis, first of all, the initial conditions had to be set. The gob loads into the blanks with T_initial_glass=1140°C. The initial mold temperature is set to T_initial_mold=300°C. After inverting the parison to the blow side, the initial glass temperature has to be reduced to T_initial_parison=1000°C to simulate the final blow process. In Figure 1 the model for the blank mold calculations is shown



After meshing the model with solid elements, one can use the isolating layer as a heat switch. During glass contact these elements are 'alive' and afterwards they were 'killed'. Therefore the resulting heat flux from glass into the mold appears only during the 'alive' period. Heat losses due to radiation are neglected within this study. When a new gob enters the mold, all elements were set to 'alive' and a new cycle can begin.

The initial thermal properties of gobs are identical at the start of each cycle. However the thermal conditions of the mold at the start of each cycle follow on from the conditions existing at the end of the previous cycle. So the time history of heat transfer within the mold is continuous. Repeated cycles are run until dynamic thermal equilibrium is established.

Calculation Results

Starting with the initial temperatures described above, Figures 2 and 3 show the temperature fluctuations in glass and *blank* mold during the first eight cycles (BB process). Figure 2 corresponds to the blank mold at half height, below the settle wave. Figure 3 represents the fluctuations near the baffle match line above the settle wave.

Quite essential is the huge difference between glass and mold temperature behaviour, Figure 2 and 3. The glass temperature at the contact surface drops almost –450°C during a glass contact period of 3.6s (first cycle). In that same time interval the mold surface temperature increase 'only' +100°C. For the next cycles, the temperature amplitude at the contact area reduces down to approximately 40°C.

The temperature gradient for the reheat process at the skin of the parison is also quite steep. Within nearly 4 seconds of reheat time, the skin temperature increase is in the range of +130°C. Because of a shorter glass contact time in the region of the baffle match line (time difference between settle blow and counter blow) – Figure 3 – the temperature profiles are somewhat different. Having 2 seconds of glass contact only, the temperature gradients are smoother and the heat up period is increased.

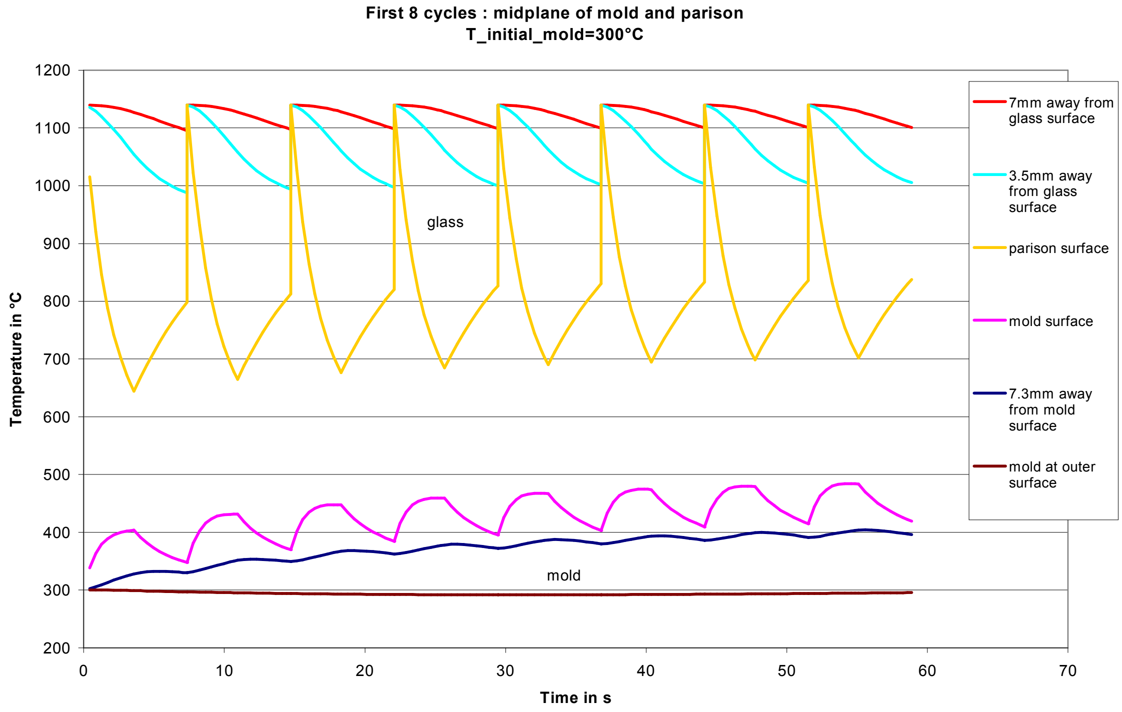


Figure 2: Temperature fluctuation in glass and mold during the first eight cycles. Blank mold simulation at half height (below settle wave). Blow and Blow process

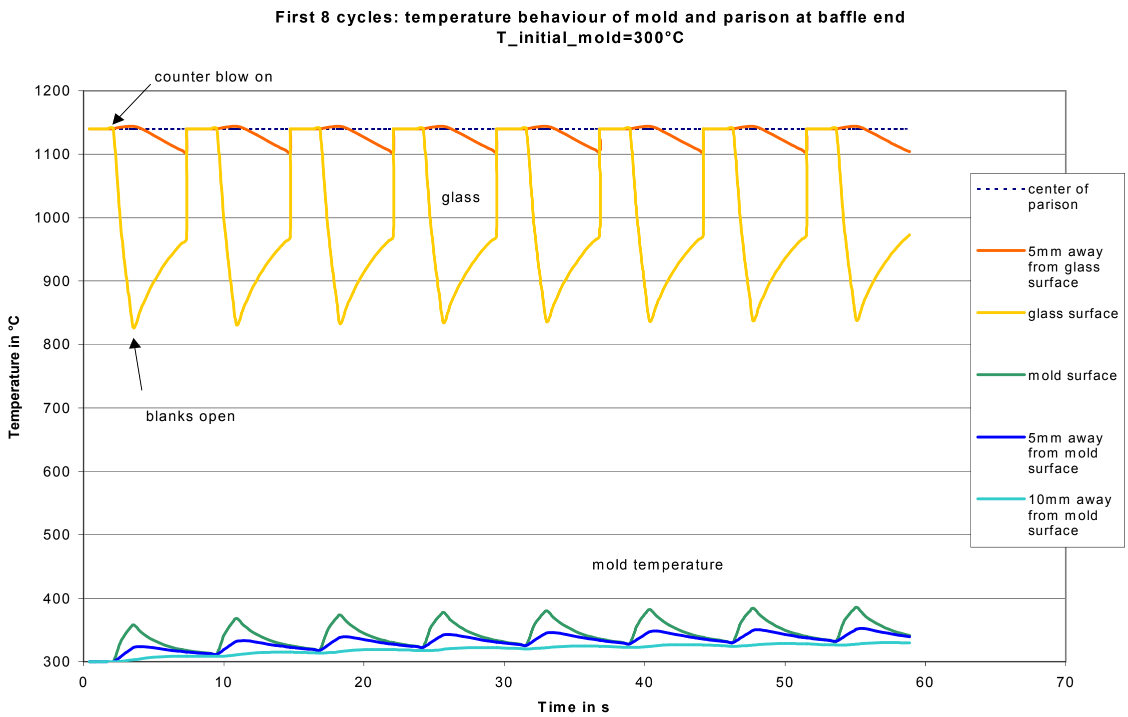


Figure 3: Temperature fluctuation in glass and mold during the first eight cycles. Blank mold simulation at baffle end (above settle wave). Blow and Blow process.

Figure 4 shows the temperature variation within a *blow* mould made out of aluminium bronze for the first 10 cycles. The glass thickness is this present case is 1.8mm. Although the blow mold is not being preheated and the Vertiflow cooling is switched on, the mold reaches rather quickly – in nearly two minutes - a temperature of 400°C.

The temperature fluctuations at the glass contact surface and the inner surface of the bottle are also shown in Figure 4. Due to the relatively thin wall, the glass temperature at the inner surface (violet line) falls significantly during the period when the glass is in contact with the mold. After opening the blow mold, the outer glass surface (red line) experiences a second reheat process whereas at the inner surface temperature continues to fall.

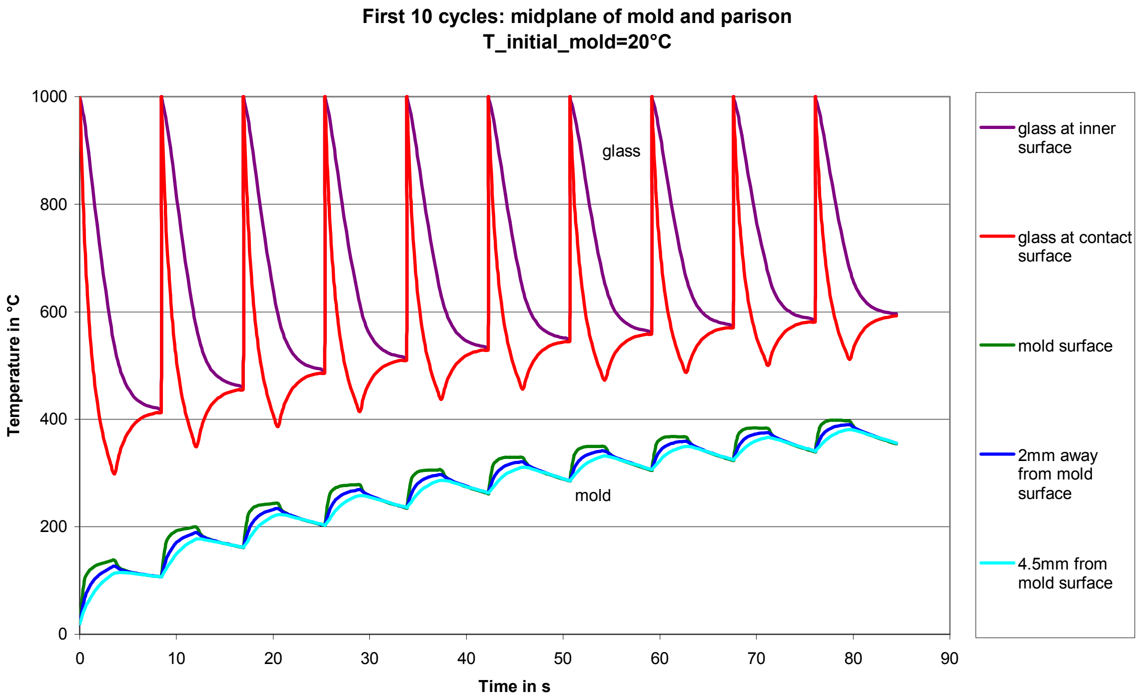


Figure 4: Temperature fluctuation in glass and mold during the first ten cycles. Blow mold simulation (aluminium bronze). No preheat, Vertiflow cooling is on.

Looking at the mold temperature fluctuations, immediately after glass contact, the temperature increases rapidly at the mold contact area. Very soon - approximately after one second of glass contact – the surface temperature of the mold remains constant, although the glass is in contact for a period of t_contact=3.6 seconds. This is due to the fall in glass temperature during the contact period.

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[1] Deidewig, F., *How to effect the temperature distribution blank and blow molds – comparison between FEM calculations and measured results*; XIX International Congress on Glass, Edinburgh, Scotland, July 1-4, 2001.