when looking at the 3D-temperature distribution in blank and blow moulds used in the hollow glass making industry, an understanding of the correct temperature field - mainly at the glass contact area - is of major importance. One of the key problems in the making of high-quality containers is the inability to achieve favourable contact temperatures for the parison, and respectively for the final bottle. Within this paper, the above topic was investigated using a numerical and experimental approach:

1. with the help of a thermal system simulation software, the stationary temperature distribution (averaged over the cycle time) can be calculated. All cycle data, cooling air pressure, heat transfer coefficients for forced and free convection, as well as radiation and heat flux from the glass into the moulds must be taken into consideration;
2. mainly, all cast-iron or bronze alloy moulds are cooled by pressurized air passing through axial holes;
3. using the heat flux from the glass into the moulds as one key boundary condition, a 1D transient model has to be implemented into the overall calculation set-up;
4. to validate numerical results, several moulds were prepared with thermocouples to a variety of moulds to read actual temperatures;
5. variations in neck-ring cooling and axial cooling times can be studied, and the effect of the obtained changes in overall temperature distribution can be outlined;
6. changing vertical temperature distribution significantly is hard
to achieve because of the huge thermal diffusivity of cast-iron/aluminium bronze moulds. The methods of variable hole lengths, counterbores and grooves are the most selective ways to go.

**ESTABLISHING BOUNDARY CONDITIONS**

To try to calculate a reasonable temperature pattern in the moulds, four boundary conditions must be taken into consideration. Solving the Laplace equation for stationary temperature field problems, only one material property must be introduced into the model - the temperature-dependent thermal conductivity. The following boundary conditions are all averaged over the cycle time and used for the Laplace equation:

- heat flux from glass into the mould as a function of glass contact time;
- forced convection for axial cooling holes;
- free convection plus radiation for outer surfaces; and
- forced convection for neck-ring cooling.

**ASSESSING FLUX LEVELS**

The heat flux could be calculated with a transient finite element programme where the diffusivity parameters of glass and cast-iron/aluminium bronze have to be taken into consideration along with their initial temperatures. It is remarkable that only approximately 60 percent of the theoretical amount of heat enters the cast-iron moulds because of a huge contact resistance. To predict realistic heat flux values, one can operate with reduced true thermal conductivity for glass in the order of 1.2...1.5 W/(mK) instead of 2.2...2.6 W/(mK), which is valid for typical glass temperatures during forming. Another way of reaching real heat flux numbers is to simulate a small isolating layer between the glass and mould surfaces. Figure 1 gives an idea of the heat flux versus glass contact time for blank moulds.

One can easily see the difference between ideal and real glass contact conditions. For practical reasons, the heat flux curves can be used as a function in the form of

\[ q = (a_0 + a_1 t + a_2 t^2)^{-1} \]

and then integrated analytically with respect to glass contact time to get the time-averaged heat flux as the first boundary condition. The same procedure can be applied for the blow side, taking into account a deeper initial glass temperature and a lower thermal glass conductivity. This leads to a lower resulting heat flux, as seen in Figure 2.

The second boundary condition is simply a function of the Reynolds number inside the axial cooling hole. The Re number is in the range of \( Re = 30k \) and therefore one can assume a fully turbulent flow. Flow velocity itself is a square root relationship of fan pressure and resulting pressure losses in the ductwork. The heat transfer coefficient (HTC) for typical cooling holes and plenum pressures is in the range of 300 W/(m²K). The third boundary condition is a combination of free convection and radiation. For a solid cylinder with an \( L/D = 2 \) and a surface temperature near 300°C, the HTC is close to 8 W/(m²K). The radiation effect could be handled as an addition to such low HTCs.

This combination leads to an overall HTC in the range of 28 W/(m²K). Finally, the neck-ring and the lower part of the blank mould are also cooled by forced convection. The HTC is in the same order of magnitude compared to the cooling holes. The cooling effect at the front stagnation point is nearly twice as high compared to the seams. Applying all boundary conditions to the given problem, studies on blank and blow side behaviour can be performed as shown in Figure 3.