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Study Of Mould Tempering

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***Abstract* — The paper deals with numerical simulation of surface temperature on complicated metallic mould and of airflow fields, used to keep this temperature on required value. Calculations were realized on simplified (spare) shape of the mould, with various layouts of air inlets. From many solved cases there are presented results of one of them.**
Next solved model shows that using hot oil bath it is possible to get uniform temperature field, some local abnormalities can be realized by few additional infrared heaters, if necessary.
After the resolution of direct transfer of inexact shape of the mould in exact code of flow numerical simulation, the results and procedures can be used directly for real shape of the mould.

Keywords—mould, heat transfer, flow numerical simulation

I. INTRODUCTION

A. *State of the art*

The solved equipment is a part of line producing shaped surfaces made from „artificial leather“ by melting of PVC powder on shaped heated surface. The metallic mould is of spacious and complicated three-dimensional surfaces, typical outline volume of about 0.4 m^3, made from 5 mm nickel sheet.

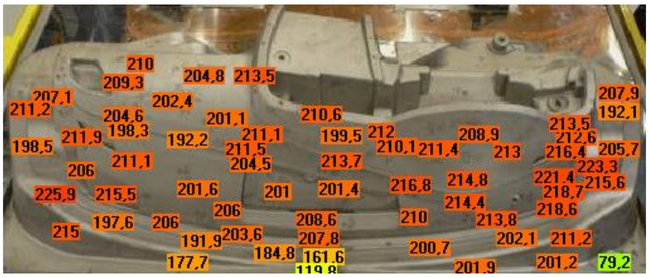

Fig. 1. *Typical temperature field on the mould surface*

First phase - the face side surface is heated at the temperature of 250-300°C, using system of 100-150 infra heaters of pulse-switched power input of 2 kW or 1,6 kW each. On the heated surface are installed thermocouples for the control of heaters activity during the production cycle. The nominal input see for instance [1], typical shape see the Fig. 1, together with recorded temperatures of individual thermocouples. It is visible quite uneven surface temperature.

Second phase - after the heating, the filled PVC powder is smelt and sticked overall on the hot surface. The powder excess is removed and on the backside there are added eight inlets of hot air with controlled temperature and the process is continuing at constant temperature. The aim is to get the uniform structure of the product, temperature is kept by infra heaters from one side, from the other side by eight air flows. The last phase is the cooling of the product, sprayed by cold water.

B. *Aim*

The aim of presented numerical simulation is the determination of optimum airflows from eight fans under the mould during the second phase of the heating (keeping the temperature 300°C approx.) and the corresponding temperature field of the mould. In contrast to the real temperatures (Fig.1) for the numerical simulation is defined the temperature of inlet air into the mould as 600 K (327°C) and surroundings temperature 300 K (27°C). In this introductory study, the influence of treated plastic layer is neglected.

II. NUMERICAL FLOW SIMULATION

A. *Description of used model*

Geometry

Complicated mould shape was created in software Catia, which creates smooth and complicated mould surface incorrectly, adding several small „patches“. Thereby arise both empty or overlapped areas, incorrect junctions of individual elementary surfaces etc. Such incorrectnesses of order 0.01 mm approx. make no problem for design, production, checking and operation, but for mathematically exact software, used for flow simulation it is not usable.

Therefore for simulation purposes the spare simple body was created as frustum of pyramid. The hot air from 8 inlets is blown under the mould body at pressure gradient of 70 Pa.

On the outer side there is defined standing surrounding (0 Pa, 300 K) for modeling the heat transfer through the nickel wall of the mould and to determine temperature of outer surface and natural flow of outer air. Such low and fully uniform temperature was defined to display temperature differences on the mould surface during heating by air. Really, the surface is heated from the previous phase and its temperature is not fully uniform (see the Fig. 1) and more, the system of infra heaters is operating, too.

B. Results

Many complex cases were solved - 3D flow of turbulent compressible flow of viscous gas with the influence of heat exchange through the metallic wall of the mould into surroundings. As an illustration there are presented typical images of the flow field (velocity, temperature, streamlines) for one of solved cases. To display individual influences on mould temperature, the situation is simplified here. Streamlines show the flow under the mould surface – as ground plan, front view and side view, see the Fig. 2 to Fig. 4. Each inlet has its own color, so it is possible to see inlets and to trace spreading and mixing of individual inlet flows, filling the volume under mould.

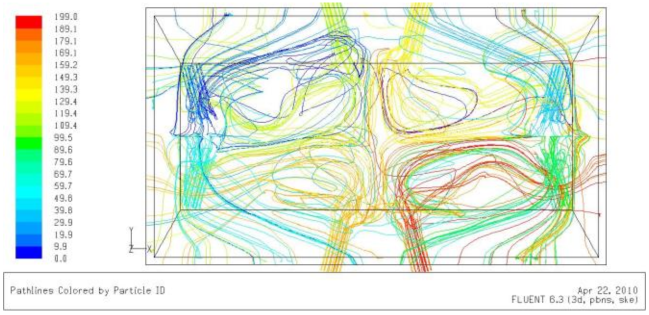

Fig. 2. *Streamlines in ground plane*

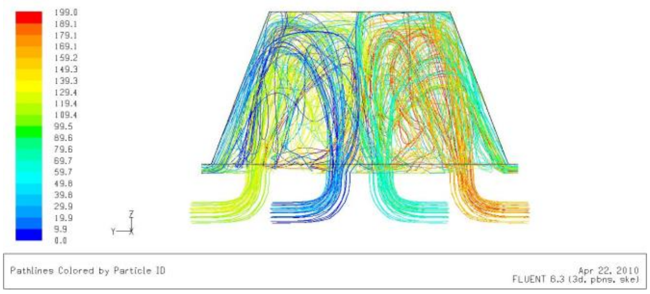

Fig. 3. *Streamlines in side view*

Fig. 4. *Streamlines in front view*

Velocity fields in vertical symmetry planes (both lengthwise and crosswise, see the Fig. 5 and Fig. 6) indicate higher velocity just after individual inlets under the mould cavity, local maxima are situated at the centre of both longer and shorter side walls.

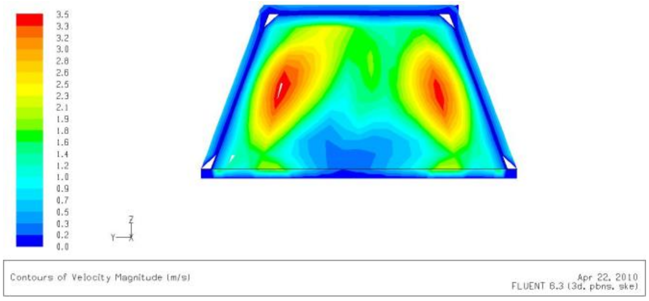

Fig. 5. *Velocity field in side view*

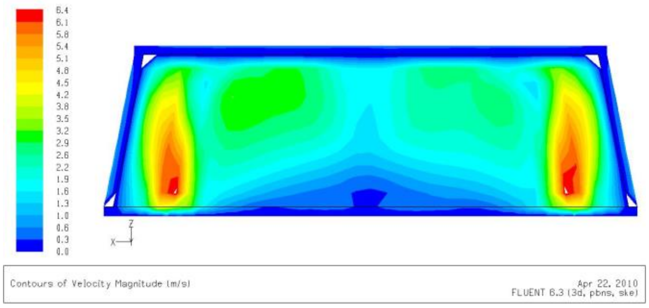

Fig. 6. *Velocity field in front view*

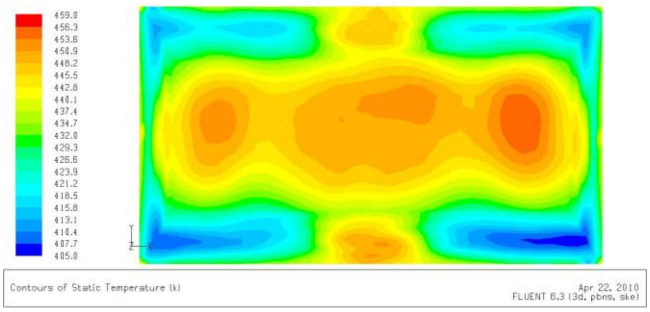

Fig. 7. *Temperature field on the mould surface*

After the Fig. 7 the upper mould surface is relatively well heated, badly heated are edges between short and long side walls. Note: the case is solved for a constant temperature in all 8 air inlets, really it is possible to set and control each of them at different temperature.

Next temperature fields in vertical symmetry planes (both lengthwise and crosswise, see the Fig. 8 and Fig. 9) are uniform very well. It is visible the temperature gradient at the heat transfer through the mould walls into the cold surroundings outside the mould.

The situation is simplified here - really the mould mass is heated at the temperature higher than surroundings and kept on it by hot air flows from the inner side and by infra heaters from the outer side (not used here).

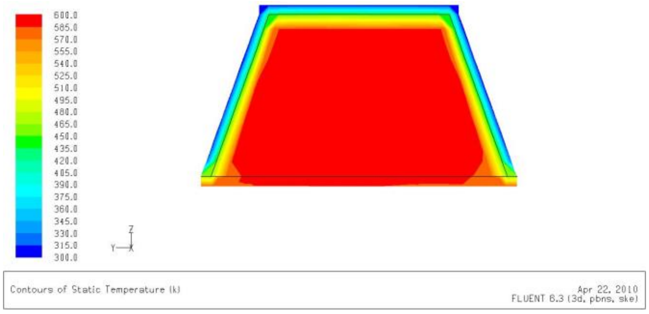

Fig. 8. *Temperature field – side view*

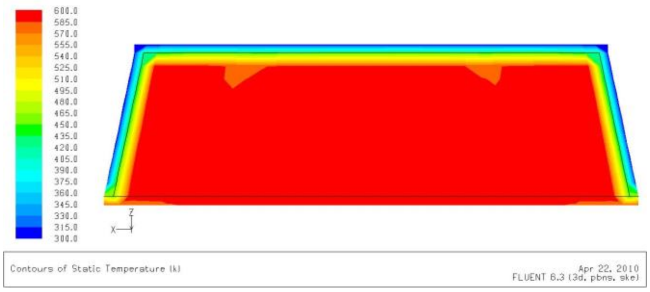

Fig. 9. *Temperature field – front view*

C. *Summary of simulated cases*

Instead large number of resulting flow fields, indicated in the previous section, here are presented several common comparative graphs, only, for 13 solved cases of various inlet arrangements and of constant boundary conditions (70 Pa, 600/300 K). Some interesting conclusions are presented below, it is possible to choose the best arrangement for next treatment.

It is evident that less flowed corners of the mould above decrease the local surface temperature. This influence will be more evident at real complicated shape.

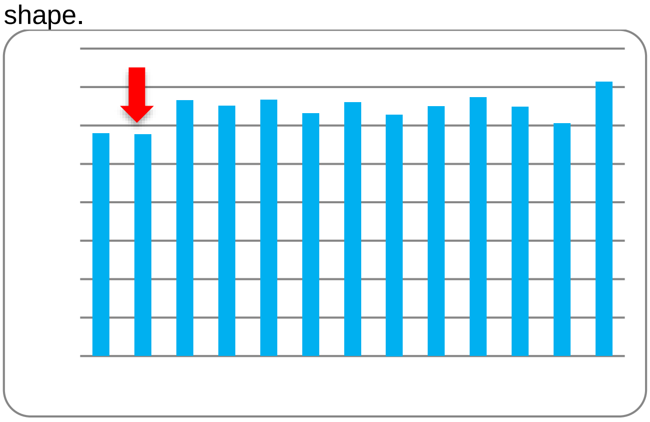

Fig. 10. *Air flow (up to 0.4 kg/s) of solved cases*

The lowest air flow (kg/s), highlighted in the Fig. 10 by the arrow is the consequence of 4+4 air inlets situated just alongside, probably due to the higher mutual constraining of individual flows.

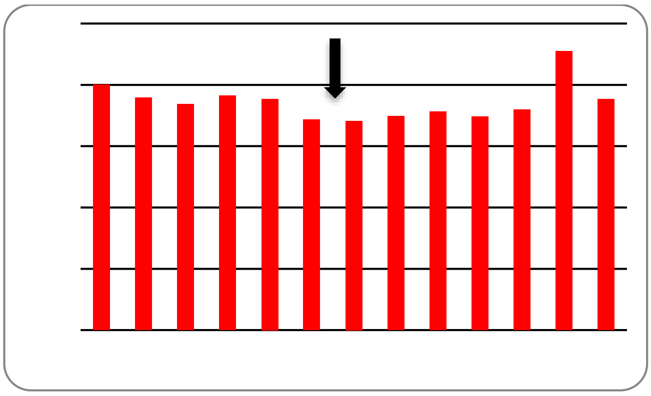

Fig. 11. *Heat flow (up to 10 kW) through the mould surface*

The differences of heat flows among individual cases are 10% approx. The values of heat flow across the material of the mould correspond well with heat input in the inlet air flow. The case highlighted in the Fig. 11 by the arrow has the air inlets situated in the vicinity of peripheral outlet orifice, so it is possible that a part of the air is flowing as the short-circuit flow out without effect – temperatures of this case are lower in general. The same is visible on lower temperatures of those cases (see the Fig. 12).

The Fig. 12 summarizes informatory values of all solved cases, as supplement to the above mentioned temperature fields. The presented extreme values were simply derived from simulated temperature fields, so they are not exact.

Note: The differences of temperatures, air flows and heat flows in the outer surroundings are higher, but not presented here. The surrounding is here defined only for simulation of the heat transfer from the mould inner volume through its walls into outer volume of surroundings, considerably reduced. This is the reason of some errors in energy (heat) balances.

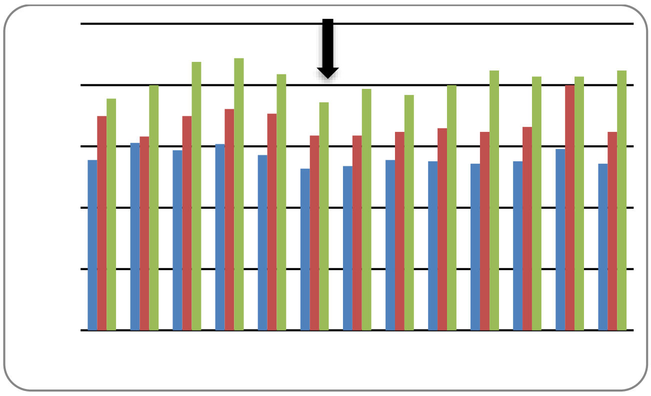

Fig. 12. *Mould temperatures (up to 250°C) – avg, min, max*

D. *Mould heating by oil*

As an alternative it is supposed the heating of outer mould surface by oil. The result of it is quick and uniform heating, confirmed by unsteady solution of the mould temperature, from the one side heated by hot oil and with cold surroundings from the other side. It should be suitable to insulate thermally this other side. The aim of simulation is to demonstrate very uniform and very quick warming of the mould surface, in comparison with actual operational results (see for instance the section I).

The oil bath assumes the quick and uniform heating of the mould mass, which is not possible to realize by individual infra heaters and individual hot air flows. During the following quick cooling of the mould by sprayed water into the inner part of the mould it is necessary to exchange the content of hot oil by cold one – analogous to the cooling of standard injection mould. Both hot and cold oil should be accumulated in tanks, well insulated, therefore the heat input covers the thermal losses into the surroundings, only.

Geometry is created as double walls of the mould, filled by oil. The outer side is working - here is the treated PVC layer and could be thermally insulated during the heating phase. The inner side should be thermally insulated permanently.

Boundary and initial conditions are defined as oil and air inlets on horizontal surfaces (perpendicular to the gravitation), outlets on side surfaces. Temperatures 600 K for oil and 300 K for air, the natural flows arise by different densities, only, due to the temperature changes.

The step of the unsteady solution is defined 1 s, 50 steps together – it corresponds to the time of the second period of operating cycle.

The oil temperature increasing in lateral volumes begins practically immediately, but in the lower horizontal volume gradually. In the narrow and horizontal gap of the mould the natural flow is suppressed. On the contrary, the air is heated practically on the whole mould bottom since the beginning of simulation – the necessary heat is coming by heat transfer through material of the mould walls.

Results

Next figures present informative fields of velocity and temperature. They are visible some instationarities, which arise in such system. Partially such image is influenced by given boundary conditions. For instance, the overall lower temperature of the mould bottom is due to the narrow volume between mould bottom and surroundings on the liquid side, where the natural flow cannot arise, as on the air side, where is the volume enough.

Some irregularity of the temperature field on the mould bottom (20 K approx.) is the consequence of unsuitable geometry, so that it cannot arise an expressive natural flow. So that the air temperature and ascending flow are a little uneven, too. But this non-uniformity is less than in the actual operation (see the Fig. 1). At increased orifice some large vortices arise, similar to the air side and temperature field becomes more uniform. Instead larger orifice it is possible to use forced liquid flow in the horizontal direction.

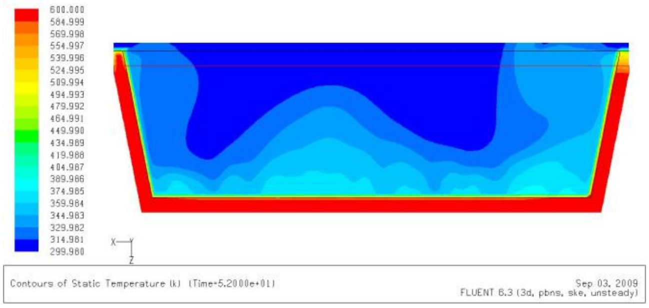

Fig. 13. *Temperature field in the lengthwise vertical symmetry plane*

The Fig. 13 presents hot oil of 327°C (600 K) between double walls of the mould, the air inside of 27°C (300 K). Really, on the outer mould surface is situated the treated PVC layer of lower thermal conductivity than metallic mould, in this first feasibility study is neglected.

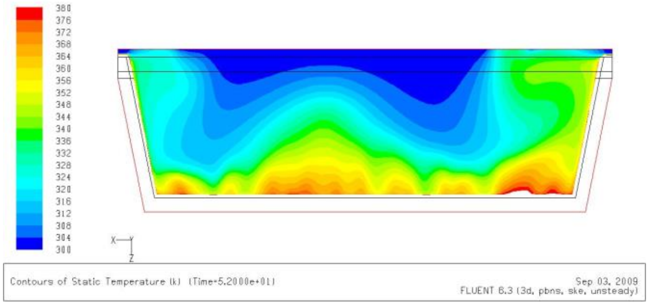

Fig. 14. *Detail of temperature field (suppressed scale)*

Using suppressed scale the details of temperature field on the air side are well visible. Air volumes are heated on the inner mould surface and irregularly are separating and flowing up. The Fig. 14 presents one of time steps of unsteady solution.

Note: Local overheating (right down) has not any natural reason, here it is probably the consequence of used rough mesh.

Similar situation presents the velocity field in the Fig. 15. They are visible the separations of heated air volumes from the bottom hot surface of the mould. The directional field on the Fig. 16 is another illustration of the same phenomenon – excessive vortex field as the consequence of air heating and separation, first of all from the lower surface of the mould.

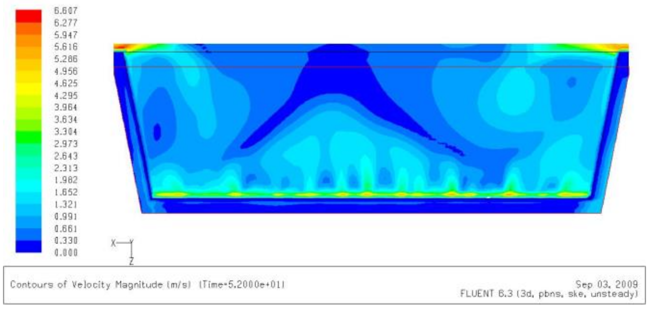

Fig. 15. *Velocity field in the lengthwise vertical symmetry plane*

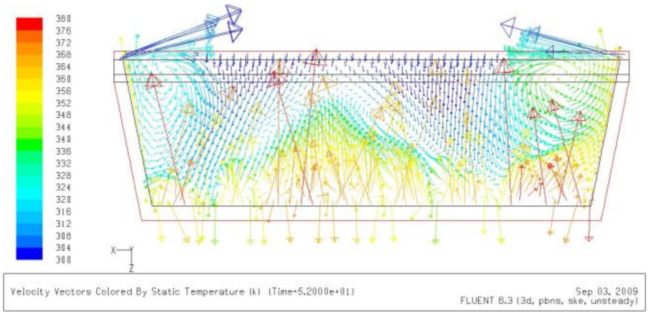

Fig. 16. *Directional field (air side)*

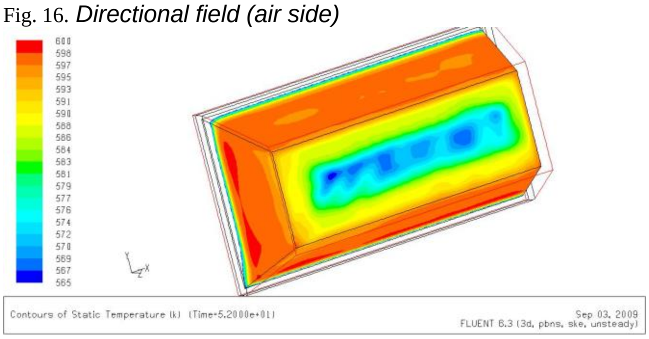

Fig. 17. *Temperature field (suppressed scale) on the mould surface*

The temperature field after the Fig. 17 is very uniform. A little colder bottom is caused by horizontally oriented bottom surface (see previous Figures), which prevents the natural vertical flow along. It should be better to operate with inclined mould or with forced oil flow inside.

From evaluated heat flow balance the thermal loss from mould material into the surroundings (for temperature difference of 300 K) is evaluated as 22.2 kW approx. It is necessary to add the heat input to the mould reheating, cooled during the previous operating cycle (warming of mould material and of treated plastic, too, heat losses in surroundings etc.). Really, the temperature of air and of treated plastic material respectively is higher than considered, therefore the total thermal loss will be lower. This input is lower, compared with 60 kW approx. for 8 fans with air heating and next 150 kW approx. of installed input for pulse-switched infra heaters [1] etc.

Note: The heating by the system of infrared heaters allows to create locally different temperature, if necessary for treated material and product shape. But the proposed oil heating at uniform temperature can be simply completed by several infra heaters in necessary areas. It should be to decide, which of above presented variants is better in general and in an actual case.

III. Conclusions

Preliminary said that heating by system of pulse-switched infrared heaters together with flows of hot air cannot ensure the uniform mould temperature. On the other side such system ensures quick heating on the operational temperature, to get required operational capacity and to use locally different temperatures, if necessary.

To get a uniform temperature of the mould surface it needs to have a source of uniform temperature, too. Therefore it is proposed to carry out the heating by hot oil flowing between doubled walls of the mould. Performed numerical simulation confirms very uniform surface temperature. It remains technical problem – the design of such system with quick switching-over of cold and hot oil, accumulated in insulated tanks and manipulation with it.

The work is not finished with the intent that it is failed the import of design data of real mould (containing small errors) into the mathematically exact program of flow numerical simulation. Nevertheless, from simple spare model result some useful conclusions for real operation.

Acknowledgment

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