EFRO Project " *INISO-MAT* "

Title : " Thermal Insulation of Injection Molding Tools: an Advantage ? "

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Abstract :

In the current context of reducing greenhouse gas emissions and their adverse impact on the climate, the use of plastics is strongly criticized. Yet it seems impossible to do without because our daily life is too impregnated with them (packaging, household appliances, electronics, various equipments, ...). Injection molding technology enables high productivity combined with unequaled freedom of design. This technology has grown exponentially over the past 50 years and still has fine days ahead but must adapt to increasing energetic and ecological constraints. Many efforts are already made in the design of machines and ancillaries. By the way, the technique requires twice a supply of energy. One to heat and melt the material and a second to cool it as quickly as possible. In an ideal world, it would be obvious to recover at cooling all the energy provided during heating. For this purpose it is necessary to minimize the losses as much as possible. These are lying at all levels of the manufacturing process: losses in the heating barrel, losses in the tooling, losses in the coolant lines, … . The present paper focuses exclusively on the tooling part that is out of the scope of the machine suppliers and evaluates the potential interest in isolating the injection molds.

1. Introduction

The goal of the INISOMAT project is to evaluate the effect of the use of insulating media on injection molding tools in order to save energy at the workshop level (mold, process, and workshop environment). Two ways are followed in the project. The first one deals with the building of a simple analytical model to evaluate the main averaged heat flows occurring during the injection molding process. This model is developed to any kind of injection molding tool and is just requiring access to a spreadsheet like Excel. The second way is dedicated to trials of insulating media on sites and measurements of their impacts and efficiencies on the energy savings.

The present paper gives an overview of the results provided by the analytical model in three totally different process cases: The first case concerns the mass production of an HDPE cap in a 8 cavities mold; the second one is a single cavity injection molding tool for a housing base made of a technical polymer like a PC; finally, the third case is related to the injection molding of high added value part made of a high performance polymer like PEEK. For each of these cases the typical mold temperature levels range from 20 to 200 degrees, which is representative of all situations that may be encountered in practice.

2. Analytical model

The calculation strategy is based on the evaluation of heat flow balance between the different volume areas of a mold without looking for details of local heat transfer and temperature. Therefore, the mold is divided in subregions that we can adapt easily in every situations. In the general concept, we assume a cold region including the moving half of the mold and a part of the fixed half side. Both are provided with cooling channels. The hot region is the one that is supplied with a hot runner if any.

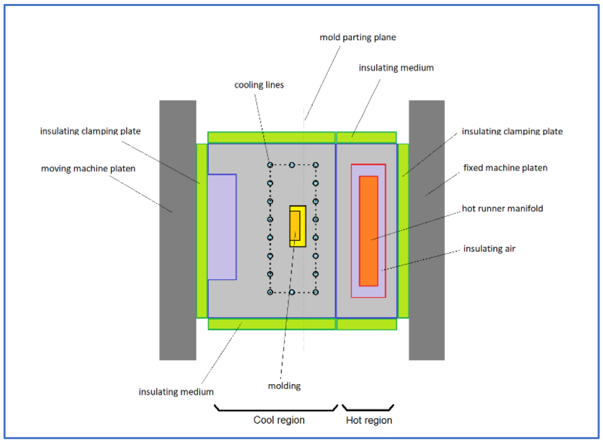

Fig.01 : Main parts of an injection molding tool.

These two regions are divided in other subregions as well. These are related to their influences on the thermal heat transfer between the moldings, the environment (air and machine platens) and the cooling medium. The figures 01 and 02 show the division of a mold by these several subregions. The central region of the cool side includes the area of the moldings surrounded by the cooling channels. This region is surrounded by a volume in contact with the air outside. On the rear side there is a region in contact with the moving platen of the machine and in the front side a region in contact with the hot region of the mold.

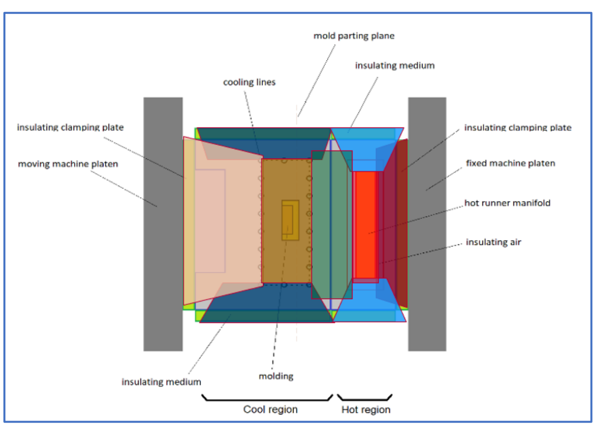

Fig. 02 : Divisions of an injection molding tool in several subregions.

The hot region is subdivided with similar subregions.

Each of these subregions have averaged geometrical parameters (averaged thicknesses and areas) and boundary conditions like power applied or temperatures. The geometrical and material properties of the regions are introduced in the calculation model through a thermal resistance term calculated by the following equations according to the type of heat transfer :

$$Conduction: \; R_{th} = \frac{\Delta e}{k.S} \cdot \left[\frac{K}{W}\right]$$

$$Convection: \; R_{th} = \frac{1}{h.S} \cdot \left[\frac{K}{W}\right]$$

$$Radiation\ (*): \; R_{th} = \frac{1}{4T_m^3.\epsilon.\sigma.S} \cdot \left[\frac{K}{W}\right]$$

With

Δe = averaged thickness of the region [m]

k = thermal conductivity of the region [W/m.K]

S = averaged area of the region [m2]

h = convection coefficient [W/m2.K]

Tm = averaged temperature between mold and ambiance [K].

ε = emissivity of the outer area [-]

σ = Stefan-Boltzmann constant (5.68E-08) [W/m2.K4].

(*) radiation was linearized around the average temperature Tm between mold and ambiance.

All the thermal resistances of the model are shown on the figure 03.

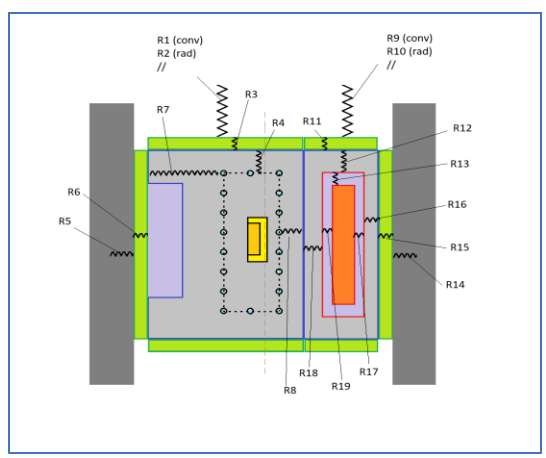

Fig. 03 : Model of thermal resistances.

Thanks to these simplifications and assumptions, we keep only 8 heat flows that are representative of the whole thermal behavior of the mold. These heat flows are shown on the figure 04.

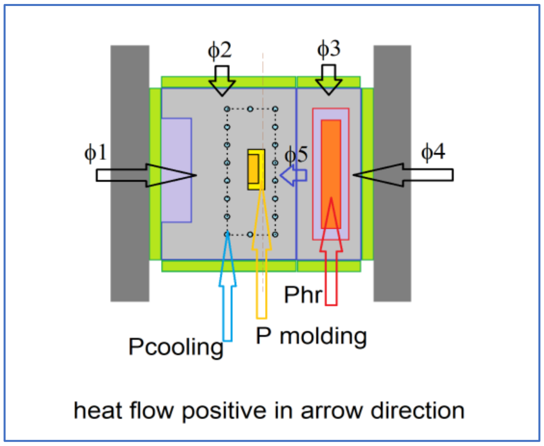

Fig.04 : Heat flows in the mold and positive orientations.

These heat flows are averaged per injection molding cycle and are the following :

Φ1 [W] = heat flow between mold and moving clamping platen.
Φ2 [W] = heat flow between cool side and ambiance.
Φ3 [W] = heat flow between hot side and ambiance.
Φ4 [W] = heat flow between mold and fixed clamping platen.
Φ5 [W] = heat flow between hot side and cool side of the mold.
P hr [W] = Power to compensate heat losses of the hot runner
P moldings [W] = Power applied by the moldings
P cooling [W] = Power applied by the cooling lines

All these heat flows are assumed to be positive when coming from outside to the mold. The arrows on the figure 04 shows the positive orientations of the heat flows. By combining these heat flows with the calculated thermal resistances, we can build the thermal model of the model like a network connecting the different elements playing a role in the heat transfer of the mold. This network is shown on the figure 05.

The goal of the model is to find the balance between the different heat flows knowing power coming from the moldings, entrance coolant temperature and flow rate, cycle and cooling time, molding and demolding temperatures. The equations of the model are integrated in a simple spreadsheet.

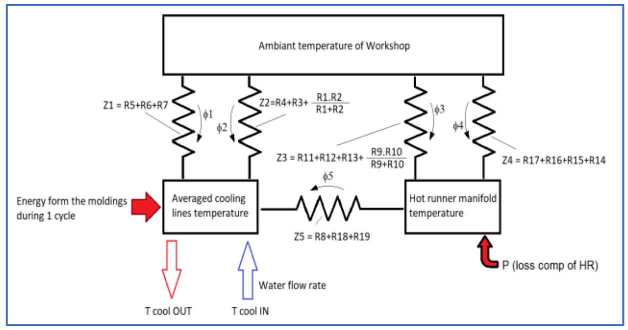

Fig. 05 : Thermal resistance network model.

3. Cases studies.

3.1 Injection molding of a commodity plastic.

The example deals with the injection molding of a bottle cap made of HDPE. The mold is a 16 cavities with a hot runner manifold of 16 hot tips. The caps have a diameter of 70 mm and a height of 35 mm. The mass product is 20 g. The main dimensions of the mold are 1m x 0.6 m x 0.6 m.

Fig. 06 : 16 cavities cap mold (courtesy of United Caps).

The main parameters for the evaluation are

- Melt temperature : 220 °C
- Coolant : water, 15°C, 10 Kg/s
- Cycle time 17.5 s
- Cooling time 9 s
- Demolding temperature 60 °C

In the study, we calculated all the heat flows described above in two different conditions: without insulation and with insulation. All the other parameters stay unchanged. The insulation of the mold includes the following :

- A strong rigid insulating plate between the mold and the machine platens, for the moving side and the fixed side. The specifications of these plates are a thickness of 15 mm and a thermal conductivity of 1 W/m.K.
- An insulating medium around the mold that could be high performance aerogel blanket with a thickness of 50 mm and a thermal conductivity of 0.02 W/m.K.

The results are given in the table below.

HDPE cap	Insulated	Not insulated	
Power supplied to the mold			
From Moldings	23483	23483	W
From Hot runner	278	329	W
TOTAL HEAT INPUT	**23761**	**23812**	W
TOTAL ENERGY PER CYCLE	116	116	W.h
Power supplied by cooling lines			
P COOLING LINES	-23651	-23847	W
TOTAL ENERGY PER CYCLE	-115	-116	W.h
Heat losses			
Through moving clamping platen	37	61	W
In the air through outer surface of cool side	2.7	174	W
In the air through outer surface of hot side	-25	-74	W
Through fix clamping platen	-124	-126	W
TOTAL HEAT BALANCE WITH AMBIANCE	**-110**	**35**	W
TOTAL ENERGY PER CYCLE	-0.5	0.2	W.h

Fig.07 : Heat flow balance (HDPE cap)

The difference between both situations show a heating power higher coming from the hot runner of + 51 W (329-278) when not insulated. If we look at the heat losses we see that the cool side of the mold absorbs from the ambiance 235 W (61+174) without insulation and only 39.7 W (37+2.7) with insulation because the mold temperature is at lower temperature than the ambiance. For the hot side, we lose 149 W (-25-124) with insulation and 200 W (-126-74) without insulation. If we assume that all the energy that is absorbed by the mold and transferred by the cooling lines can be saved further (in a heat exchanger e.g.), the real losses between both cases include the extra power put in the hot runner and the negative heat flows between mold and ambiance. In this case we have thus

- Without insulation: 329 W + 200 W = 529 W
- With insulation: 278 W + 149 W = 427 W

In these conditions, the savings realized with the insulation are **102 W.** On one cycle (17.5 s = 0.004861 h) that means 0.496 W.h. Knowing that we inject 16 parts per cycle with 20 g each, the savings per mass unit is **1.55 W.h/Kg.**

3.2 Injection molding of a technical plastic.

The next example concerns the molding of a PC housing base. The housing has dimensions of 150 mm x 80 mm x 44 mm and has 4 threated holes on its bottom and 2 each on the narrow end.

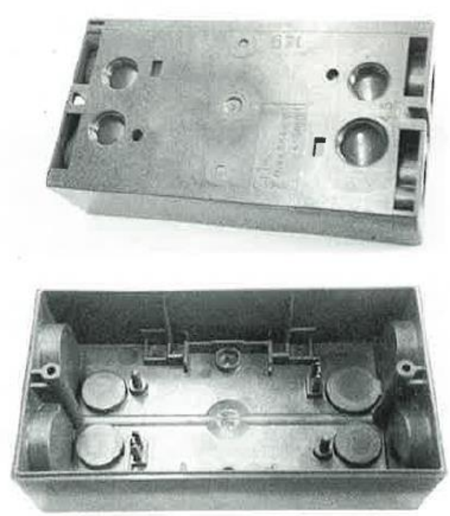

Fig. 08: PC housing base (ex. from "Gastrow - Injection Molds - 2nd ed. - 108 proven design - p.164)

The narrow ends also have recesses between the threaded holes. The interior contains snap hook, bosses and mounting eyes. Average thickness is about 2 mm but the cycle time (about 30 sec) is more affected by the geared release of the several in-mold threads. The part is gated on its bottom and filled via a central hot runner nozzle. The product mass is 74 g.

The main parameters for the evaluation are

- Melt temperature : 290 °C
- Coolant : water, 90°C, 0.5 Kg/s
- Cycle time 30 s
- Cooling time 20 s

- Demolding temperature 120 °C

In the study, we calculated all the heat flows described above in two different conditions: without insulation and with insulation. All the other parameters stay unchanged. The insulation of the mold includes the following :

- A strong rigid insulating plate between the mold and the machine platens, for the moving side and the fixed side. The specifications of these plates are a thickness of 15 mm and a thermal conductivity of 1 W/m.K.
- An insulating medium around the mold that could be high performance aerogel blanket with a thickness of 50 mm and a thermal conductivity of 0.02 W/m.K.

The results are given in the table below.

PC housing base	Insulated	Not insulated	
Power supplied to the mold			
From Moldings	1030	1030	W
From Hot runner	10	19	W
TOTAL HEAT INPUT	**1040**	**1049**	W
TOTAL ENERGY PER CYCLE	8.67	8.74	W.h
Power supplied by cooling lines			
P COOLING LINES	-896	1442	W
TOTAL ENERGY PER CYCLE	-7.2	12	W.h
Heat losses			
Through moving clamping platen	-144	-256	W
In the air through outer surface of cool side	-19	-2217	W
In the air through outer surface of hot side	-6	-15	W
Through fix clamping platen	-2	-2	W
TOTAL HEAT BALANCE WITH AMBIANCE	**-171**	**-2490**	W
TOTAL ENERGY PER CYCLE	-1.4	-20.8	W.h

Fig.09 : Heat flow balance (PC housing base)

Without insulation, the consumption of the hot runner is 9 W (19-10) higher. Concerning the pure heat losses in the environment, the difference is 2319 W (2490 - 171). Considering the power supplied by the cooling lines, this value is positive without insulation: in that configuration, we need to put heat into the mold to keep it warm and a large content of this heat is lost in the environment. On the other hand, with insulation this flow is negative, meaning that the cooling lines are extracting heat from the mold (but this heat has still to be used recovered in the heat exchanger downstream). To summarize, the total real heat losses in both cases are:

- Without insulation: 2490 W+19 W =2509 W.
- With insulation : 171 W+10 W = 181 W.

In these conditions the savings realized with the insulation are **2328 W**. On one cycle (30 s = 0.0083 h) that means 19.3 W.h and per mass unit we have (1 cavity of 74 g) **260.8 W.h/Kg**.

3.3 Injection molding of a high performance plastic.

In the following example, we deal with the molding of a part made of a high performance unreinforced PEEK. The part is the insulator of a connector molded in 16 cavities fed by a hot runner manifold. The mass of each part is 0.4 g and the local maximal thickness is 1.5 mm.

Fig. 10: PEEK connector.

The main process parameters are

- Melt temperature : 385 °C
- Coolant : oil, 200°C, 0.1 Kg/s
- Cycle time 12 s
- Cooling time 9 s
- Demolding temperature 220 °C

The insulation solution is the same as already used for the previous case studies :

- A strong rigid insulating plate between the mold and the machine platens, for the moving side and the fixed side. The specifications of these plates are a thickness of 15 mm and a thermal conductivity of 1 W/m.K.
- An insulating medium around the mold that could be high performance aerogel blanket with a thickness of 50 mm and a thermal conductivity of 0.02 W/m.K.

The results are given in the table below.

PEEK Connector	Insulated	Not insulated	
Power supplied to the mold			
From Moldings	348	348	W
From Hot runner	183	314	W
TOTAL HEAT INPUT	**531**	**661**	W
TOTAL ENERGY PER CYCLE	1.77	2.2	W.h
Power supplied by cooling lines			
P COOLING LINES	-36	3286	W
TOTAL ENERGY PER CYCLE	-0.12	10.95	W.h
Heat losses			
Through moving clamping platen	-341	-621.7	W
In the air through outer surface of cool side	-25	-3069	W
In the air through outer surface of hot side	-25	-150	W
Through fix clamping platen	-103	-107	W
TOTAL HEAT BALANCE WITH AMBIANCE	**-495**	**-3947**	W
TOTAL ENERGY PER CYCLE	-1.6	-13.2	W.h

Fig.11 : Heat flow balance (PEEK connector) .

Without insulation, the consumption of the hot runner is 131 W (314-183) higher. Concerning the pure heat losses in the environment, the difference is 3452 W (3947 - 495). Considering the power supplied by the cooling lines, this value is positive without insulation: in that configuration, we need to put heat into the mold to keep it warm and a large content of this heat is lost in the environment. On the other hand, with insulation this flow is negative, meaning that the cooling lines are extracting heat from the mold (but this heat has still to be recovered in the heat exchanger downstream). Note that this extracted heat is only 36 W. Compared to the input heat (531 W) this is still quite low and the difference (495 W) is lost in the environment.

To summarize, the total real heat losses in both cases are:

- Without insulation: 3947 W+314 W= 4261 W.
- With insulation : 495 W+183 W= 181 W.

In these conditions the savings realized with the insulation are **4080 W.** On one cycle (12 s = 0.003 h) that means 13.6 W.h. Knowing that we inject 16 parts per cycle with 0.4 g each, the savings per mass unit is **2125 W.h/Kg.**

3.4 Summary

The following table summarizes the final results for each case study. The order of magnitude of the energy savings per kg of material processed are 100 and 1000 times higher when the mold temperatures are far above the environment. It seems to be clear that the use of an insulation is a uselessness for tools working at low temperatures

	Mold temperatures (°C)	Savings with insulation		
		Power [W]	Energy per kg processed [W.h / Kg]	c€ per kg processed (*) [c€ / Kg]
HDPE cap	15	102	1.55	0.026
PC housing base	90	2328	260.8	4.43
PEEK connector	200	4080	2125	36.13

(*) 17 c€ / kW.h

Fig.12 : Relative savings for each case study

On the other hand, the savings for the applications requiring a warmer tool temperature have to be balanced with the extra costs induced by the placement of insulating media and their maintenance during the whole process life. For example, if we consider a total production of 100 thousands parts for the PEEK connectors, this means a total production of 40 Kg of PEEK. The total savings, during the whole production, are only 14.5 €, better to say a droplet in the ocean, at least for this example.

4. Conclusions.

A simple and efficient analysis calculation spreadsheet was set up to establish the global heat flow balance in the injection molds. Thanks to this tool one can quickly evaluate the advantage of insulating them. Three case studies were investigated, representing three situations with totally different processing and mold temperatures.

We assumed that the heat conveyed into the chiller can be recovered and we considered as losses the heat that leaves the mold through its all faces plus the extra energy that is required to keep the hot runner at its initial set temperature. Under these conditions, we obtained the heat losses for the various cases and compared the situations with and without insulation. The conclusions showed that the energy savings could be in the order of 100 to 1000 times higher for molds at temperatures well above ambient temperature.

However, in the context of our examples, the absolute gains in an economical point of view remain very low relatively to production volume. They amount to just a few Euros for the best case investigated and for the total production life. They can rarely justify additional investments and maintenance costs required by the insulation. Nevertheless, insulation from a technical point of view remains important for applications requiring a high mold temperature. Maintaining this high temperature can be crucial for the final properties of the product and also to protect the thermal environment of platens and other sensitive components of the injection molding machines. It keeps also a safe working environment for the technicians and prevent any injury by burning. Another advantage of the thermal insulation in such a case is the shorter time to heat up the molds. For high added values parts like the PEEK connector, batch series are smaller and the impact of the setup time length on the processing costs can be very important.

The final conclusion does not want to undermine the efforts to be made in terms of thermal insulation and energy savings. The insulation approach is still important, but the mold does not seem to be the priority target: the insulation of the heating barrel, the insulation of the cooling circuitry downstream the mold to the chillers and the recovery of heat at the exchanger are certainly the priorities to guide the injection molding technology towards an increasingly economical and environmentally friendly process.

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