

# Design of Micro Cooling Channel for Plastic Injection Moulding by Using Mold Flow Advisor

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**Abstract** - The cooling channels of a mold for plastic injection have to be as close as possible to the part surface in order to ensure fast and homogeneous cooling. A different approach is adopted to design "Micro cooling channels". A comparison is done among the effects of cooling circuit on the PIM process and the quality of the product. The work comprises of various analysis performed for different types of cooling circuits. First, the relationship between the micro cooling channel and the cycle time of cooling circuit is formulated. Then, efforts are put to create conformal micro channel design, so that to take the benefit of conformal which will provide uniformity in cooling due to minimum pitch gap. Mold flow simulations are performed to visualize the effect of different type of cooling circuits. The results provide a uniform temperature distribution with reduced non-uniformity in cooling effect due to the pitch gap in cooling circuit and hence reduction in cycle time for the plastic part.

**Key Words:** Mold Flow Advisor, Micro cooling channels , Plastic injection molding.

## 1. INTRODUCTION

Injection molding is a manufacturing process for producing parts by injecting material into a mold. Injection molding can be performed with most of the materials including metals, glasses, plastics, (thermosetting and thermoplastic polymers mainly). Material for the desired part is fed into a heated barrel or material is heated along the feeding path in case of reciprocating screw injection system, and forced into a mold cavity, where it cools and hardens to the configuration of the cavity the part product is taken out [1]. Among these, part cooling takes up 50 to 80 percent of the cycle time [2]. Cutting down the cycle time for each part is a major concern in injection molding machine. Design of the cooling system in the thermoplastic injection molding process is one of the most important steps during mould design. It has a direct influence on the quality of the parts produced, and thereby impinges on the cycle time. Cooling channel design was traditionally limited to relatively simple configurations due to the main process for manufacturing being limited to drilling of straight holes. Nowadays, helped by 3D printers, complex shapes are able to be produced with intricate details and more complex geometries [3]. The manufacturing of conformal cooling with 3D printing presents several challenges. The loose powder within the channels must be removed. This presents a constraint on the length and diameter of the channels as well as a challenge in determining the point of completion of the powder removal operation. Porosity can also present challenges. There are also some issues associated with the material's properties, such as hardness and toughness [4].

In the sense of cooling circuit design micro channel is the word used for cooling circuit having very small diameter of about 1mm -2mm. It have been proven with the analysis that micro-channel cooling effects are more closely conform to the theoretical minimum cooling time while the standard cooling channel results are closer to the adjusted theoretical value. The effectiveness of micro channel cooling is high because of minimal pitch gap of cooling circuit. Through these channels the flow of coolant is possible throughout the area near to the part surface. Moreover, due to less diameter of channels it is not effecting the strength of the mold therefore we can provide micro channels near as possible to the surface of the core and cavity.

## 2. METHODOLOGY

### 1) Cooling Channel Design Computational and Mathematical Modeling

#### a) Modes of heat transfer for PIM

In the case of heat transfer with in plastic injection mould, heat flow into the mould by polymeric melt  $Q_{\text{polymer}}$ , and flow away via conduction, convection and radiation under a heat exchange system[5].

According to energy balance, the heat flowing in and out the injection mould can be described as follows:-

$$Q_{\text{polymer}} = q_{\text{cond}} + q_{\text{conv}} + q_{\text{rad}}$$

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**Table 1 : Modes of heat transfer for PIM**

Mode of heat transfer	The route of heat flow in plastic injection mould
Conduction ( $q_{cond}$ )	From polymeric melt to cooling channel
Convection ( $q_{conv}$ )	From cooling channel inlet to outlet
Radiation ( $q_{rad}$ )	From the mold to surrounding

The conductive rate of heat transfer  $q_{cond}$  is described by Fourier [5] and is shown in Equation as follows:

$$q_{cond} = \frac{kA}{l} (T_0 - T_1) \tag{2}$$

where  $q$  [ $W \cdot s^{-1}$ ] is the heat energy conducted per unit time,  $k$  [ $W/mK$ ] is the coefficient of heat conduction of the medium,  $l$  [ $m$ ] is the length or distance traveled  $T_0$  [ $K$ ] are temperatures of different sides of solid, and  $A$  [ $m^2$ ] is the cross section area.

To express the effect of convection heat transfer, Newton’s law of cooling is applied [5] and is shown in equation (3) as follows:-

$$Q_{conv} = hA(T_w - T_f) \tag{3}$$

Where  $h$  [ $W \cdot m^{-2} \cdot K^{-1}$ ] is the coefficient of convection heat transfer,  $A_c$  [ $m^2$ ] is the surface area for coolant flow, and the temperature of wall and fluid are  $T_w$  [ $K$ ] &  $T_f$  respectively.

The energy transferred is the result of temperature gradient as shown in the equation

$$q_{rad} = F_e F_g \sigma A (T_1^4 - T_2^4) \tag{4}$$

Where  $F_e$  is emissivity function,  $F_g$  is geometric view factor,  $\sigma$  Stefan-Boltzmann constant,  $T_1$  [ $K$ ] is the temperature of body at higher temperature, and  $T_2$  [ $K$ ] is the temperature of the body at lower temperature. ( $\sigma = 5.67 \times 10^{-8} W \cdot m^{-2} \cdot K^{-4}$ ).

**b) Injection Moulding Cycle**

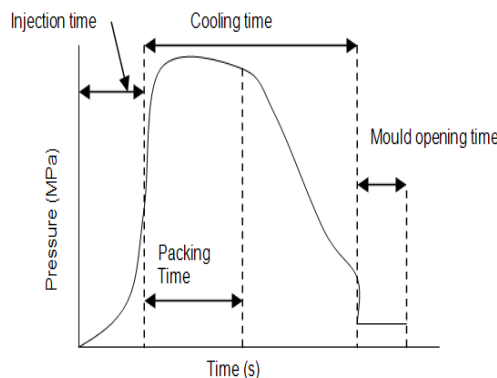


Figure 2: Mould cycle stages ( Moammer 2011 )

**• Injection (filling) Stage :**

The estimation of the injection time requires an extremely difficult analysis of the polymer flow as it flows through the runners, gates and the cavity of mould. the injection time ( $t_f$ ) as shown in the equation (5) [4].

$$T_f = \frac{2VP_j}{p_j} \tag{5}$$

where  $V$  is the volume of the molten polymer ( $m^3$ ),  $P_j$  is the full pressure of the injection moulding machine (Watt) and  $p_j$  is the recommended injection pressure for the moulded polymer ( $N/m^2$ ). [4].

**• Cooling Time:**

The variation in temperature across the wall thickness and over time is described by one-dimensional heat conduction according to equation 5 [4].

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{5}$$

where  $x$  is the coordinate distance centre plane of the wall normal to the plate surface ( $mm$ ),  $T$  is the temperature ( $^{\circ}C$ ),  $t$  is time ( $s$ ) and  $\alpha$  is the thermal diffusivity coefficient ( $mm^2/s$ ). With boundary condition  $T(0) = T_m$ , and  $T(t_c) = T_e$ , thus the cooling time  $t_c$  is given by equation (6) [4].

$$t_c = \frac{l_m^2}{\pi^2 \alpha} \log_e \frac{4(T_{melt} - T_m)}{\pi(T_e - T_m)} \quad 6$$

where  $T_e$  is the recommended ejection temperature.

**c) Determination of the coolant mass flow rate**

The amount of heat removed can be calculated from the mass of the part and its specific heat at moulding temperature, allowing for the fact that the temperature of the mould when ejected will generally be well above ambient (Shoemaker, 2006). The rate at which heat must be removed from the moulded part can be calculated from equation (7).

$$Q_{part} = \frac{\rho_p V_s c_p \Delta T_p}{t_c} \quad 7$$

Where  $t_c$  is the cooling cycle time,  $\rho_p$  is the part density,  $V_s$  is the molded part volume,  $c_p$  is the specific heat of the moulded part, and  $\Delta T_p$  is the temperature difference between the plastic melt temperature  $T_{melt}$  and the plastic ejection temperature  $T_e$ .  $\Delta T_p$  can be calculated from equation (8):

$$\Delta T_p = (T_{melt} - T_e) \quad 8$$

The energy balance equation applied to heat removal rates results in :

$$Q_{part} = Q_{coolant} \quad 9$$

$$Q_{coolant} = \dot{m} c_c \Delta T_c \quad 10$$

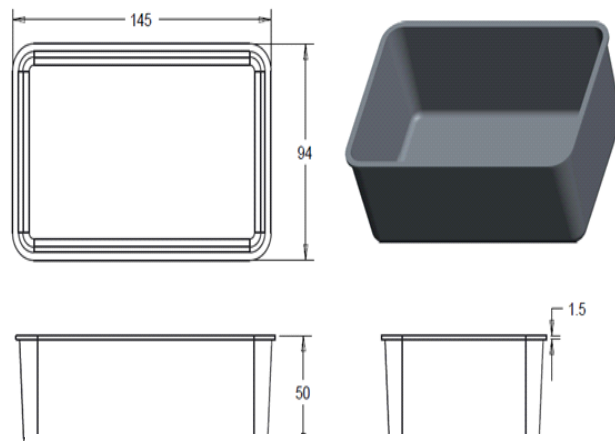
$$\Delta T_c = (T_{out} - T_{in}) \quad 11$$

$$\dot{m} = \frac{Q_{part}}{\Delta T_c c_c} \quad 12$$

where  $c_c$  is the specific heat of the coolant,  $\dot{m}$  is the coolant mass flow rate, and  $T_c$  is the coolant temperature difference [10]

**2) Propagation of The Project Work**

First of all we have created the same part with the given dimensions shown in the reference paper. This model is created on CREO Parametric 2.0 (Educational version). The basic drawing with the dimension of the product is shown in figure 1. This model is then saved in to IGES format (integrated graphics exchange system), so that to import it in to Auto-DESK Mold Flow Advisor for simulation the simulation of plastics injection molding process. Material for mold tool “steel P-20” is selected.



**Figure 1: Orthographic Drawing of Food Container**

First of all, we create the same cooling circuits as given in the base paper to validate the approach of the project. We have incorporated a new micro conformal cooling channels design, with circuit diameter of about 2 mm. The pitch is kept minimum as possible to avoid non-uniformity in cooling effect. The inlets & outlets of all the channels are located at the same side and close to each other.

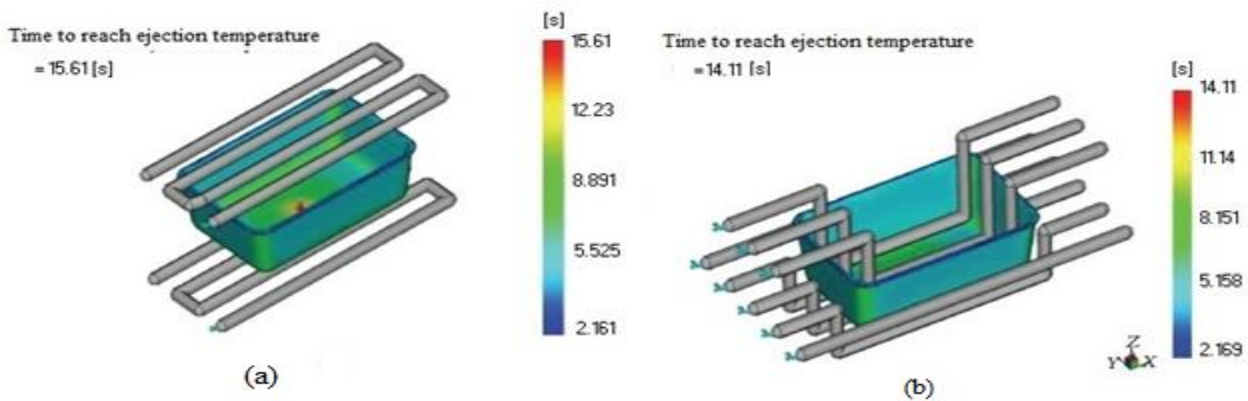


Figure 3 : Time to reach ejection temp (a) CCC (b) SCC (c) PCC (d) CCAL

Water is used as a coolant and its temperature is about 25°C and the coolant Flow rate is maintained to  $6.67 \times 10^{-5} \text{ m}^3/\text{s}$ . In this project two types of micro cooling channels were designed, straight micro cooling channel was designed on the basis of numbers of inlet or outlet i.e. to provide more numbers of inlet or outlet to improve the uniformity of cooling effect (fig 4a) and spiral micro cooling channel designed to conforms the shape of the product, so that the coolant can flow throughout the regions of the part as the cooling circuits are near as possible to the wall (fig 4b).

- **Material Assigned:-** Polypropylene (PP) Purell HM671T (density  $0.9 \text{ g/cm}^3$ , melt temperature  $168^\circ\text{C}$ , thermal conductivity  $2.8 \times 10^{-4} \text{ cal/sec cm }^\circ\text{C}$  and heat capacity  $0.9 \text{ cal/g }^\circ\text{C}$ ) [2].
- **Parameters selected :-** Mold temperature ( $38.89^\circ\text{C}$ ), Melt temperature ( $225^\circ\text{C}$ ), Injection time .6912 and proper gate location is at the center of the base.
- **Mold flow analysis :-** The mold flow analysis is performed after assigning material to plastic part .Using these input parameter Fill + Pack + Warp + Cool analysis is performed

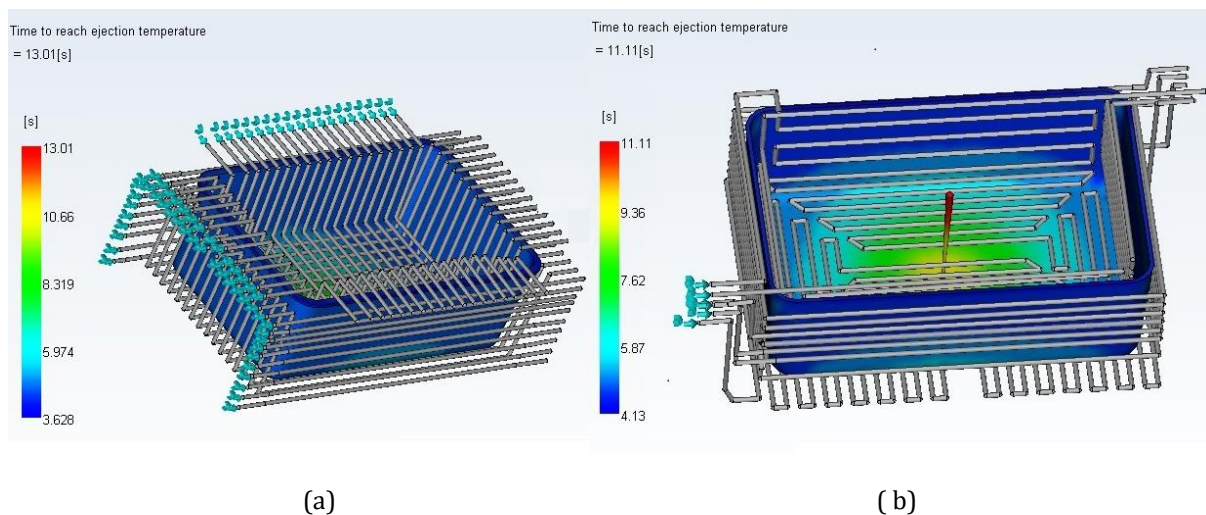


Figure 4.19: Time to reach ejection temperature (a) straight micro cooling channel (b) Spiral micro cooling channel.

### 3. RESULTS

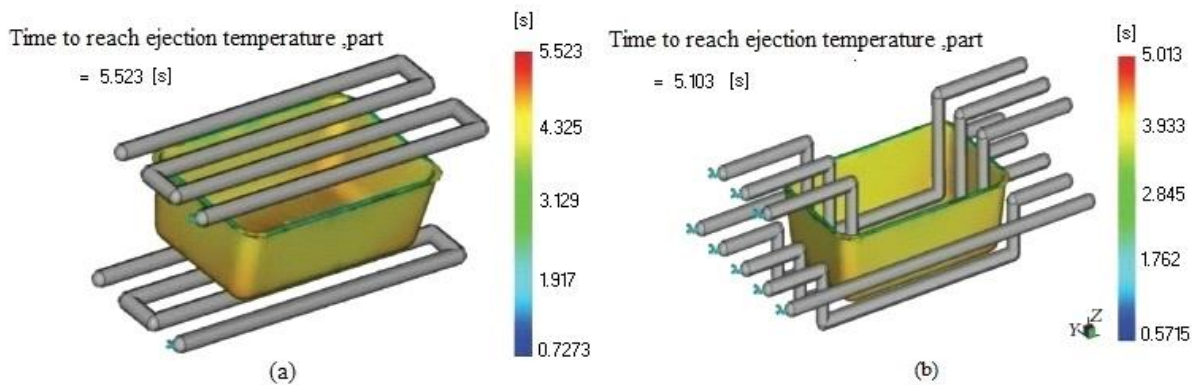
Comparing the various results of CCC, CCAL and Micro Channel cooling channels, the simulation result in the term of reach ejection temperature (time to reach the ejection , which is measured from the start of fill),time to reach part ejection temperature (time required by the part to freeze), volumetric shrinkage at ejection, and the temperature variance of the part are discussed here .

**Table 2 : Project Results**

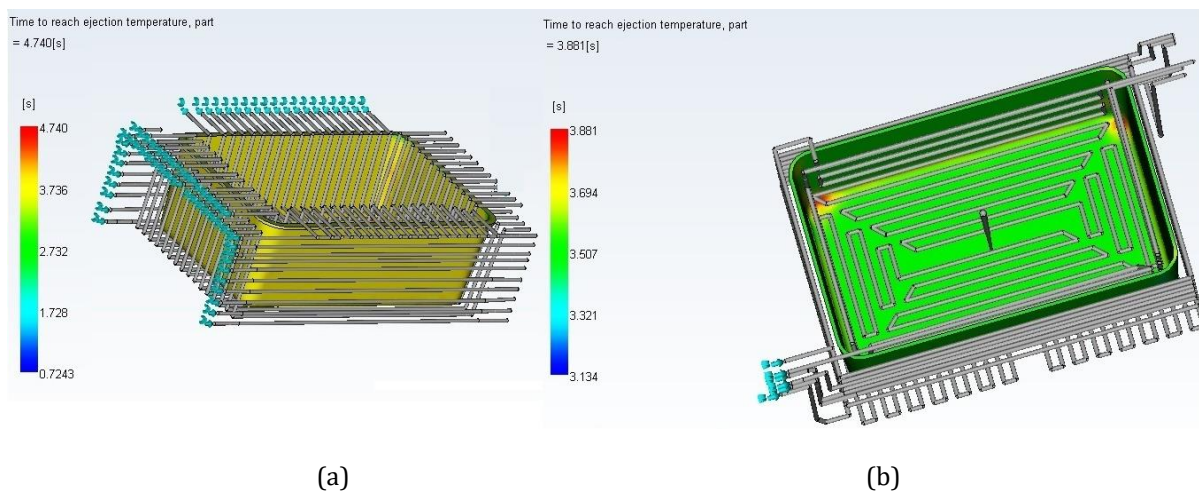
OUTPUT RESULTS	PROJECT RESULTS			
	CCC	CCAL	Straight Micro CC	Spiral Micro CC
Time to reach ejection temperature [seconds]	14.11	15.61	13.01	11.11
Time to reach part ejection temperature [seconds]	5.103	5.523	4.740	3.881
Volumetric shrinkage at ejection [%]	11.34	8.468	7.576	7.101
Temperature variance [°C]	9.712	5.114	5.135	4.295

Micro Cooling Channels have lower time to reach ejection temperature (figure 4), lower time to reach part ejection temperature (figure 6), lower volumetric shrinkage (figure 8 ), and lower temperature variance (figure 10) is; thus it will lead to better part quality with minimum cycle time. As the temperature variation is minimum in Micro Cooling Channel ,there will be minimum warpage of the part that translate to better part quality as compared to CCC and CCAL because of more uniform cooling in micro cooling channels.

The simulation results show that both the micro cooling channels are most efficient and suitable cooling channel among other cooling channel. Micro Cooling Channels have lower time to reach ejection temperature (figure 4), lower time to reach part ejection temperature (figure 6), lower volumetric shrinkage (figure 8 ), and lower temperature variance (figure 10) is; thus it will lead to better part quality with minimum cycle time. As the temperature variation is minimum in Micro Cooling Channel ,there will be minimum warpage of the part that translate to better part quality as compared to CCC and CCAL because of more uniform cooling in micro cooling channels.



**Figure 5 : Time to reach part ejection temp (a) CCC (b) SCC (c) PCC (d) CCAL**



**Figure 6 : Time to reach part ejection temp ( (a) straight micro cooling channel (b) Spiral micro cooling channel.**

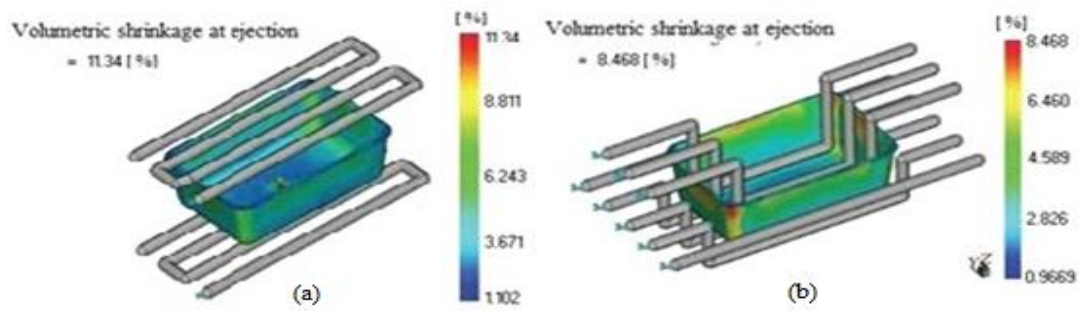


Figure 7: Volumetric shrinkage (a) CCC (b) SCC (c) PCC (d) CCAL

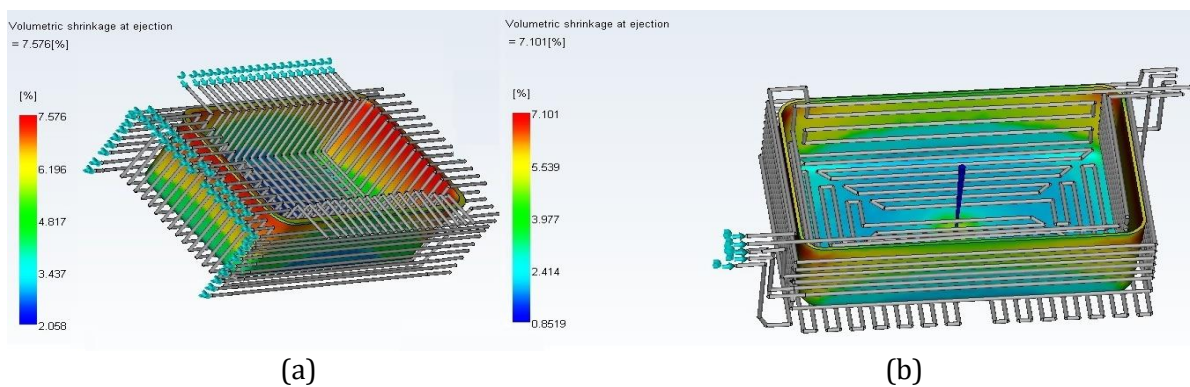


Figure 8: Volumetric shrinkage at ejection (a) Straight micro cooling channel (b) Spiral micro cooling channel.

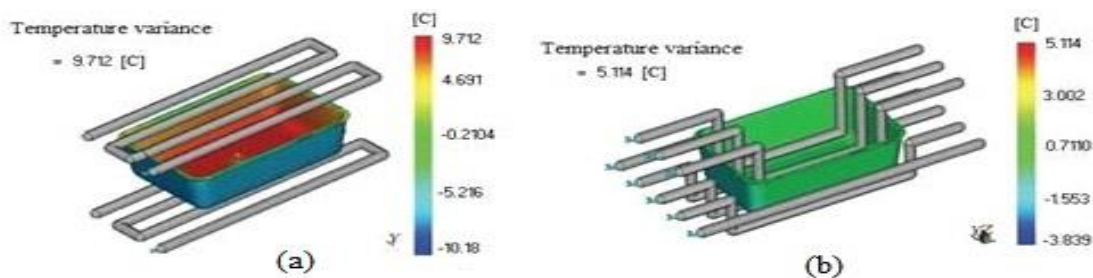


Figure 9 : Temperature variance (a) CCC (b) SCC (c) PCC (d) CCAL

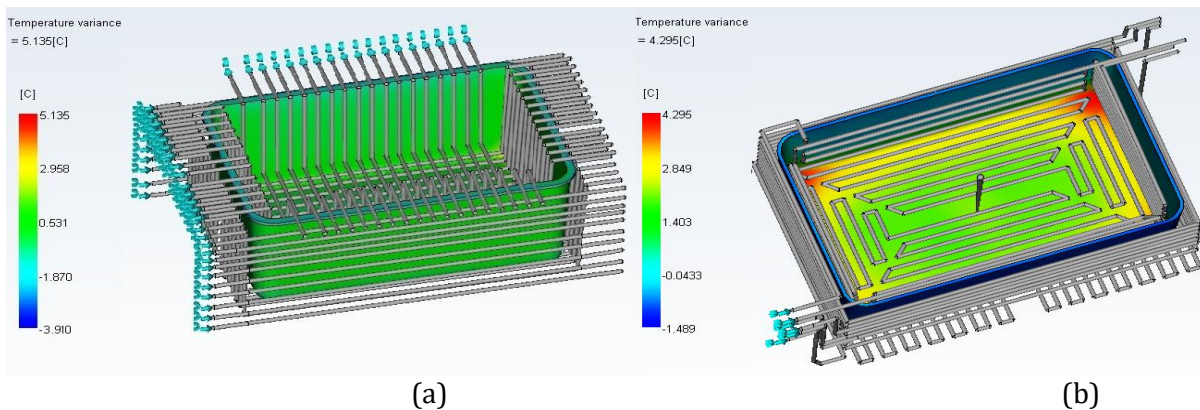


Figure 10 : Temperature variance (a) straight micro cooling channel (b) Spiral micro cooling channel

#### 4 CONCLUSIONS

In this project, four different types of Micro Cooling Channel layouts are studied named as “CCC, CCAL, Straight Micro Cooling Channel and Spiral Micro Cooling Channel” for cooling of a food container. In our design the pitch gap between the cooling circuits are reduced to great extent which results in uniform cooling throughout the part surface. So the designer must think about reducing the pitch gap while designing cooling circuits. The shape of micro cooling circuit conforms to the shape of the object which brings the cooling circuit near to the impression, by this we can say the circuit must be designed in such a way so that it will keep closer as possible to the cavity reason. Smaller the diameter of cooling circuit place more number of circuits, which will cover more surface area. Hence result in uniform cooling effect. Uniform cooling effect will results in uniform shrinkage and minimum warpage. Hence, we can get better quality product by improving the cooling circuit design. Moreover, the better cooling system will reduce the volumetric shrinkage of the part.

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