Advanced Manufacturing Technologies 2018

CONSIDERATIONS REGARDING THE INFLUENCE OF TEMPERATURE INJECTION MOLDING PROCESS OF THERMOPLASTIC POLYMER

Adrian Popescu, Ioan Turcin
Faculty of Machine Building, Technical University of Cluj-Napoca, Romania, Degree Programmes in Automation Technology, CAMPUS 02 University of Applied Sciences in Graz, Austria

Abstract: *The injection molding of polymeric materials is a technological process in a continue operation, through which can be obtain various profiles on infinite length such as: tubes, pipes, different isolations for electrical cables, sheets, plates, etc. Temperature has a very important role into injection molding process, because its value modifies the viscosity of processed material. Depending on the viscosity of melt polymeric materials are determined the parameters of machining conditions and the products quality, which is achieved. In this paper is presented a modality to calculate the temperature of thermoplastic material during the injection molding process.*

Keywords: *injection molding, polymeric material, temperature, viscosity, screw channel.*

1. Introduction

The processing by injection molding of the polymeric materials supposes detailed known of processing features of materials (temperature, pressure, contraction, etc.). One of the most important features is processing temperature, because it affects the viscosity, homogeneity and in the same times the quality of injection product [7].

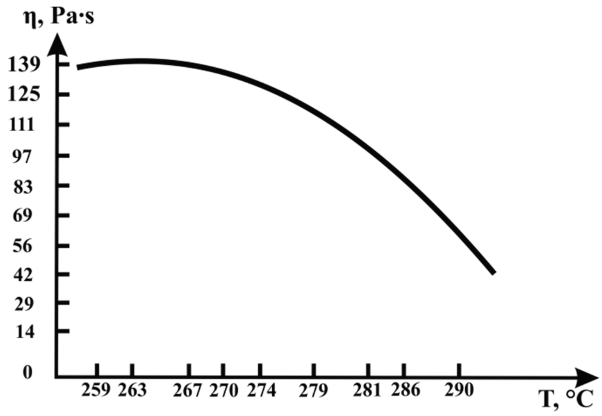

Fig. 1. Variation of viscosity with temperature for a polyamide type PA6

From figure 1, we observe the variation mode of viscosity of one polyamide type PA6 with the increasing processing temperature.

It can be seen the fact, once with increasing of the temperature, the material viscosity decrease, this drop must be done up to an optimal value of viscosity after which must be maintain of this value. This thing it is not very easy to realise.

The control of processing temperature of one injection molding installation it is realized with the aid of thermocouples. The polymeric material on granular or powder form is layout into a feed hopper from which is taken by the screw of injection. With the help of the screw, the material is transported through cylinder being forced to cross all tree characteristic areas of the injection molding process (power zone, transition zone and pumping zone) [5]. The path that follows the polymeric material, the melting of the material is realised gradually, in the first phase is formed a melt film between the flight screw and cylinder after which, the film increases its dimensions until the melt material reach the bottom side of the screw channel, in this way, it is forming an melt pool.

In theoretical approach of the flow phenomenon through the injection channel, it is taken account the held of this, which can be considered being a transversal rectangular section, thus, it can be used the Cartesian coordinate system (figure 2). The error introduced by this approximation is negligible, because the channel depth is much smaller than the diameter of the screw, therefore, the width of channel B and the inclination angle of the propeller are become constants [1, 3, 6]. It can be observed that, the polymeric material is crossing from a solid phase recorded in zone 1 at the melt phase present in zone 2, after which continues to be homogenised and transported at the pumping zone [4].

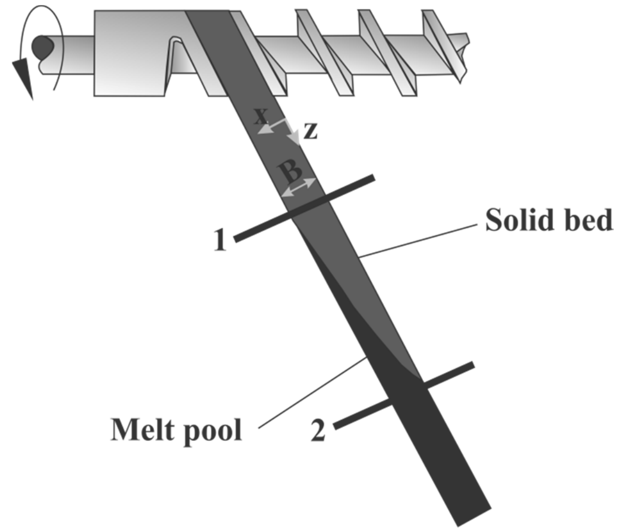

Fig. 2. Unwrapped channel

2. Calculus of temperature of polymeric material

The temperature profile along of screw's channel can be determined with the aid of equation (1), where the left term represent the heat convection, and the right term represent transmission of the heat:

$$V_{sz}\frac{\partial T(y)}{\partial z}=\alpha_s\frac{\partial^2 T(y)}{\partial y^2} \qquad (1)$$

where V_{SZ} represent the speed of polymeric material on solid form (solid mixture), T(y) is transversal profile of temperature (on y direction) and α_s represent the coefficient of thermal diffusivity of the material.

The friction which occurs between the cylinder walls, respectively of the screw and polymeric material, and due the heat transmitted by the cylinder injection, leads to the increasing of the temperature of the solid melt (especially nearly at the contact surfaces). The pressure, temperature and relative speed affect in a direct mode the friction coefficients of the polymeric material, and hence, it will influence the temperature of solid melt.

In Figure 3 are shown in transversal section, the heat flows which appear on surface of one "slice" of solid melt; because of the frictions, which are have place between the polymeric material and contact surfaces [2].

Heat flows due the friction between polymer-spiral (q_s) and the frictions which have place at the base of the screw (q_m) are in general negligible. The heat generated at the screw base it will take in consideration in this paper, because it helps to identify the location of the melting point of the polymer.

The polymeric material takes up a part of the heat generated on the surface of the cylinder, and the other part is distributed along of the cylinder [6]:

$$q_c=-k_s\left.\frac{\partial T(y)}{\partial y}\right|_{y=H}+k_c\left.\frac{\partial T(y)}{\partial y}\right|_{barrel} \qquad (2)$$

where k_s and k_c represent the thermal conductivity of the polymeric material, respectively of the material from which is confectioned the cylinder of the injection.

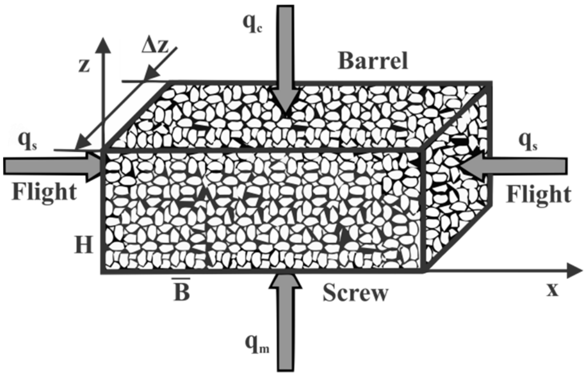

Fig. 3. Representation of transversal sections of heat flows, due the friction of one "slice" of polymeric material

The assessment of the conductibility of heat flow into cylinder injection it is realize by measuring the value of temperature in (T_c) at a distance c by a separation surface, and counting by the linear profile of the temperature along the thickness of cylinder:

$$\left.\frac{\partial T(y)}{\partial y}\right|_{barrel} \approx \frac{T_c - T}{c} \tag{3}$$

where T is the temperature in the separation area.

To determinate, the heat flow into the screw injection is more complicated, because the temperature of the screw is unknown. Eventually, it can be considered that, the temperature at the surface of the screw (T_m) is constant (for example, is equal with the temperature of the polymer - T_m) or can admit that, the screw is comporting like an adiabatic system. In this case, the heat flow it can be determined by the relationship:

$$q_m = k_m \left.\frac{\partial T(y)}{\partial y}\right|_{y=0} \tag{4}$$

where km represent the thermal conductivity of the material from which is realised the screw of the injection.

Equation (1) can be solved by using of implicit method of finite differences, like an example, it can be use the Crank-Nicolson scheme, together with boundary conditions in cylinder (equation 2) and at the screw injection (equation 4). It can be considered that, a rectangular network, which is having the sides parallel with y, forms the screw channel and z-axis (figure 4); Δy and Δz are the differential elements of the network, by y direction, respectively z. The coordinates of the points Y, Z of the network are given by the:

$$\begin{cases} Y = j\,\Delta y \\ Z = i\,\Delta z \end{cases} \tag{5}$$

where i = 0, 1, ... M and j = 0, 1, ..., N.

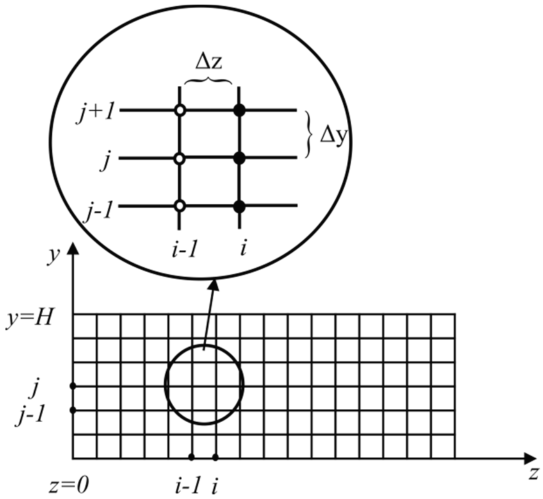

Fig. 4. The diagram of finite differences

Discredited form of equation 1 is it obtained by derivation first grade approximations of central differences on direction y, respectively z:

$$\left.\frac{\partial T}{\partial z}\right|_{i,j} = \frac{T_{i,j} - T_{i-1,j}}{\Delta z} \tag{6}$$

$$\left.\frac{\partial T}{\partial z}\right|_{i,j} = \frac{T_{i,j+1} - T_{i,j-1}}{2\Delta y} \tag{7}$$

Using the Crank-Nicolson scheme for derivate grade 2 of central differences on *y* direction, we obtain:

$$\left.\frac{\partial T}{\partial z}\right|_{i,j} = \frac{1}{2}\left[\frac{T_{i,j+1} - 2T_{i,j} + T_{i,j-1}}{\Delta y^2} + \frac{T_{i-1,j+1} - 2T_{i-1,j} + T_{i-1,j-1}}{\Delta y^2}\right] \tag{8}$$

From equations (8) and (1) after replacement and necessary reengagement it can be calculate the value of temperature in point $T_{(i,\, j)}$:

$$-\frac{\alpha_s}{2\Delta y^2}T_{i,j-1} + \left(\frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2}\right)T_{i,j} - \frac{\alpha_s}{2\Delta y^2}T_{i,j+1} = \frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,j-1} - 2T_{i-1,j+2}\right) + \frac{V_{sz}}{\Delta z}T_{i-1,j} \tag{9}$$

where, the temperatures from left side are the unknowns, and the temperatures from right side, they have been calculate in a previously phase, or corresponding with the initial temperatures for z = 0 (i = 0). By replacement of j with 1, 2, ..., N-1, result an equations system, which can be put an matrix form type:

$$AT = B \tag{10}$$

where

$$A = \begin{bmatrix} -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} & 0 & 0 \\ 0 & -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} \end{bmatrix} \tag{11}$$

$$T^T = \begin{bmatrix} T_{i,0} & T_{i,1} & \ldots & T_{i,N-1} & T_{i,N} \end{bmatrix} \tag{12}$$

$$B = \begin{bmatrix} \frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,0} - 2T_{i-1,1} + T_{i-1,2}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,1} \\ \frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,1} - 2T_{i-1,2} + T_{i-1,3}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,2} \\ \ldots \\ \frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,N-3} - 2T_{i-1,N-2} + T_{i-1,N-1}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,N-2} \\ \frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,N-2} - 2T_{i-1,N-1} + T_{i-1,N}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,N-1} \end{bmatrix} \tag{13}$$

Because this system is having N-2 equations with N unknowns, by using the two boundary equations (equations 2 and 4), results two additional equations:

$$-\frac{k_s}{2\Delta y} T_{i,N-2} + \left(\frac{k_s}{2\Delta y} + \frac{k_c}{c}\right) T_{i,N} = -\frac{k_c}{c} T_c - q_c \tag{14}$$

$$\frac{k_s}{2\Delta y} T_{i,0} - \frac{k_s}{2\Delta y} T_{i,2} = -q_m \tag{15}$$

In this case, the matrix A (11) and vector B (13) are having the next form:

$$A = \begin{bmatrix} & \frac{k_s}{2\Delta y} & 0 & -\frac{k_s}{2\Delta y} & 0 & 0 & 0 & 0 \\ & -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} & 0 & 0 & 0 & 0 \\ & 0 & -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} & 0 & 0 & 0 \\ 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ & 0 & 0 & 0 & 0 & -\frac{\alpha_s}{2\Delta y^2} & \frac{V_{sz}}{\Delta z} + \frac{\alpha_s}{\Delta y^2} & -\frac{\alpha_s}{2\Delta y^2} \\ & 0 & 0 & 0 & 0 & -\frac{k_s}{2\Delta y} & 0 & \frac{k_s}{2\Delta y} + \frac{k_c}{c} \end{bmatrix} \tag{16}$$

$$
B = \begin{bmatrix}
-q_s \\
\frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,0} - 2T_{i-1,1} + T_{i-1,2}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,1} \\
\frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,1} - 2T_{i-1,2} + T_{i-1,3}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,2} \\
\cdots \\
\frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,N-3} - 2T_{i-1,N-2} + T_{i-1,N-1}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,N-2} \\
\frac{\alpha_s}{2\Delta y^2}\left(T_{i-1,N-2} - 2T_{i-1,N-1} + T_{i-1,N}\right) + \frac{V_{sz}}{\Delta z} T_{i-1,N-1} \\
-\frac{k_c}{c} T_c - q_c
\end{bmatrix} \tag{17}
$$

The solution of this type of system can be achieved for example by using the elimination method of Gauss with partial pivoting.

Conclusions

The temperature is having a significant role regarding the processing of polymeric materials through injection molding process.

Knowing it is valuation it is very helping very much, to obtain an optimal viscosity and a better quality of extruded profile. Because of that, is very important to have a control during processing of temperature and to exist the possibility to calculate temperature in different phases of injection molding process. During the injection molding process, the temperature of the processed material is variably, calculation of its value at a certain point is shown above. It can be observe the complexity of the phenomenon, which occurs during on manufacturing process, because of frictions, which have place between material and screw, respectively material and cylinder.

References

[1] A. Popescu, L. Hancu, P. Bere, Research Concerning the Optimum Extrusion Temperature for Reinforced Polyamide, 17th International Conference on Innovative Manufacturing Engineering, IManE 2013, Applied Mechanics and Materials, 2013, Vol. 371, ISSN: 1662-7482, ISBN-13: 978-303785786-1, 23-24 Mai, Iaşi; Romania, pp. 394-398.

[2] R. T. Fenner, Principles of Polymer Processing, McMillan, London, 2002.

[3] M. James, Engineering Plastics Handbook, The McGraw-Hill, USA 2006.

[4] G. Martin, Mixing in Single Screw Extrusion, Smithers Rapra Press, ISBN: 1847351298, United Kingdom, 2009.

[5] E. Sabau, A. Popescu, C. Vilău, Mechanical behavior of composite materials using the finite element analysis, MATEC Web Conf. Volume 137, 2017, Modern Technologies in Manufacturing (MTeM 2017 - AMaTUC), Article Number: 08006, Number of page(s): 6, Section: Processes of Plastics and Composite Materials, DOI: https://doi.org/10.1051/matecconf/201713708006, Published online 22 November 2017.

[6] S. A. Radu, N. Balc, A. Popescu, N. A. Panc, Experimental determination of surface roughness of parts obtained by rapid prototyping, The 3rd Virtual International Conference on Advanced Research in Scientific Areas (ARSA-2014), ISBN: 978-80-554-0958-0, ISSN: 1338-9831, Zilina, Slovakia, December 1 - 5, 2014, pp. 342-345.

[7] C. Morar, A. Popescu, The design of a plastic injection mold for The Part “Tensile test specimen” Journal: ACTA TECHNICA NAPOCENSIS-Series: APPLIED MATHEMATICS, MECHANICS, and ENGINEERING, ISSN 1221-5872, Volume 60, Issue 2, 2017, pp. 319-324