Numerical study of influence polymers properties on the co-extrusion process

Maria V. Kozitsyna [a], Natalia M. Trufanova [b]

Perm National Research Polytechnic University (PNRPU), 29 Komsomolsky prospect, Perm, 614990, Russian Federation

[a] bachurinamaria@gmail.com
[b] trufanova@pstu.ru

Abstract. The paper studies process coextrusion of the three-layers insulation coating. The main focus this investigation is the analysis effect rheological and thermophysical characteristics on the process of heat and mass transfer in the forming tool. In this paper consider six sample polyethylene. Model have been implemented by through of the finite volume method in Ansys software package. Dependency graphs for temperature, pressure along the channels lengths and temperature fields have been obtained.

1. Introduction

The cable industry included a huge variety of products. The people apply these products in all areas of the life, for example, from the distribution of electrical energy at homes to the transmission of signals to the International Space Station. Today the coextrusion is the most effective method for the production of electric cables including several layers of polymer insulation [1]. In such case, the melts of polymers came from three extruders to the forming tool (see Fig. 1.). One side, coextrusion reduced time and material spending of the process, at once, the quality of the products is raised [2-3]. The object of this research is a cable head of complex spatial geometry in a three-dimensional description. The process of the flow of non-Newtonian fluid is described in [4-6]. In the investigation papers Russian and foreign authors researched to coextrusion, the main focus is the influence of technological and rheological parameters on the area of the stratified flow of polymer melts [7]. The aim of this paper is to study the stratified flow different property materials in the channels of the forming tool.

2. Mathematical modelling

The geometry of the model forming tool is shown in Figure 1. The mathematical assumptions of heat and mass transfer processes in stratified flow the polymer melts are based on the conservation equations. To make the analysis feasible, the process has to be simplified, so thus the following assumptions are made: the process is stationary at constant mass flow; environment is incompressible and there are no elastic properties [8]; surface forces exceed the mass forces; – are axisymmetric properties of the flow; slip and impermeability conditions are defined at the channel boundaries; thermophysical characteristics are constant.

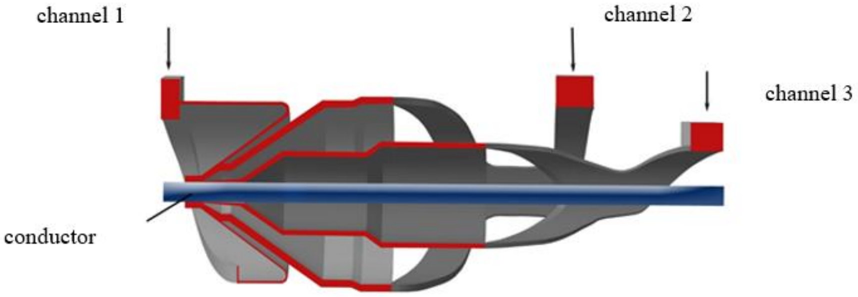


FIGURE 1. Configuration of forming tool

As a result, the mathematical model is a following set of differential equations [9], where each one relates to every layer in the flow:

$$\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}+\frac{\partial V_z}{\partial z}=0, \tag{1}$$

$$\rho_m\left(V_x\frac{\partial V_x}{\partial x}+V_y\frac{\partial V_x}{\partial y}+V_z\frac{\partial V_x}{\partial z}\right)=-\frac{\partial P}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}, \tag{2}$$

$$\rho_m\left(V_x\frac{\partial V_y}{\partial x}+V_y\frac{\partial V_y}{\partial y}+V_z\frac{\partial V_y}{\partial z}\right)=-\frac{\partial P}{\partial y}+\frac{\partial \tau_{yx}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}, \tag{3}$$

$$\rho_m\left(V_x\frac{\partial V_z}{\partial x}+V_y\frac{\partial V_z}{\partial y}+V_z\frac{\partial V_z}{\partial z}\right)=-\frac{\partial P}{\partial z}+\frac{\partial \tau_{zx}}{\partial x}+\frac{\partial \tau_{zy}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}, \tag{4}$$

$$\rho_m C_m=\lambda_m\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}C_m\left(V_x\frac{\partial T}{\partial x}+V_y\frac{\partial T}{\partial y}+V_z\frac{\partial T}{\partial z}\right)+\frac{\partial^2 T}{\partial z^2}\right)+\Phi, \tag{5}$$

$$\tau_{xx}=2\mu_{\text{Э}}\frac{\partial v_x}{\partial x};\tau_{yy}=2\mu_{\text{Э}}\frac{\partial v_y}{\partial y};\tau_{zz}=2\mu_{\text{Э}}\frac{\partial v_z}{\partial z};\tau_{xy}=\tau_{yx}=\mu_{\text{Э}}\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right); \tag{6}$$

$$\tau_{yz}=\tau_{zy}=\mu_{\text{Э}}\left(\frac{\partial v_y}{\partial z}+\frac{\partial v_z}{\partial y}\right);\tau_{zx}=\tau_{xz}=\mu_{\text{Э}}\left(\frac{\partial v_z}{\partial x}+\frac{\partial v_x}{\partial z}\right) \tag{7}$$

$$\Phi=\mu_{\text{Э}}\frac{I_2}{2}, \tag{8}$$

$$I_2=2\left[\left(\frac{\partial v_x}{\partial x}\right)^2+\left(\frac{\partial v_y}{\partial y}\right)^2+\left(\frac{\partial v_z}{\partial z}\right)^2\right]+\left[\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right)^2+\left(\frac{\partial v_y}{\partial z}+\frac{\partial v_z}{\partial y}\right)^2+\left(\frac{\partial v_x}{\partial z}+\frac{\partial v_z}{\partial x}\right)^2\right], \tag{9}$$

$$\mu_0=\mu_{0|_{T_0}}\,exp\left(-\beta(T-T_0)\right), \tag{10}$$

$$\mu_{\text{Э}}=\mu_0\left(\frac{1}{2}I_2\right)^{\frac{n-1}{2}}, \tag{11}$$

Where V_x,V_y ,V_z – the components of the velocity vector; ρ – is a density; P – is a pressure, τ_{xx} , τ_{xy} , τ_{xz}, τ_{yx} , τ_{yy} , τ_{yz}, τ_{zx} , τ_{zy} , τ_{zz} – are the normal and tangential stresses, C – is a heat capacity, λ – is a thermal conductivity; ; $\mu_{\text{э}}$ – is an effective viscosity, μ_0 –s the consistency coefficient at temperature T_0 , I_2 – quadratic invariant of the tensor of the deformation rates; β – the temperature coefficient of viscosity; T– is a temperature; n – an anomaly of viscosity. System of differential equations have been implemented by through of the finite volume method in Ansys software package [10].

The thermophysical and rheological properties of polymer liquids are presented in Table 1.

TABLE 1. The Thermophysical and Rheological Characteristics of the Materials

№	Material	ρ_m, kg/m^3	λ_m, W / (m·K)	C_m, J (kg·K)	μ_0, Pa·c	β, 1/°K	n	T_0,°C
1	153-10K	914	0,238	2484	23623	0,0121	0,35	160
2	273-81K	940	0,182	2782	32019	0,0078	0,39	200
3	ME 6052	929	0,182	2468	24515	0,0101	0,41	160
4	LE 0592	1080	0,182	1974	14000	0,010	0,4	120
5	LE 4205	900	0,182	2368	49000	0,012	0,4	120
6	LE 0505	1080	0,170	2000	17500	0,010	0,4	120

The title of materials indicating the numbers, technological parameters were presented in table 2,3.

TABLE 2. Title of Materials According to Channel Numbers

	Experiment number		
Channel number	**1**	**2**	**3**
1	153-10K	273-81K	LE 0592
2	273-81K	ME 6052	LE 4205
3	ME 6052	273-81K	LE 0505

TABLE 3. **The Technological Parameters**

T_0, °C	$T_к$, °C	T_c, °C	V_c, m/c	Q_1, kg/c	Q_2, kg/c	Q_3, kg/c
150	120	110	0,45	0,016	0,09	0,023

Where T_0 °C – is a temperature of materials, $T_к$, °C - is a temperature of forming tool, T_c, °C - is a temperature of conductor, V_c, m/c - is a velocity of conductor, Q_1, Q_2, Q_3, - is a flow rate of the material on the first, second, third channels.

3. Results and Discussion

Model have been implemented by through of the finite volume method in Ansys software package. The configuration of the first channel with indication of characteristic lengths is presented in figure 2.

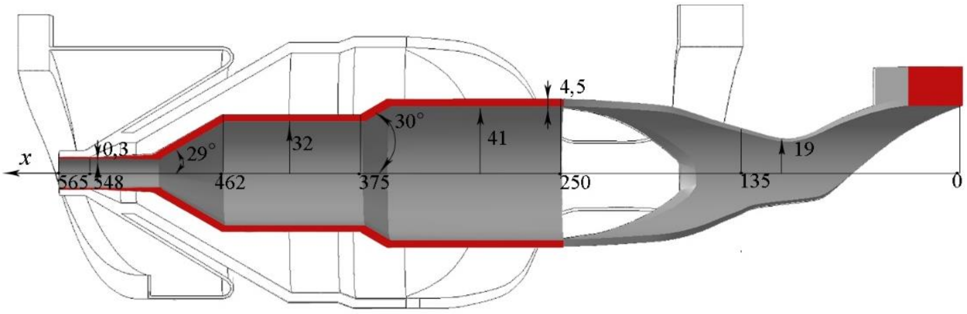
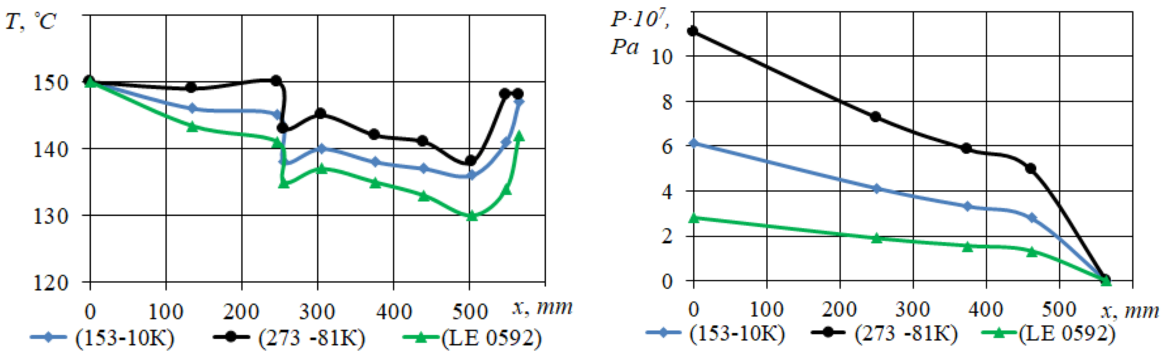


FIGURE 2. The configuration of forming tool (channel 1)

The change average values of temperature and pressure along the longitudinal coordinate x for channel 1, was presented in figure 3. Numerous figures show that regularity of the investigated quantities has been a similar character. The character of the flow for the three considered materials have been similar. As shown in Figure 3a, the temperature of the polymer melt was decreases as it moving through the channel. The temperature on the length x = 250 mm, Fig. 3(a), sharply decreased (change in the channel geometry). Further the temperature has been decreased by reason of contact with the colder walls of the channels of the forming tool. The constriction of the geometry at the outlet was a consequence to an increased in shear rate and an increased in temperature. The maximum pressure, Fig. 3(b), at the channel inlet has been realized for the case of the flow of the polymer with the highest viscosity. The difference between the maximum values (green and black curves) was 3.9 times.



(a) (b)

FIGURE 3. Change average values of temperature (a), pressure (b) along the longitudinal coordinate x for channel 1

The configuration of the second channel with indication of characteristic lengths is presented in figure 4.

The largest increase the temperature at the length of 0-200 mm was associated with an increased the shear rate, the maximum value of which is 2 times higher than for the case of flow in the first channel, Fig. 5 (a). This is determined by the significantly higher flow rate in the second channel. The temperature at the length of 213 - 255 mm was decreased. Since the cross section has been increased of the channel and the area of contact with the isothermal wall (T = 120 °C). The maximum temperature was corresponded to the number 1, the most viscous melt (black curve). The highest pressure drop was corresponded to the material with higher viscosity, Fig. 5 (b). As a result, the difference between highest alterations for the pressure (green and red curves) have been 1.5 times.

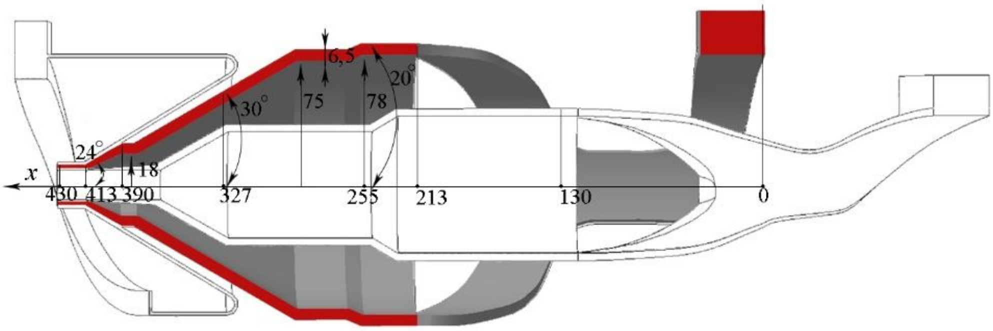
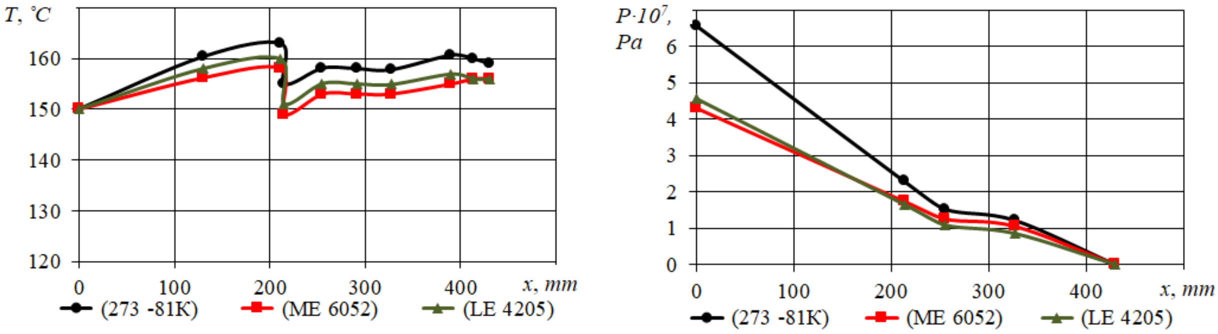


FIGURE 4. The configuration of forming tool (channel 2)



(a) (b)

FIGURE 5. Change average values of temperature (a), pressure (b) along the longitudinal coordinate x for channel 2

The configuration of the third channel with indication of characteristic lengths is presented in figure 6.

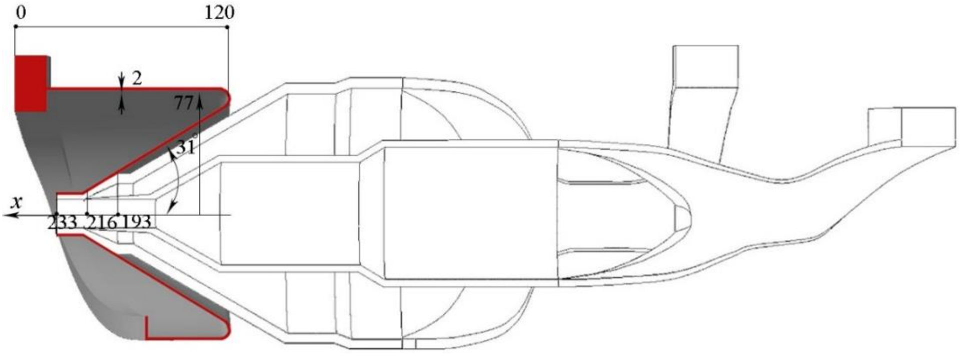
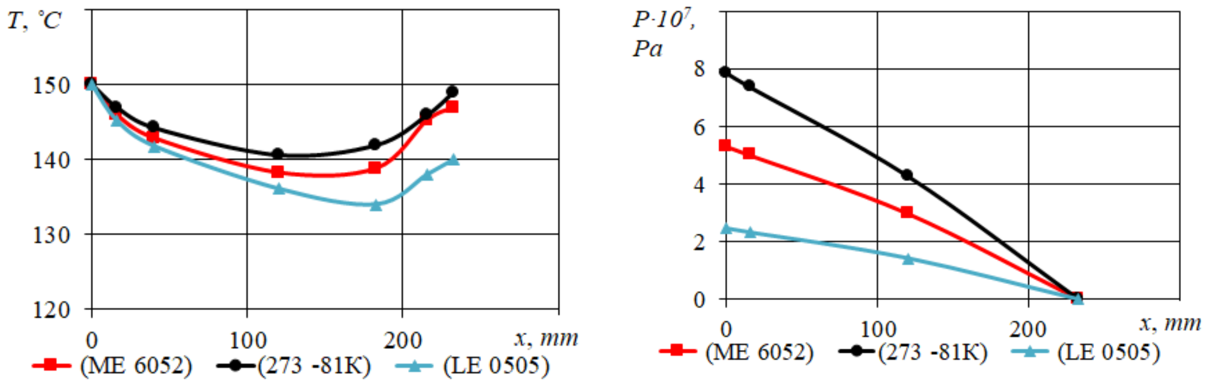


FIGURE 6. The configuration of forming tool (channel 3)

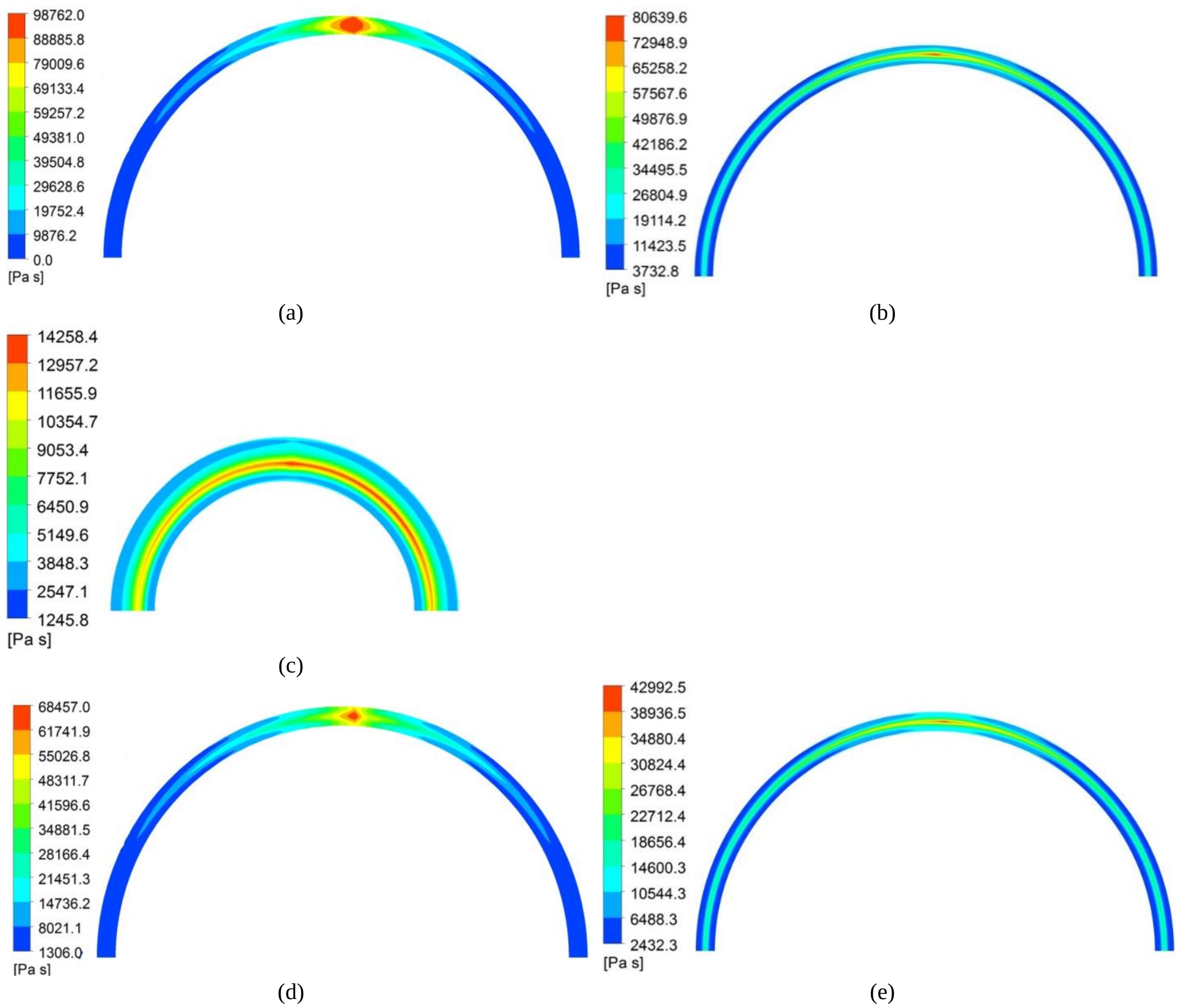
The dependence change average value of the polymer temperature on the length channel are presented in Figure 7. For all calculation variants, the temperature drop in the first half channel length was associated with intense heat transfer through the channel walls. The temperature in the conical part was increased (on the length of 120 mm). It has been caused with an increase in the shear rate in the section of the stratified flow with a more heated polymer from the second channel. The highest pressure drop was corresponded to the material with higher viscosity. As a result, the difference between highest alterations for the pressure (blue and black curves) have been 3.1 times.



(a) (b)

FIGURE 7. Change average values of temperature (a), pressure (b) along the longitudinal coordinate x for channel 1.

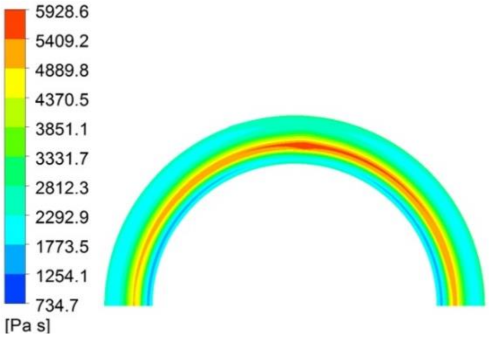
The viscosity fields in the cross sections of the second channel for polymers with different rheological parameters are presented in Figure 8. At the same time the temperature of polyethylene 273-81K in the area of confluence of flows compared to the temperature of polyethylene ME 6052 has been exceeded by 9 °C. The highest viscosity was corresponded to the area of the lowest temperatures (x = 213 mm). As results has been established that the maximum viscosity for channel 2 corresponds to option 1.



(a) (b)

(c)

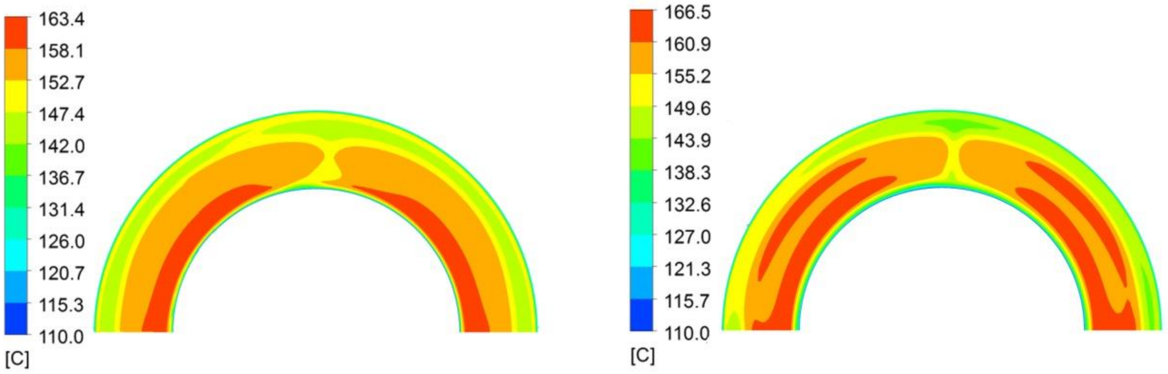
(d) (e)



(f)

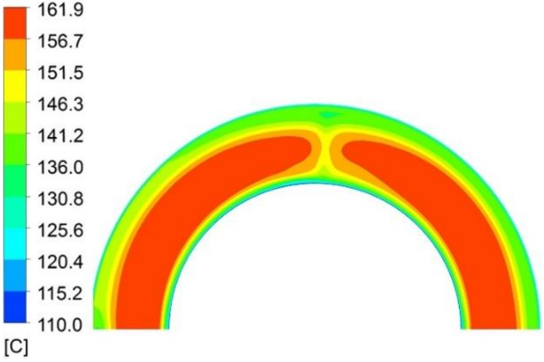
FIGURE 8. Viscosity fields in cross sections of the second channel: a) *x*=213 mm (273-81K); b) *x*=255 mm (273-81K); c) *x*=390 mm (273-81K); d) *x*=213 mm (ME 6052); e) *x*=255 mm (ME 6052); f) *x*=390 mm (ME 6052).

Figure 9 shows the temperature fields in the area of stratified flow of melts for the three experiments. The analysis of temperature fields allows to conclude that the most homogeneous temperature distributions in the region of flow confluence is realized in experiment 1 and 2. In this case the temperature drop the angular coordinate has been 5 ° C. At the same time temperature drop for experiment 3 was 10 ° C.



№1 (153-10K; 273-81K; ME 6052)

№2 (273-81K; ME 6052; 273-81K)



№ 3 (LE 0592; LE 4205; LE 0505)

FIGURE 9. Temperature fields in the area of stratified melt flow for experiment 1–3

4. Conclusion

The results of this paper can be applied for the descriptions the process stratified flows of polymer materials in the forming tool. The influence of technological and rheological parameters on the processes of flow and heat transfer has been investigated. The influence of the rheology of the melts on the maximum values of temperatures and the pressure drops in the channels was established. However, it is necessary to take into account, that the change in the value of the pressure drop in the channel of the forming tool can reach 3.9 times, when changing from one material to another, and all other conditions being equal. Finally, the case characterized by the most homogeneous temperature field in the aria of the stratified flow, was determined. Namely the homogeneous temperature field is a guarantee of quality insulating cover.

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