https://doi.org/10.31891/2219-9365-2023-74-2
УДК 678.023

NOVODVORSKYI Volodymyr
НТУУ «Київський політехнічний інститут імені Ігоря Сікорського»
https://orcid.org/0000-0002-2895-4506
e-mail: novodvorskiyvolodymyr@gmail.com
SHVED Nikolai
НТУУ «Київський політехнічний інститут імені Ігоря Сікорського»
https://orcid.org/0000-0001-7725-1447
e-mail: npchved46@gmail.com

CONTROL OF THE SHEAR STRAIN IN THE HOMOGENIZATION ZONE OF THE DISK EXTRUDER

A simple method for determining the quality of a polymer melt is very important in production. A method that provides simplicity and quick use, making it valuable for optimizing extrusion processes.

This work describes how the mixing effect can be improved by changing the velocity fields and thereby changing the shear strain values. The shear strain has been calculated for all four channels of the homogenization zone of a disk extruder. It was found that changing the disk rotation frequency allows changing mean value of the channel shear strain rate from 3324 to 4966 with constant performance for the entire homogenization zone. The impact of the different channels on the mixing effect was evaluated, with the first, second, third, and fourth channels contributing 21%, 57%, 15%, and 7% respectively to the overall homogenization zone's effectiveness of mixing. Additionally, it was found that the second channel experiences the highest shear strain values. In the case of the third channel, although the shear rate values are relatively high, the short residence time of the melt element results in comparatively smaller shear strain values. The average shear strain values remain constant for a given disk speed. It is indicated that it is possible to assess the quality of mixing by the amount of energy supplied, which simplifies the process of determining the quality of the melt, as well as its regulation.

Keywords: extrusion; melt quality; temperature homogeneity; homogenization; disk extruder

НОВОДВОРСЬКИЙ Володимир, ШВЕД Микола
НТУУ «Київський політехнічний інститут імені Ігоря Сікорського»

РЕГУЛЮВАННЯ ДЕФОРМАЦІЇ ЗСУВУ В ЗОНІ ГОМОГЕНІЗАЦІЇ ДИСКОВОГО ЕКСТРУДЕРА

Простий метод визначення якості розплаву полімеру є дуже важливим у виробництві. Метод який забезпечує простоту і швидке використання, що робить його цінним для оптимізації процесів екструзії.

В роботі описано те, як можна покращити змішуючий ефект змінюючи швидкісні поля і тим самим змінюючи значення деформації зсуву. Для усіх чотирьох каналів зони гомогенізації дискового екструдера проведено розрахунок деформації зсуву.

Встановлено, що зміна частоти обертання диска дозволяє змінювати деформацію зсуву від 3324 до 4966 при незмінній продуктивності для усієї зони гомогенізації. Було оцінено вплив різних каналів на ефект перемішування: перший, другий, третій і четвертий канали вносять 21%, 57%, 15% і 7% відповідно до загальної ефективності перемішування в зоні гомогенізації. Крім того, було виявлено, що другий канал зазнає найвищих значень деформації зсуву. У випадку третього каналу, хоча значення швидкості зсуву відносно високі, короткий час перебування розплавленого елемента призводить до порівняно менших значень деформації зсуву. Середні значення деформації зсуву залишаються постійними для заданої швидкості обертання диска. Описане вказує на можливість оцінювання якості змішування по кількості підведеної енергії, що спрощує процес визначення якості розплаву, а також його регулювання.

Ключові слова: екструзія; якість розплаву; температурна однорідність; гомогенізація; дисковий екструдер

Problem definition

In recent decades, polymer extrusion has been seen significant development and improvement in polymer extrusion technologies. However, the determination and control of melt quality remains a rather difficult task and requires further research.

The homogeneity of the melt determines the quality of the product. The uneven distribution of components can cause product defects.

Analysis of recent research and publications

Among the different methods for determining melt homogeneity, the best is the one that can be applied directly during the extrusion process [1]. The work shows the possibility of assessing melt homogeneity by temperature homogeneity directly during the extrusion process.

As productivity increases in screw extruders, the screw rotation speed increases. This increases the dissipation of energy in the melt, and therefore increases the melt temperature [2]. At high screw speeds, the melt quality worsens [3].

The screw speed is the most important process parameter that affects the melt temperature level and thermal homogeneity in the melt flow [4].

The melt is considered to be sufficiently homogenized when temperature fluctuations at different points are within 2 °C [1].

Article [5] analyzes the impact of different types of static mixers using two criteria: energy consumption and compactness. Energy consumption was determined by the value of the pressure drop, and compactness by the length of the mixer. It is indicated that the problem of some mixing elements is a significant pressure difference, especially in elements of short length.

A disk extruder can also be used, where the extruder disk is a dynamic mixer. The homogenization zone consists of several consecutive channels of different configurations [6]. In this case, a high level of mixing is ensured with the possibility of adjusting the mixing effect at a constant melt output. The pressure drop in such an extruder is not significant and, accordingly, energy consumption is low.

The process of homogenization with the possibility of adjusting the quality of the melt in four channels of the homogenization zone of a disk extruder at constant productivity is considered for the first time. The work points out the possibility of determining the melt quality by shear strain.

Formulation of the goals of the article

The purpose of this work is to determine the effect of all channels of the homogenization zone on the mixing effect and to compare the effect of each channel.

Presenting main material

The graphs are presented on the example of calculating the first straight annular channel formed by two horizontal co-axial cylinders, one of which is the inner one with a radius of R_1=0,0875 m rotating, and the inner one with a radius of R_2=0,0925 is stationary, the width of the annular clearance is $h = R_2 - R_1$=0,005 m, the length is L=0,01 m with a constant given volume flow rate $G_V = 9,058 \cdot 10^{-6}\ m^3/s$. The residence time is defined as:

$$\tau = L/v \tag{1}$$

Here, L - the length of the channel under consideration is the lengthwise velocity. The definition of the velocity field components is shown in [7].

It is possible to adjust the velocity field by changing the rotational speed by ± 30 rpm, which is $\pm 20\%$ of the nominal value of the disk speed ω, and by ± 2 mm of the nominal value of the disk clearance width. The total shear rate γ_{sum} is determined from Eq:

$$\dot{\gamma}_{sum} = \sqrt{\dot{\gamma}_{lon}^2 + \dot{\gamma}_{\tan}^2}\,. \tag{2}$$

Where $\dot{\gamma}_{lon}$ is the shear rate of the longitudinal melt flow, and $\dot{\gamma}_{\tan}$ is the shear rate of the tangential melt flow, they are given in [7].

The product of the total shear rate by the time the melt element is in the channel makes it possible to determine the shear strain:

$$\bar{\gamma} = \dot{\gamma}_{sum} \cdot \tau \tag{3}$$

The results.

The figures show the calculation results for the first channel. The distribution of the residence time of the melt element is shown in Fig. 1, and the shear strain along the width of the first channel is shown in Figs. 2-3.

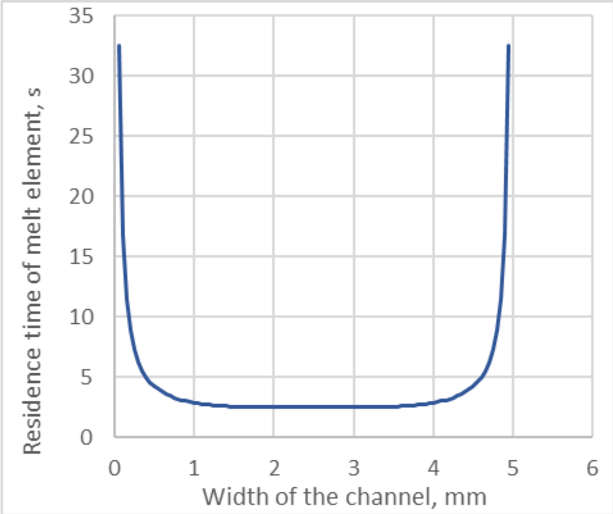


Fig. 1. Distribution of melt element residence time along the width of the channel

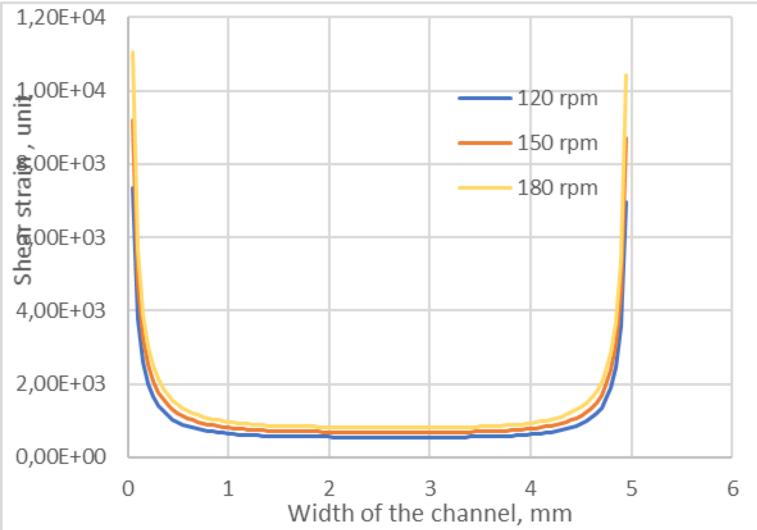


Fig. 2. Distribution of the accumulated shear strain along the width of the first channel;

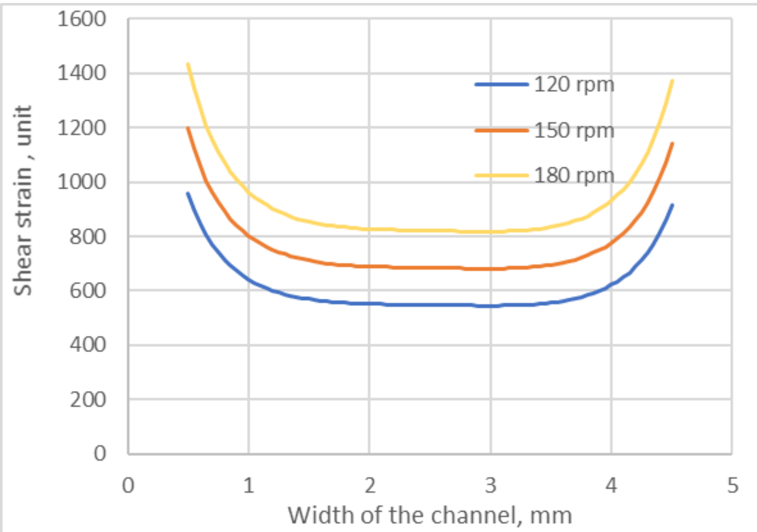


Fig. 3. Distribution of shear strain along the width of the first channel in the range from 0.5 to 4.5 mm;

Table 1

With a disk clearance of 3 mm

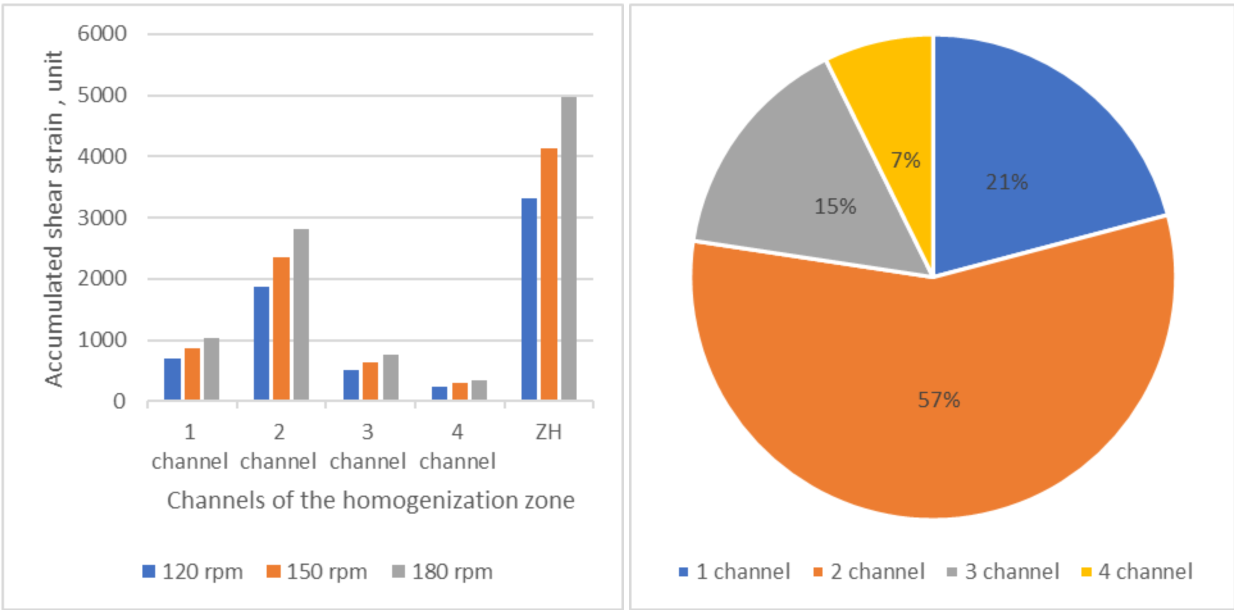
	Shear strain value, unit			**Average value of shear rate, s-1**			**Average value of shear rate, s^{-1}**		
	120 rpm	**150 rpm**	**180 rpm**	**120 rpm**	**150 rpm**	**180 rpm**	**120 rpm**	**150 rpm**	**180 rpm**
1 channel	694	869	1041	222	278	333	3,13	3,13	3,13
2 channel	1879	2345	2812	310	387	464	6,06	6,06	6,06
3 channel	509	633	763	176	219	264	2,89	2,89	2,89
4 channel	242	296	350	54	66	78	4,49	4,49	4,49
ZH	3324	4144	4966						

*ZH- zone of homogenization

Table 2

With a disk clearance of 1 mm

	Shear strain value, unit			**Average value of shear rate, s-1**			**Average value of shear rate, s^{-1}**		
	120 Об/хв	**150 Об/хв**	**180 Об/хв**	**120 Об/хв**	**150 Об/хв**	**180 Об/хв**	**120 Об/хв**	**150 Об/хв**	**180 Об/хв**
1 channel	694	869	1041	222	278	333	3,13	3,13	3,13
2 channel	1859	2318	2786	925	1153	1386	6,06	6,06	6,06
3 channel	530	652	776	551	678	807	2,89	2,89	2,89
4 channel	242	296	350	54	66	78	4,49	4,49	4,49
ZH	3325	4134	4952						



a **b**

Fig. 4 Diagram 1 of the shear strain values of the channels of the homogenization zone: a) columnar, b) sectoral

In the cylindrical annular channel of a disk extruder, it is possible to adjust the shear strain by changing the rotational speed of the disk by changing the tangential component of the melt flow velocity (Fig. 1-2).

It is stated in [8] that the heterogeneity of the shear strain field, where the shear strain values are not significant in the middle of the channel, leads to a low level of mixing quality.

Since the longitudinal velocity varies along the width of the clearance according to a parabolic law, from 0 at the edges to the maximum in the center of the channel, the residence time of the melt element depends on the location of the element along the width of the zone Fig. 1.

Good mixing is ensured at shear strain values of 2000 and more [9]. The arithmetic mean value of the channel shear strain rate in the range from 1 to 4 mm, which is 60 % of the channel width, differs by 7,6 % from the average value in this range Fig. 2, and in the range from 0,5 to 4,5 mm, i.e. 80 % of the channel width, differs by 21,6 % from the average value of the shear strain rate in this range Fig. 3, which indicates that in general, the majority of the channel cross-section has a uniform distribution of shear strain values. This is explained by the fact that where the shear rate and velocity are also lower, the residence time of the melt in the channel is longer.

It should be noted that we can both improve the quality of mixing and reduce energy consumption and, with this in mind, choose the appropriate operating mode when a sufficient level of mixing is ensured with minimal energy consumption.

Comparing Tables 1 and 2, we can see that the arithmetic mean values of the shear strain are the same at the same disk speed. Since with a smaller gap of the working body, the cross-sectional area decreases and the volume remains unchanged, the longitudinal velocity increases, as well as the longitudinal and tangential shear rates increase. At the same time, the residence time of the melt element decreases. Therefore, the product of the shear rate and the residence time of the melt element remains constant Table 1.2.

Fig. 4 shows that, at constant productivity, changing the disk speed allows changing the shear strain from 3324 to 4966 and that the value of the shear strain depends on the value of the disk speed and does not depend on the value of the disk gap. The influence of the first, second, third, and fourth channels on the mixing effect was also determined, which account for 21%, 57%, 15%, and 7%, respectively of the total value for the entire homogenization zone. And that the values of shear strain in the second channel are the largest. In channel 3, the values of the shear rate are quite large, but since the residence time of the melt element is not significant, the values of the shear strain are also relatively small.

Thus, it can be concluded that the quality of mixing in the homogenization zone of a disk extruder can be assessed by the amount of energy supplied. This will greatly facilitate the process of determining and controlling the quality of the melt.

Conclusions from this study and prospects for further research in this direction

The possibility of improving the mixing effect by adjusting the velocity fields and thereby changing the value of the shear strain is described. The shear strain was calculated for all four channels of the homogenization zone of the disk extruder and the influence of each channel was determined, as well as the fact that the highest values of shear strain are in the second channel. Changing the speed of the disk allows changing mean value of the shear strain rate from 3324 to 4966 with constant productivity for the entire homogenization zone.

In a disk extruder, the quality of mixing can be assessed by the amount of energy supplied, which simplifies the process of determining the quality of the melt, as well as its regulation.

References

1. Novodvorskyi V., Shved N., Shved D. (2021). Evaluation of melt quality during polymer extrusion.

2 Rauwendaal, C. (2000). Estimating fully developed melt temperature in extrusion. In *Conference Proceedings, 58 th SPE ANTEC* (pp. 307-311).

3 Domingues, N., Gaspar-Cunha, A., & Covas, J. A. (2008). Global mixing indices for single screw extrusion. International Journal of Material Forming, 1(1), 723-726.

4 Abeykoon, C., Kelly, A. L., Martin, P. J., & Li, K. (2013, December). Dynamic modelling of die melt temperature profile in polymer extrusion. In *52nd IEEE Conference on Decision and Control* (pp. 2550-2555). IEEE.

5 Jian, R., Shi, Z., Liu, H., Yang, W., & Sain, M. (2020). Enhancing Mixing and Thermal Management of Recycled Carbon Composite Systems by Torsion-Induced Phase-to-Phase Thermal and Molecular Mobility. Polymers, 12(4), 771.

6 Novodvorskyi, V. V., Shved, N., (2022). Process of melt homogenization in a metering disk extruder. *Science and Transport Progress*, (3-4 (99-100)), 48-54, doi: https://doi.org/10.15802/stp2022/275702

7. Novodvorskyi, V., Ivanitsky G., (2023). Modeling of polymer melt flow in the annular channel of a disk extruder. *Science and Transport Progress*, №1 (101).

8. Rauwendaal, C. (2014). Polymer extrusion. Carl Hanser Verlag GmbH Co KG.

9 Mikuljonok I. O. Obladnannja i procesy pererobky termoplastychnykh materialiv z vykorystannjam vto-rynnoji syrovyny : monoghrafija. Kyjiv : IVC “Vydavnyctvo «Politekhnika»”, 2009. 265 c.