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FEATURES OF CASCADING DISK-GEAR EXTRUSION OF PLASTICS

The relevant task of today is to improve the installations for thermostat extrusion, in order to increase the indicators of resource/energy efficiency. The study of the features peculiar to the loading and melting area (LMA) and the elimination of shortcomings can significantly reduce the energy costs of the process.

To achieve high-quality results in cascading disk-gear extrusion, the main methods of the dispersion melting of thermoplastic granules are analyzed, taking into account all the features of the physical model of the extrusion process.

The dispersion model of melting is achieved by observing a limited supply of raw materials to the loading area. This ensures the intensification of the process and significantly reduces the total length of the LMA. In this case, the length of the area with the most filled channel directly depends on the resistance of the disk zone. With increasing resistance, the polymer stopper moves to the loading neck. The polymer is gradually compacted, and each leakage of the LMA is periodically filled.

From the rotating disk heated to 107 °C, samples of the polymer were removed and cut into separate sections. Previously, to facilitate the process of visual research, the polymer was colored with 0.5% blue pigment. The results of the analysis confirmed the performance of the proposed physical model for the processes occuring in the disk-gear extruder. As a result, it is possible to calculate the time over which the granules stay in the LMA and the length of the screw cutting in this area, depending on the performance.

Taking into account all the features of the disk-gear extrusion process allows creating an upgraded productive, resource-efficient installation and implementing it into practice.

Keywords: *extrusion, loading-melting area, thermoplastic, resource/energy efficiency, dispersion melting.*

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Problem statement. The processing of thermoplastics is becoming more and more common in the world every year. The volume of production and processing of thermoplastics is gaining wide momentum, the process itself is long-term, complex and resource-consuming, so the relevant task is the introduction of new technologies in order to minimize the impact of production results on the environment.

One-worm extrusion is still considered the most common, but since power, melting and homogenization operations are carried out by one working body, a worm, it is very difficult to control all processes and influence their regulation. Therefore, cascading extruders are more convenient, from the point of view of control, in particular, a disk-gear extruder with all zones being autonomous, which allows you to flexibly manage the above processes without stopping the installation with unchanging performance. This allows for consistently high performance, minimizing the consumption of resources and energy. There is also the ability to identify problems in a timely manner and eliminate them.

Analysis of previous studies. Melting processes were studied on the basis of different mathematical and physical models that, respectively, differently interpreted the process, took into account various factors, and had different advantages and disadvantages.

Maddock became the very first to investigate the loading plastic area in a single-piece extruder, based on the melting model of a continuous solid phase layer [1]. Then, based on these studies, Tadmore, having conducted experimental and theoretical analysis, developed a new classical mathematical model of melting (1980s), which remains relevant to this day. A common scientific problem is the creation of a rational physical model of melting in the LSD, and an unresolved part of the scientific problem is the implementation of a dispersion model of melting in a disk extruder.

Tadmore's "cork" model is considered through the Cartesian coordinate system. As a result of friction of the cork with the cylinder and the disk in the melting area, the movement of the material occurs. Next, a thin layer of the melt film appears, resulting from the action of friction forces, as well as the transfer of thermal energy to the surface of the cylinder wall. Over time, the film layer becomes thicker, and when its size exceeds the radial gap between the cylinder and the disk ridge and the comb peels off the melt layer that accumulates on its pushing surface. The further the cork moves, the smaller becomes its width over time. Over time, the cork completely disappears and this ends the melting process. There is a hypothesis that the material moves stationarily, the thermoplastic has a clear melting point, and the channel has a constant field of temperature and velocity. For the following simplifications, it is assumed that the stopper is continuous and homogeneous and homogeneous, and its cross-section is rectangular. The inner surface of the cylinder transfers heat through a thin film of thermoplastic to the hard cork. In the film there is even additional warmth, as a result of viscous friction. [2]

Heat transfer along the cylinder axis and from the pushing wall of the axles to the melt layer is not taken into account, since the height of the solid stopper is much lower than the width on a significant part of the melting area. The thickness of the granule layer is considered weighty and, because of the small coefficient of thermal conductivity and the temperature of the granules that interact with the film, it sharply decreases from the temperature of the molten thermoplastic to the temperature of the cork layers far from the contact zone. Melting speed in a thin layer on the edge of the "melt – cork" surface in any cross-section is determined by the power of the heat flow, which is supplied to the melting surface. [3]

As already known, melting of a continuous solid phase layer is the most common approach technique for modeling the extrusion process. The following was found as a result of certain studies: certain conditions are necessary for the compression of solid granules and, if they are absent, the granules will be dispersed in the melt. Figure 1 shows a dispersion model of melting.

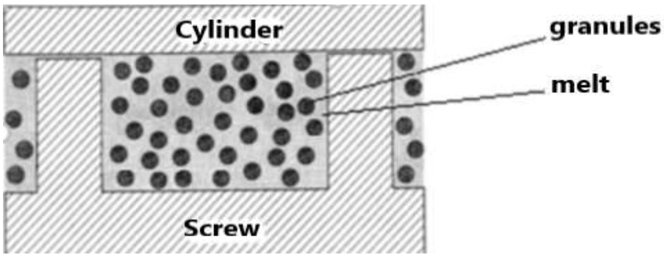
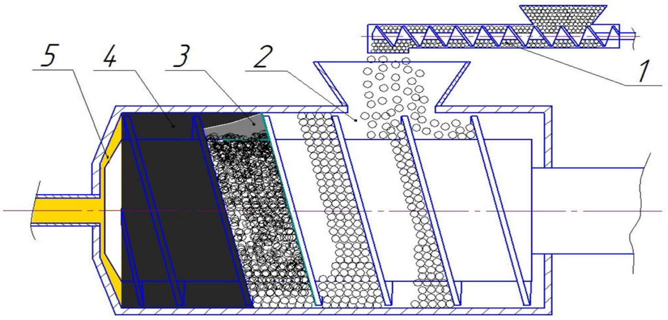


Fig. 1 – Dispersion model of thermoplastic melting

From previous studies, it is known that the use of the dispersion model allows almost 3 times the length of the loading and melting area (LMA), compared to the Tadmore model.

In order to ensure the intensification of the process and reduce the total length of the FSF, it is proposed that the dispersion melting model is applied in a dosed powered disk extruder, which is used as a homogenizer melter in a cascading disk-gear extruder. "Hungry" power supply (limited supply of raw materials to the loading area) makes it possible to implement a dispersion model of melting in a disk extruder, which is shown in Fig. 2.



1 - weighing dispenser, 2 - loading and melting area, 3 - dispersion polymer stopper, 4-semi-melt polymer, 5-homogeneous melt polymer

Fig. 2 – Dispersion model of melting with a "hungry power" disk extruder

The purpose of the article is to increase the efficiency of melting in the channels of the cascading disk-gear extruder, which will reduce the energy inability of the process.

Presentation of the main material. The main task of the dispersion model of melting is to determine the duration of melting and the length of the melting area channel. At each time value, the temperature distribution by the radius of the particle located in the melt is determined. The calculation ends when the temperature at the center of the granule reaches the melting point.

Figure 3 shows the power scheme for n-inputting drive of the LMA, where it can be seen that each of the n–turns is in the area of the loading neck only 1/n of the rotation. Therefore, the loading and plastic area always operates in the mode of dosed power supply. At the same time, the length of the site with a fully filled channel depends on the resistance of the disk zone. To overcome the resistance, a certain pressure needs to be created in the loading and plastic area. With the growth of such resistance, the polymer stopper moves towards the loading neck. Thus, each source n-inputting the LMA is periodically filled with the polymer, which, as it moves along the channel, is gradually compacted by the worm. The degree of compaction and the length of the channel fully filled with the polymer depend on the resistance of the disk head.

Another distinctive feature is the increased angular speed of the worm, so the effect of scraping the melt film with the worm in the melting area is higher than in the usual extruder and thus the average thickness of the melt film is smaller. This effect, together with an increased angular vein, causes much greater heating of the polymer melt at the cylinder wall, which must be taken into account in processing thermally sensitive materials. In the installed mode, it is not necessary to supply heat from external heaters and the extruder works almost in adiabatic mode. These features require clarification of existing mathematical models describing similar processes in a conventional worm extruder.

Along the length of the multi-inputting LMA worm disk extruder, the following zones can be distinguished.

The zone of "hungry" power supply, in which the worm channel is not completely filled with a polymer but, unlike the single-tap auger dosage, the polymer, depending on the position of the coil, is constantly touching the surface of the worm and cylinder and quickly moves to the compression zone.

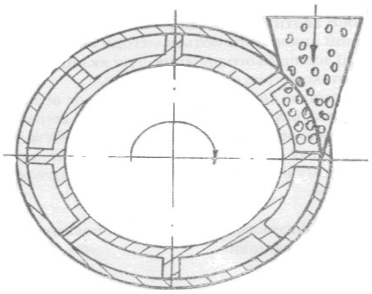


Fig. 3 – Power circuit of the disk extruder LMA

The length of the zone with a fully filled disk channel depends on the resistance of the disk head and increases with the latter. That is, the resistance of the following zones will not affect productivity until the zone, which increases with a fully filled worm channel, reaches the bootable neck or until the zone of "hungry" nutrition disappears. On the first section of the area under consideration, the polymer stopper is transported, but without its melting due to forces induced by friction of the polymer with the cylinder wall and the worm. The heat released by "dry" friction goes to partial heating of the polymer and is partially released into the environment through the wall of the cylinder if the cylinder is cooled. Melting of the polymer will begin when the temperature on the surface contacting with the wall or worm reaches the melting point. The formation of a melt film on the cylinder surface will begin much earlier than on the surface of the worm, because the speed at which the cork moves relative to the cylinder is greater than relative to the worm. We will not take into account the transitional area between the "dry" friction area and the melting area in which the melt space between the granules is filled, since the above-described effect of scraping the melt film, insignificant pressure and channel depth and greater angular speed contribute to the rapid filling of space between the granules. On the second part of the area with a fully filled worm channel, the melting of polymer granules occurs, which become completely wrapped in the melted polymer. In this area, the melting process proceeds almost adiabatically due to the heat of dissipation.

When the cops are more than 80% filled, the screw cutting LMA ends. Next is the end working gap, where the polymer is melted and its homogenization occurs.

This physical model was tested experimentally on a single-brush disk extruder by its instant stopping in working mode and rapid cooling of the working bodies ("freezing"). Then, after preheating the body of the disk extruder to 107 ºC, it was removed and samples of the material remaining on the LMA were visually examined, Fig. 4.

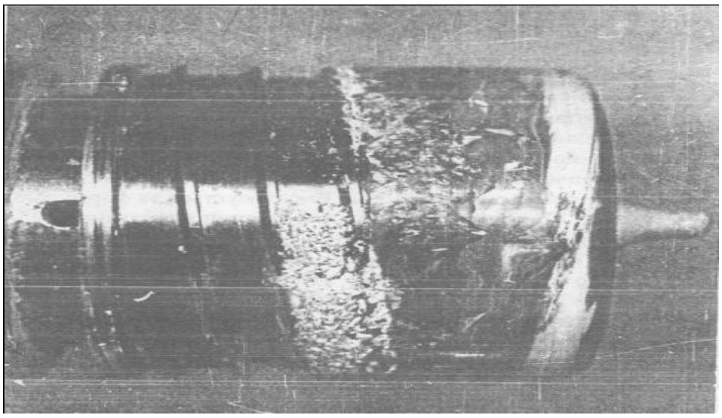


Fig. 4 – LMA scheme with polymer samples

The samples were studied by thickness after warming the rotating disk to 107 ºC and then the samples were removed and cut into separate sections. Polyethylene and polystyrene pellets processed were previously colored with 0.5% blue phthalziapine pigment, which facilitated a visual study of the samples taken as slices in different places of the worm cutting area. Analysis of the studies with the samples confirms the performance of the described physical model characterizing the processes that occur in the disk extruder [4,5].

Conclusions. The presented article analyzes the main physical models to obtain a quantitative result for the melting process in cascading disk-geared extrusion. The use of a dispersion model of melting in a dosed-powered disk extruder is proposed and substantiated.

Preliminary experimental studies have shown that the above algorithm allows calculating the time over which the granules stay in the melting area and, accordingly, the length of the screw cutting in this area, depending on the performance.

Prospects for further research. The implementation of the results obtained in the study makes it possible to create a resource/energy-efficient installation with the most productive and efficiently working loading and plastic area. In the future, it is possible to design such equipment or continue researching the installation in other zones.

References

1. Nichols R. and Kheradi F, (1984). *Modern Plastics*. Part 1 (1). Polymer Process
2. Griffith R., 1962. *Fully Developed Flow in Screw Extruders.* Part 27 (3). Eng. Chem. Fundam.
3. Voronin L., Shved M., Shved D., Lutsenko I, 2013. *Research of polymer melting process in worm extrusion*. №7 (62) / Volume 2, Eastern European Journal of Advanced Technologies.
4. McKelvey D., 1965. *Polymer Recycling*, Chemistry.
5. Shved M., Reznik R., Shved D. *Features and physical model of processes in the loading and plasticizing zone of disk extruder*, №41, Part 1. Odessa National Academy of Food Technologies. Scientific works.
6. Tadmor S., K. Gogues, 1984. *Theoretical Foundations for Polymer Processing* , Chemistry
7. Tadmor Z., E. Broyer, 1972. *Solids Conveying in Screw Extruders. Part II. Non Isothermal Model.* Part 117(12). Polym. Eng. Sci.

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ОСОБЛИВОСТІ КАСКАДНОЇ ДИСКОВО-ШЕСТЕРЕННОЇ ЕКСТРУЗІЇ ПЛАСТМАС

Актуальною задачею сьогодення є вдосконалення установок для екструзії термоластів, з метою підвищення показників ресурсоенергоефективності. Дослідження особливостей завантажувально-пластикувальної зони (ЗПЗ) і ліквідація недоліків дозволяє значно знизити енерговитрати процесу.

Для досягнення якісних результатів при каскадній дисково-шестеренній екструзії проаналізовано головні методи процесу дисперсійного плавлення гранул термопласту, враховуючи всі особливості фізичної моделі процесу екструзії.

Дисперсійна модель плавлення досягається шляхом дотримання обмеженої подачі сировини в завантажувальну зону. Це забезпечує інтенсифікацію процесу і значно зменшує значення загальної довжини ЗПЗ. При цьому довжина ділянки з максимально заповненим каналом напряму залежить від опору дискової зони. Із зростанням опору полімерна пробка переміщується до завантажувальної горловини. Полімер поступово ущільнюється, а кожен виток ЗПЗ періодично заповнюється.

З розігрітого до 107С диску, що обертається, знімались і розрізались на окремі ділянки зразки полімеру. Попередньо для полегшення процесу візуального дослідження, полімер був забарвлений 0,5% блакитним пігментом. Результати аналізу підтвердили працездатність пропонованої фізичної моделі процесів, що протікають в ЗПЗ дискового екструдера. Внаслідок цього з'являється можливість розрахувати час перебування гранули в ЗПЗ і довжину гвинтової нарізки в цій зоні в залежності від продуктивності.

Врахування всіх особливостей процесу дисково-шестеренної екструзії дозволяє створити модернізовану продуктивну, ресурсоефективну установку і реалізувати її на практиці.

Ключові слова: *екструзія, завантажувально-пластикувальна зона, термопласт, ресурсоенергоефективність, дисперсійне плавлення.*

Список використаної літератури

1. Ніколс Р. і Ераді Ф. 1984. *Сучасні пластмаси*. Частина 1 (1). Полімерний процес
2. Гріффіт Р., 1962. *Повністю розвинений потік в гвинтових екструдерах.* Частина 27 (3). Англійський хімічний фонд
3. Воронін Л.Г., Швед М.П., Швед Д.М, Луценко І. В.. *Дослідження процесу плавлення полімеру при черв'ячній екструзії, 2013.* № 7 (62) , том 2. Східно-Європейський журнал передових технологій.
4. Мак-Келві Д.М., 1965. *Переробка полімерів* пер. с англ. М.: Хімія
5. Швед М.П., Резнік Р.Ю., Швед Д.М. *Особливості і фізична модель процесів у завантажувально-пластикуючій зоні дискового екструдера* №41, Том 1. Одеська національна академія харчових технологій. Наукові праці.
6. Тадмор З, К. Гогос. *Теоретические основы переработки полимеров.*М.: Хімія, 1984.
7. Тадмор З., Броєр Е.. *Тверді речовини, що передаються в гвинтових екструдерах. Частина II. Неізотермічна модель* Частина 117(12), 1972. Полімерні англійські науки.