



## Study on the influence of geometric parameters of screw extruder on the shear rate of polymer melt

Yuntao Hu<sup>1,\*</sup>

<sup>1</sup> College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, 100029, Beijing, China

**SUMMARY:** *In order to investigate the influence of geometric parameters of screw extruder on the shear rate of polymer melt, the flow morphology and mixing mechanism of polymer material melt in twin-screw extruder were deeply explored. This study focuses on polymer melt materials and takes the industrial prototype of a fully meshed co rotating twin-screw extruder as the object. Combined with POLYLOW software modeling, three-dimensional isothermal flow field numerical simulation of polymer melt materials is carried out, and the fluid velocity field and other field quantities of polymer melt materials are solved; Then, the POLYSTAT post-processing software was used to introduce concepts such as cumulative maximum shear rate distribution to evaluate the dispersion and mixing ability of polymer melt materials; Finally, the laminar shear theory is applied to calculate the viscous shear heat generation of polymer melt materials and compared with actual experimental data. The experimental results show that the change in pitch has little effect on the mixing index and the fluid motion mode; As the pitch increases, the maximum mixing index slightly increases, but the overall dispersion and mixing ability of the screw shows a weakening trend; Small pitch is beneficial for improving the distribution mixing ability; As the pitch increases, the average mixing efficiency shows an increasing trend, and a larger pitch is beneficial for improving the mixing efficiency. Research has shown that the geometric parameters of screw extruders have a significant impact on the shear rate and mixing effect of polymer melts, providing a theoretical basis for optimizing extruder design.*

**KEYWORDS:** *screw extruder; Geometric parameters; Polymer melt; Shear rate; Numerical simulation; mixed ability*

## 1 Introduction

Polymer inorganic nanocomposites are developed on the basis of macroscopic composite materials, but they are one of the rapidly developing and most advanced composite materials. They are widely used in aerospace materials, military industry, and residential life [1]. By introducing inorganic nanoparticles with specific functions into the polymer matrix, composite materials with flame retardancy, antibacterial properties, conductivity, UV resistance, self-cleaning properties, far-infrared radiation and other functions can be manufactured. Although a series of achievements have been made in the application research of inorganic nanoparticles, the aggregation of inorganic nanoparticles themselves greatly limits their applications and leads to insufficient utilization of their excellent properties [2].

The current research on new composite methods between inorganic nanoparticles and

\*hu\_yunt4work@163.com

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polymer matrices, as well as the use of new surfactants for surface modification of nanoparticles, is a feasible approach. However, melt blending is undoubtedly the most efficient, economical, and labor-saving production method, but it places high demands on the distribution and dispersion mixing ability of processing equipment [3]. In the production of polymer materials industry, compared with single screw extruders, the modular structure and adaptability of meshing co rotating twin-screw extruders, as well as their excellent mixing performance, make them widely used in polymer processing fields such as molding, mixing, modification, and reactive extrusion. By rational combination of high-efficiency mixing element screws, the mixing capacity of the extruder can be greatly improved, and different mixing effects can be obtained. In polymer blend extrusion processing, due to the complex fluidity of the melt itself and the influence of external objective factors, the shear mixing process of the polymer exhibits irregular viscoelasticity in actual processing, usually accompanied by thermal effects [4]. The real flow behavior of the melt is very complex. Traditional research methods often use mathematical analysis and experimental research, but in the process of research and analysis, mathematical analysis involves many ideal assumptions and oversimplifies formulas, which can easily lead to errors; In experimental research, repeated design and trial production of equipment parameters such as screws and barrels are required, resulting in long production cycles and low efficiency [5]. The cost of building an intuitive experimental platform to observe the movement trajectory of particles in the barrel and analyze the movement rate and force conditions of polymer melt particles is also very high, which cannot meet the needs of scientific research and practice. With the continuous improvement of computer technology, numerical analysis and solving techniques are gradually being applied in scientific research. Numerical simulation technology has been applied to polymer processing and molding since the 1970s. POLYLOW, as a software based on finite element method specifically designed for flow simulation of viscoelastic materials, can analyze extrusion, mixing, blow molding and other problems of various flow models, and has a wide range of application prospects [6].

With the upgrading of computer computing power and the development of finite element software, numerical simulation methods have become an important means of studying the flow field of screw extruders. In order to conduct a more in-depth study on the flow morphology and mixing mechanism of polymer material melt in twin-screw extruders, this paper used the polymer flow analysis software POLYLOW to conduct research in the following aspects [7]: (1) Modeling the screw parameters of the industrial prototype of the fully meshed co rotating twin-screw extruder, conducting numerical simulation of the three-dimensional isothermal flow field, studying the flow morphology and mixing mechanism of materials, and solving the velocity field, pressure field, shear rate field, and viscosity field of non Newtonian polymer melt. (2) In order to evaluate the dispersion and mixing ability of twin-screw extruders, POLYSTAT post-processing software was used, and concepts such as cumulative maximum shear rate distribution and probability density distribution were introduced to analyze and compare the flow trajectory, residence time distribution, and maximum shear rate of materials. By describing the motion trajectories of four tracer polymer melt particles starting from different positions, the multiple exchanges of materials in the spatial position inside the twin-screw extruder are more intuitively expressed. (3) The laminar shear theory was applied to calculate the viscous shear heat generated by twin-screw extrusion, and compared with the shear of twin-screw. Combined with actual experimental test data, the correctness of the calculation method and results were compared and discussed.

## 2 Related research

### 2.1 Development status of screw extruder

Polymer material blending modification is a popular science abroad, and using modification technology to promote the development of polymer material industry has become an effective method for changing product structure and improving product quality in the field of polymer material processing. Screw extrusion technology has become widely used in blending modification processes due to its continuous, efficient, and controllable technical characteristics [8]. High quality blending modification technology requires good distribution and dispersion of various components. In order to achieve better blending modification effects, screw extruders have evolved from single screw extruders to twin-screw and multi screw extruders. The research group led by Professor Jiang Nan from the Institute of Polymer Materials Machinery at Beijing University of Chemical Technology, in collaboration with a cooperative enterprise, has taken the lead in researching and developing a fully meshed twin-screw extruder with a triangular arrangement. The key factors affecting the morphology and structure of blends in screw extruders are shear (or stretching) and the orientation of the relative shear stretching direction. The higher the shear rate (stretching rate), the more favorable it is for mixing; The more times the material passes through the high stress zone, the more favorable it is for dispersion [9]. The increase in the meshing area of the twin-screw extruder has doubled the rolling area, resulting in efficient extrusion and shearing of the material during operation. The existence of three meshing zones has a complex and beneficial impact on the exchange of material flow direction, velocity, and spatial position. The central area is a unique area of the twin-screw extruder. The area of the central area undergoes a cyclic change from large to small and then from small to large; Numerically, the maximum area of this region is approximately 7 times the minimum area. If the existing single screw extrusion theory is simply applied, it may be assumed that the unique central area of the twin-screw extruder is an area that cannot be swept by the screw edges at any phase, and there will inevitably be backflow and stagnation, which is unfavorable for pressure building and positive displacement conveying [10]. Due to the advancement of the thread in the direction of screw rotation, the material will enter the central area. The elastic compression and forward pumping caused by the squeezing effect of the meshing area and the rapid change in the central area area result in the rapid advancement of the material in this area, forming an efficient pumping and stretching flow, which is a unique flow of twin-screw extruders. Due to the large chamber of the twin-screw extruder and the unique extrusion effect in the central area, the production capacity of the twin-screw extruder is higher.

### 2.2 Limitations of screw extruder development

Early extruders were conventional three-stage screws, which had certain limitations in terms of equipment output, plasticizing quality, and dispersion distribution effect. In order to meet the new requirements in polymer processing and molding, screw extruders are constantly innovating. For example, in the development of screw structures, various structural forms of screws have evolved, such as separation type screws, screws with different groove depths in the compression section, and mixing elements such as pineapple heads and barrier sections [11]. In the 1930s, Italian scientists first proposed the concept of twin-screw extruders and introduced the first co rotating twin-screw extruder. The conveying mechanism of twin-screw extruders eliminates many "friction" relationships, especially in the case of counter rotating twin-screw extruders that rely on the "meshing space" of two screws to force the material forward, known as "positive displacement conveying". Compared with single screw extruders, twin-screw

extruders are easier to control the extrusion process, especially for powder materials with poor thermal stability, and have the characteristics of high extrusion efficiency, uniform heating of materials, and "self-cleaning" [12]. These properties have enabled the rapid development of twin-screw extruders. In 1935, LMP Roberto Colombo and Pasqrllti from Italy developed co directional and co directional twin-screw extruders, which were more suitable for mixing operations such as GF reinforcement, coloring, filling, hard PVC, and some powders with low friction coefficients. Due to the poor thermal conductivity of polymer materials, large-diameter extruders (with a diameter of over 130mm) may have "static" material in the threaded cavity due to the relatively deep groove depth, resulting in uneven plasticization. The problem of uneven plasticization at the local level cannot be solved by increasing the screw speed, as this can cause overheating. Although it can also be solved by increasing the aspect ratio of the screw, it increases the many negative effects caused by the cantilever of the screw. This cantilever structure causes the weight of the front section of the screw to sag, resulting in a significant asymmetric load on the bearing fitted on the other end. Especially under the dynamic friction of continuous operation of the screw, it will inevitably directly affect the structural strength of the bearing. Over time, the screw may sag in the front section, affecting the smoothness of operation. The combination of multiple screws with small diameter and short aspect ratio is one of the effective ways to solve this contradiction [13].

### **2.3 Study on the Melting Effect of Screw Extruder**

The melting effect of materials in screw extruders directly affects the performance of the final product. Therefore, although the melting theory is in a relatively mature stage, further research and model simulation on this theory are still hot topics. [14] used the SSEM model to predict the curve of solid bed temperature and pressure changes during the melting process. [15] proposed a novel melt approximation simulation method, which is not based on the Tadmor model as in previous simulations, but fully considers the circulating flow in the melt pool. Therefore, it can effectively solve the problem of thermal convection in the cross-sectional direction of the spiral groove. Researchers have conducted in-depth and systematic studies on the influence of vibration parameters in the induced extrusion melting process (as shown in Figure 1) using numerical simulation methods. In the study, the White Metzner constitutive model was referred to, and a modified Maxwell non isothermal constitutive model with relaxation spectrum characteristics was adopted. Combined with finite element numerical simulation (FEM) technology, the influence of dynamic parameters on the melting process and more effective melting conditions were explored. This provides a theoretical basis for the design of vibration induced polymer extrusion molding equipment, vibration parameter setting and optimization, and process control.

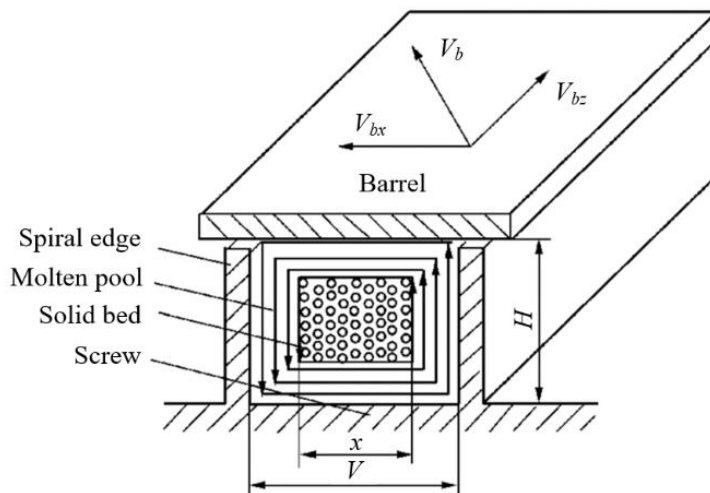


Figure 1: Melting mechanism and coordinate system diagram under vibration field

By simulating the sensitivity of the melting curve to the screw temperature during the three-dimensional melting process, it was found that the predicted melting rate in the compression section decreases with the increase of screw temperature, which is contrary to what we usually think. [16] studied the melting process of solid beds. By visualizing the barrel, it was found that the melting rate of the solid bed in the thickness direction is greater than that in the width direction, indicating that the melting is completed first in the thickness direction. This indicates that the melting rate of the solid bed depends on the melting rate in the thickness direction, rather than the widely recognized width direction as the dominant factor.

### 3 Mixing effect index of screw extruder

#### 3.1 Dispersion and mixing characterization

In dispersed mixing, it is difficult to visually observe the stretching, shearing, and other movements of the melt inside the barrel. The mixing index can be used to characterize the stretching and rotating behavior of the fluid in the flow field [17]:

$$\lambda_{Mz} = \frac{|D|}{|D| + |W|} \quad (1)$$

where,  $D$  represents the deformation rate tensor, and  $W$  represents the rotation tensor.

The characterization range of the mixed index is  $[0,1]$ . Between 0 and 1, different flow states are represented, and when  $\lambda=1$  occurs, the melt exhibits pure tensile behavior;  $\lambda=0.5$ , at this point, it can be considered that the flow field only exhibits a single shear behavior;  $\lambda=0$ , the default is the same rotational motion as the rigid part of the screw.

When analyzing simulation results, the mixing degree of the extrusion flow field can be predicted based on the frequency of the statistical distribution occupied by the three factors. Since stretching is more conducive to dispersion mixing than shearing, a higher proportion of mixing index indicates better dispersion mixing effect of the extrusion flow field. However, this characterization method is sometimes one-sided. Some polymer materials have high cohesion, and the maximum stress in the flow field cannot reach the critical value for particle breakage, resulting in some aggregates still unable to break. Therefore, it is also important to investigate the stress generated in the flow field for characterizing dispersed mixing. The dispersion and

mixing of extruders can be analyzed from the perspective of stress, and the solution model for stress invariants is as follows [18]:

$$\sigma = \sqrt{4(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2) + (\tau_{xx} - \tau_{yy})^2 + (\tau_{yy} - \tau_{zz})^2 + (\tau_{zz} - \tau_{xx})^2} \quad (2)$$

where,  $\tau_{xy}$ ,  $\tau_{yz}$ , and  $\tau_{zx}$  are shear stresses;  $\tau_{xx}$ ,  $\tau_{yy}$ , and  $\tau_{zz}$  are normal stresses.

### 3.2 Distribution mixture characterization

(1) Mixing principle and characterization method. In characterizing distribution mixing, the distance between two fixed particles at the starting moment is calculated. As the mixing continues, the farther the distance between the two, the better the distribution mixing. At time  $t_0$ , the line segment  $d\vec{X}$  composed of two particles oriented  $\vec{M}$  changes to the line segment  $d\vec{x}$  oriented  $\vec{m}$  through motion  $\vec{\chi}$  at time  $t$ . The calculation model for the elongation rate of the length at this time is as follows:

$$\lambda_p = |d\vec{x}| / |d\vec{X}| \quad (3)$$

Using the same principle, the infinitely small interface  $d\vec{A}$  with a normal direction of  $\vec{N}$  at the initial moment has an area of  $d\vec{a}$  at time  $t$ . The calculation model for the area expansion rate of the fluid at this time is as follows:

$$\eta_{ex} = |d\vec{a}| / |d\vec{A}| \quad (4)$$

The use of area expansion ratio can characterize the distribution and mixing of fluids. In extruder processing, the fluid is constantly subjected to shear and tension, and the surface of the fluid is constantly changing, rearranging and tending to mix evenly [19, 20]. The displacement of particles in the flow field and the expansion rate of interface area are both related to orientation and strain. The shear force acting on the fluid interface can be calculated as:

$$\frac{A}{A_0} = \sqrt{1 - 2\gamma \cos \alpha_x \cos \alpha_y + \gamma^2 \cos^2 \alpha_x} \quad (5)$$

where,  $\gamma$  is the shear stress;  $A$  is the interface area during mixing;  $A_0$  is the initial interface area;  $\alpha_x$  and  $\alpha_y$  are interface orientation angles.

The changes in the interface after random orientation under shear action are as follows:

$$\frac{A}{A_0} = \frac{\gamma}{2} \quad (6)$$

In a shear flow field, the growth rate of interface random orientation is half of the total shear stress in the flow field. Assuming that there is no reorientation phenomenon during the interface growth process, after  $n$  times of processing with a shear stress of  $\gamma$ , the area change is:

$$\frac{A}{A_0} = \frac{n\gamma}{2} \quad (7)$$

Considering reorientation, after experiencing  $n$  shear strains, the area change is:

$$\frac{A}{A_0} = \left( \frac{\gamma}{2} \right)^n \quad (8)$$

By comparing the two equations, it can be found that changing the direction of structures such as screw edges on the fluid flow path can effectively enhance fluid distribution and mixing. The change in interfacial area of the fluid under tension is shown in the equation:

$$\frac{A}{A_0} = \sqrt{\frac{\cos^2 \alpha_x}{\lambda_x^2} + \frac{\cos^2 \alpha_y}{\lambda_y^2} + \frac{\cos^2 \alpha_z}{\lambda_z^2}} \quad (9)$$

where,  $\lambda_x$ ,  $\lambda_y$ ,  $\lambda_z$  are stretch rates.

Due to the fact that the stress-strain inside the extruder changes over time, the area elongation rate is indirectly related to time [21]. Therefore, it is more effective to characterize the area stretching efficiency using the surface stretching transient mixing efficiency. The specific model is as follows:

$$e_\eta = \frac{\dot{\eta}_{ex} / \eta_{ex}}{\sqrt{\bar{D} : \bar{D}}} = \frac{d \ln \eta_{ex} / dt}{D} \quad (10)$$

where,  $\bar{D}$  is the strain rate tensor,  $D$  is the dissipation rate, and  $\dot{\eta}_{ex}$  is the derivative of  $\eta_{ex}$ .

Due to the predominance of shear flow distribution in the flow field, the distribution mixing performance can also be characterized by weighted average total strain:

$$WATS = \int_0^t \frac{dv}{dx} dt \quad (11)$$

where,  $dv/dx$  stands for shear rate.

In the extrusion flow field, the distribution position and flow pattern of the fluid change constantly, and the number of shear cycles experienced by the fluid micro clusters varies. The more cycles, the better the mixing situation.

### 3.3 Statistical characterization

The weave structure of polymer mixtures is used to represent the spatial distribution of various polymer blends, whether they exhibit a block like or layered distribution after blending. The morphological structure of the mixture in the extrusion flow field is characterized by the separation scale and separation strength [22, 23]. As the separation strength and separation scale decrease, the woven structure of the polymer mixture will be difficult to observe or even disappear. The correlation coefficient between the concentrations of each component during the mixing process is defined as:

$$R(|r|) = \frac{\sum_{j=1}^M (\dot{c}_j - \bar{c}_p) \cdot (\ddot{c}_j - \bar{c}_p)}{M \cdot \sigma_c^2} \quad (12)$$

$$\sigma_c^2 = \frac{\sum_{p=1}^{N_p} (c_p - \bar{c}_p)^2}{N_p - 1} \quad (13)$$

where,  $R(|r|)$  represents the correlation between the concentrations of two points separated by  $|r|$ , and represents the correlation between the concentrations of two points separated by  $|r|$ ;  $M = N_p(N_p - 1)/2$  represents the logarithm of particles;  $N_p$  represents the total number of particles;  $\sigma_c^2$  is the variance.  $c_j$  and  $\bar{c}_j$  are the concentrations of the  $j$ -th pair of particles. The range of variation for the correlation coefficient is  $[-1, 1]$ . When  $R(|r|) = 1$  represents a completely positive correlation, that is, one point is a pure primary component and the other point is a pure secondary component.

The segmentation scale is obtained by integrating the correlation coefficients:

$$L_s = \int_0^\zeta R(|r|) d|r| \quad (14)$$

where,  $R(|0|) = 1$ , at this point, the two points overlap and have the same concentration;  $R(\zeta) = 0$  means that when two particles are farthest apart by  $\zeta$ , they are no longer correlated with each other. The separation scale is related to the distance length.

The definition of separation strength is:

$$I_{seg} = \frac{\sigma_x^2}{\sigma_0^2} = \frac{\sum_{j=1}^N (x_j - \bar{x}_j)^2}{N - 1} / \sigma_0^2 \quad (15)$$

where,  $\sigma_0^2$  is the variance of component concentration in a completely separated state;  $\sigma_x^2$  is the actual variance in the system.

The separation strength characterizes the spatial distribution of polymers after mixing. Since the micro clusters of the mixed blend cannot achieve absolute mixing uniformity, the ratio of the variance of micro clusters with different concentrations to the ideal concentration of micro clusters in the blend is used as a mathematical characterization of the separation strength [24].

## 4 Finite element model and numerical simulation conditions

### 4.1 Geometric Model and Finite Element Model

As the main equipment for polymer processing, twin-screw extruders are widely used in polymer extrusion molding and mixing technology due to their excellent mixing, self-cleaning, and exhaust properties. With the widespread application of twin-screw extruders, more new and efficient multi screw extruders have emerged. But its theoretical research is limited and the depth of research is shallow, so it has not been put into practical application [25, 26]. This article mainly uses a diamond shaped twin-screw extruder as the basic model and POLYLOW as the main computational tool to study its complex flow field mixing mechanism and transport characteristics. And compare it with the mixed evaluation parameters of the twin-screw extruder. The specific geometric parameters, geometric model, and finite element model of the model are shown in Table 1.

Using Gambit commercial software to generate the geometric shape and mesh files of the

extruder, the finite element model is divided into quadrilateral element meshes, and the mesh refinement is carried out at the meshing area, the inner wall of the barrel, and the root of the screw [27]. The mesh superposition technique (MST) is used to ensure that the flow field is fully filled, effectively improving the efficiency and accuracy of particle trajectory tracking speed interpolation. The geometric model and finite element model of the twin-screw extruder are also included. The finite element model of the twin-screw extruder used for simulation contains 43946 nodes. Use the commercial computational fluid dynamics software POLYFlow to solve the two-dimensional flow during the simulation process.

*Table 1: Basic Geometric Parameters of Screw Extruder*

Parameter	Symbols/Units	Value
Inner diameter of barrel	$R_o/\text{mm}$	18.45
Screw root diameter	$R/\text{mm}$	16.73
Screw top diameter	$R^2/\text{mm}$	12.68
Screw center distance	$L/\text{mm}$	32.87
Screw angular velocity	$w/\text{rpm}$	0.45

## 4.2 Simulated boundary conditions

The simulation boundary settings for the screw extruder are as follows:

- (1) The set inlet flow rate for the mobile inlet is  $15 \times 15\text{m}^2/\text{s}$ ;
- (2) According to the basic assumption that there is no slip on the inner surface of the barrel, the normal velocity and tangential velocity are set to zero, that is,  $V_n=0$ ,  $V_s=0$ ;
- (3) The screw speed is  $0.5\text{r}/\text{min}$ ;
- (4) The flow outlet is set to zero normal and tangential forces, i.e.  $F_n=0$ ,  $F_s=0$ ;
- (5) Particle release adopts free release at the entrance position;
- (6) Use the Picard iteration method for iteration.
- (7) The transient flow field adopts the Crack Nicolson method.

## 4.3 Numerical Calculation Method

The numerical calculation method used in this article's numerical simulation is the commercial software POLYLOW, which can perform complex calculations for high viscosity polymer melt blending. Due to the low power exponent and strong nonlinearity of the transient Bird Carreau viscosity model [28, 29]. So in the calculation, this article uses quadratic interpolation for velocity and coordinates, selects atmospheric pressure for pressure, and uses the Picard iterative method with slow convergence but relatively stable viscosity. The integral method used for transient flow field calculation is the Krank Nicolson method, with a simulated convergence accuracy level of  $1 \times 10^{-4}$ . By comparing with existing research results, all the numerical simulation parameters selected in this article can ensure the reliability of the numerical simulation results.

The numerical simulation flowchart in this article is shown in Figure 2. Firstly, use the finite element partitioning software GAMBIT to draw the finite element structural mesh required for simulation; Subsequently, the structural mesh is imported into POLYDATA to set simulation boundary conditions and related numerical parameters. The software is used to track the trajectories of polymer particles and calculate the local deformation and other related properties of the fluid along these trajectories; Finally, statistical tools are applied to analyze the global fluid flow characteristics and quantify mixing. The flowchart on the right shows the entire simulation process of calculating the Lagrangian coherent structure in this article, releasing polymer molten fluid particles at random positions in the watershed and tracking their motion

trajectories. Visualize its structural field diagram, compare the mixed evaluation parameters, and analyze the transport and mixing capabilities of polymer melt fluid particles.

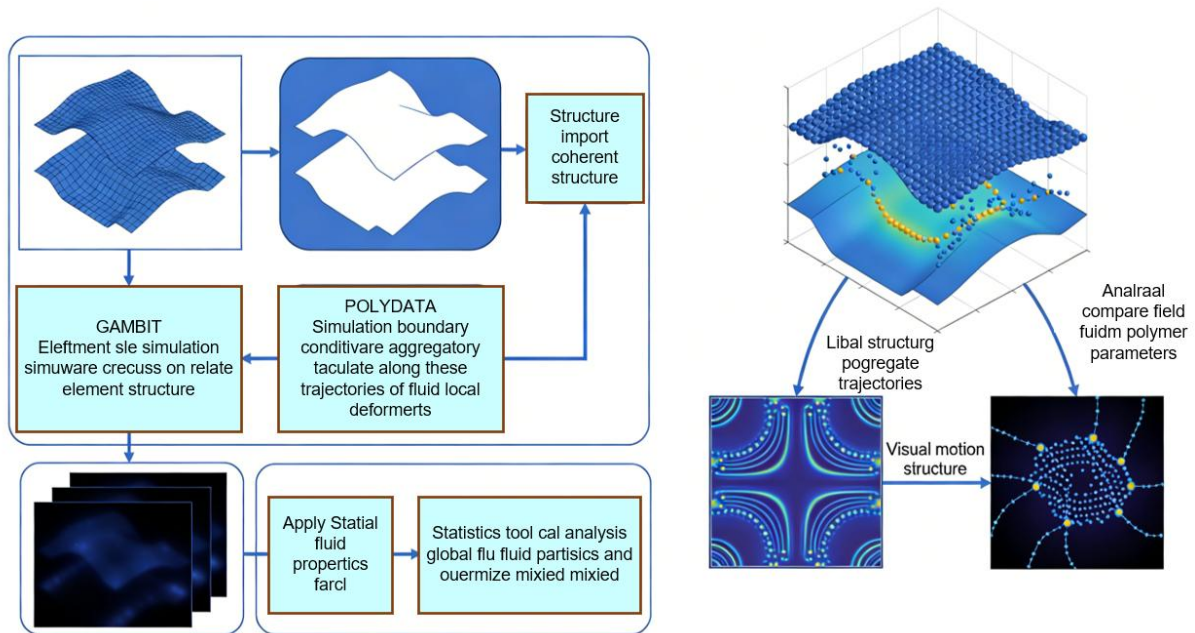


Figure 2: Numerical simulation flowchart

## 5 Experimental analysis

The shear zone of the twin-screw extruder is shown in Figure 3. The area circled in red in the picture is a cutting area. There are four twin-screw extruders with double head threads in this cutting area. There are three shear zones formed with the barrel surface and one shear zone formed between the screws [30].

Use grid drawing software to divide the flow channel and screw into grids separately. Firstly, a grid independence test was conducted using CTS4 as the model. Three sets of grids with different accuracies were set up, with M1 having 161093 grid cells, M2 having 302147 grid cells, and M3 having 56308 grid cells. The fluid velocity on a straight line ( $x_1=-0.0227$ ,  $y_1=0$ ,  $Z_1=-0.003$ ;  $x_2=0.0086$ ,  $y_2=0$ ,  $Z_2=0.187$ ) at the boundary of the flow channel was selected as the reference for comparison. Figure 4 shows the influence of different screw configurations on the mixing index distribution on the  $Y=0$  m plane (screw speed=40rpm, feed rate=1.75kg/h). It can be seen from Figure 4 that the change in pitch has a small effect on the mixing index, indicating that pitch has a small impact on the fluid motion mode.

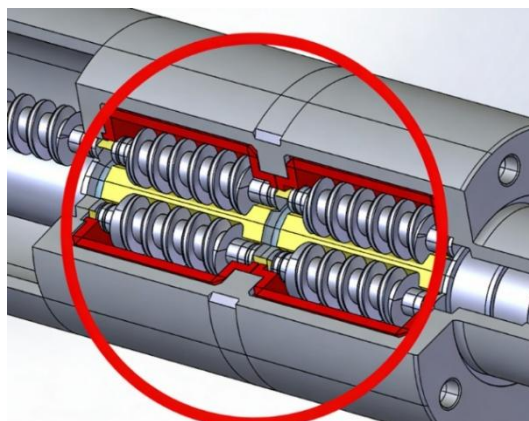


Figure 3: Shear zone of twin-screw extruder

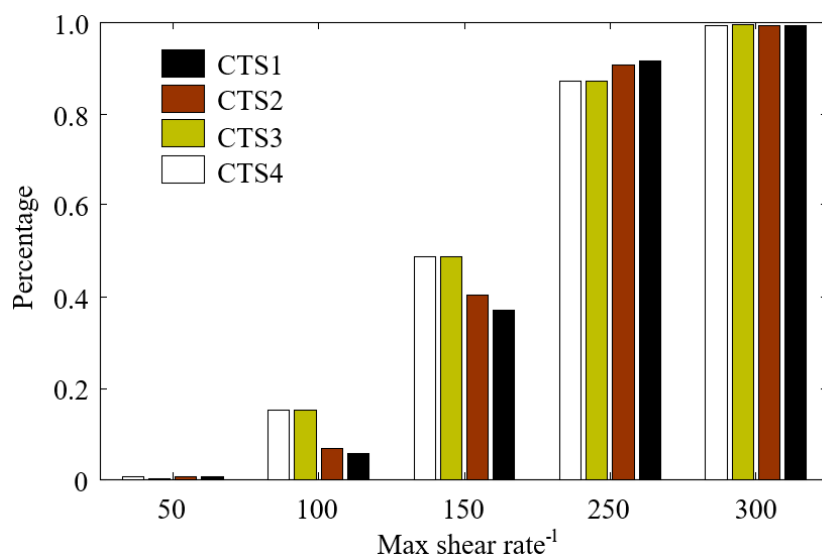


Figure 4: The Effect of Pitch on Maximum Shear Rate

Figure 5 shows the effect of screw configuration on the maximum mixing index of tracer polymer melt particles (screw speed=40rpm, feed rate=1.75kg/h). From Figure 5, it can be seen that for the same percentage of tracer polymer melt particles, the maximum mixing index slightly increases with the increase of pitch. However, as the pitch increases, the number of screw edges per unit length decreases, and the shear effect of the screw on the material weakens. The trend of the maximum mixing index between CTS3 and CTS4 is approximately a curve, indicating that as the pitch increases to a certain extent, the influence on the fluid flow mode will gradually decrease. Therefore, as the pitch increases, the overall dispersion and mixing ability of the screw still shows a weakening trend.

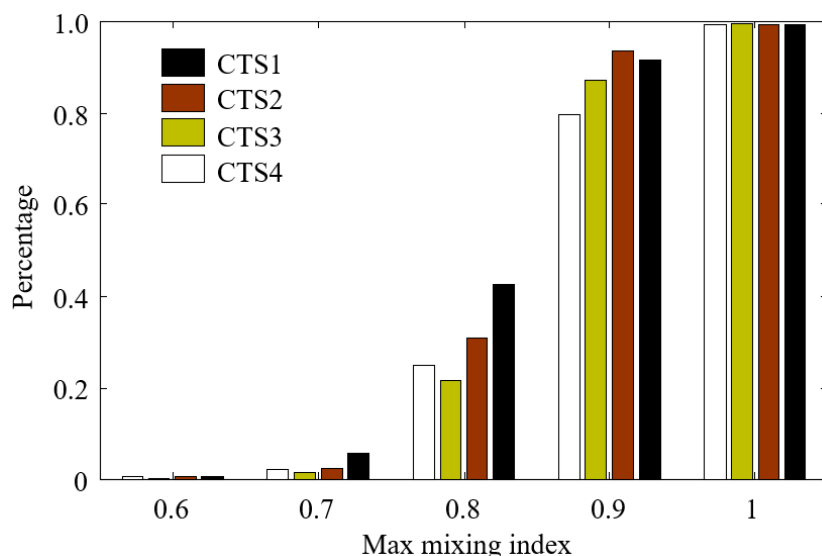


Figure 5: The Effect of Pitch on the Maximum Mixing Index

The variation of average tensile length with axial distance is shown in Figure 6 (screw speed=40rpm, feed rate=1.75kg/h). From Figure 6, it can be seen that as the axial distance increases, the average tensile length changes exponentially, which is a necessary condition for good laminar mixing performance. However, the curve does not always rise steadily because the material is prone to stretching at the initial stage, and as the axial distance increases, stretching becomes difficult, resulting in fluctuations on the curve. From Figure 6, it can be observed that as the pitch increases, the average tensile length decreases accordingly, indicating that a smaller pitch is actually beneficial for improving the distribution and mixing ability of the screw.

The effect of pitch on the average mixing efficiency is shown in Figure 7 (screw speed=40rpm, feed rate=1.75kg/h). For the change in average time averaged mixing efficiency, when the material first enters the extruder, the mixing efficiency of the extruder will reach a high value in a short period of time. Then, as the flow field tends to stabilize, the average mixing efficiency over time will gradually decrease. During this period, the average time averaged mixing efficiency remains positive, indicating that the material has been experiencing strong redirection throughout this time. When the pitch increases, the average time averaged mixing efficiency shows an increasing trend, indicating that a larger pitch is beneficial for improving the mixing efficiency of the extruder.

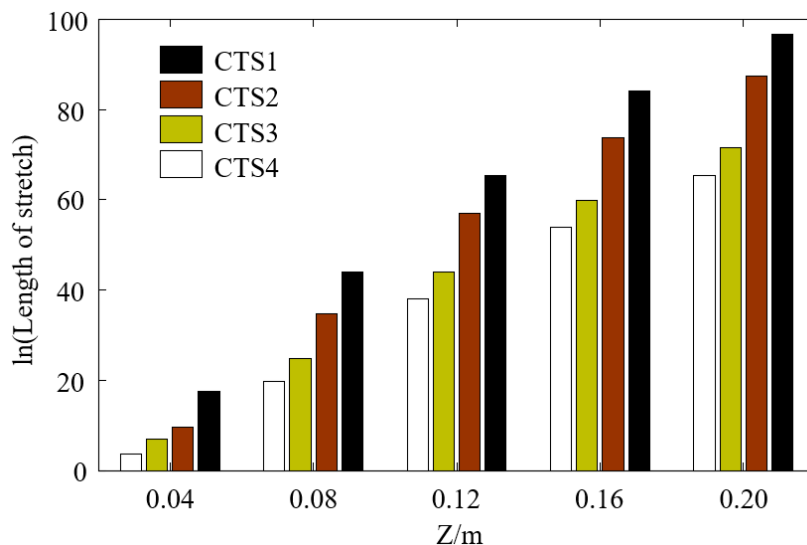


Figure 6: The Effect of Pitch on Average Stretching Length

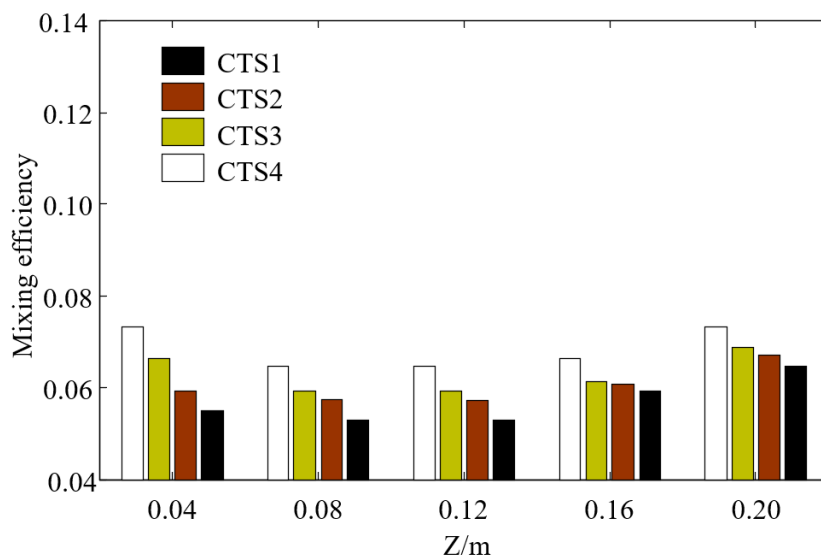


Figure 7: The Effect of Pitch on Average Time averaged Mixing Efficiency

## 6 Conclusion

As the core equipment in polymer material processing, the geometric parameters of screw extruder have a decisive impact on the shear rate and mixing effect of polymer melt. This article takes the fully meshed co rotating twin-screw extruder as the research object, constructs a three-dimensional isothermal flow field numerical model through POLYLOW software, and systematically analyzes the dynamic mechanism of key geometric parameters such as pitch on the shear rate, mixing index, tensile length, and mixing efficiency of polymer melt. The research results indicate that the change in pitch has a relatively small impact on the fluid motion mode, but significantly affects the dispersion and distribution mixing ability. As the pitch increases, although the maximum mixing index slightly increases, the decrease in the number of screw edges per unit length leads to a weakening of the overall dispersion ability of the screw; And small pitch can effectively improve the distribution mixing ability by enhancing the shear effect; In addition, increasing the pitch shortens the average stretching length, but the average time

averaged mixing efficiency shows an upward trend, indicating that a larger pitch is more conducive to improving mixing efficiency. The comparison between experimental data and numerical simulation results validates the applicability of laminar shear theory in the calculation of viscous heat generation in polymer melts, providing a theoretical basis for the optimization design of extruder screw geometry parameters.

Although this study has achieved preliminary results in the analysis of the correlation between screw geometric parameters and mixing effects, there are still the following limitations: firstly, numerical simulations are based on isothermal assumptions and do not consider the influence of temperature gradients on the viscoelasticity of the melt in actual processing; Secondly, experimental verification only focuses on specific screw configurations and operating conditions, lacking universal verification of different screw combinations and operating parameters (such as screw speed and back pressure); Finally, the evaluation of dispersion mixing ability still relies on empirical indicators, and a quantitative prediction model based on the critical stress of melt fracture has not been established. Future research will focus on the following directions: 1) constructing a thermal fluid solid coupling model to reveal the synergistic mechanism between temperature field and shear field; 2) Develop a multi parameter collaborative optimization platform, combined with machine learning algorithms to achieve intelligent design of screw configurations; 3) Introduce microstructural characterization techniques such as SEM and rheometer to establish a correlation model between macroscopic mixing indicators and product performance. Through the above research, it is expected to promote the paradigm shift of screw extruders from empirical design to theoretical driven, providing technical support for high-performance processing of polymer materials.

## About the Author

Yuntao Hu was born in China, in 2000. He obtained a bachelor's degree from Beijing University of Chemical Technology in China. He currently studying at the College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology. His main research direction is Polymer Material Processing Technology

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