RESEARCH ON NUMERICAL SIMULATION OF FORMING PROCESS FOR SINGLE SCREW EXTRUDER

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ABSTRACT*: Polymer materials have been widely used in various fields of national economy, such as medical treatment, transportation, agriculture, industry, etc. In engineering, most plastic products are processed by extrusion molding, and the single screw extruder is an important processing tool. This article takes the single screw extruder widely used in plastic production as the research object. Based on the Flow Simulation fluid dynamics analysis function in SolidWorks software, the simulation study of its molding process is carried out, and the temperature field, pressure field and velocity field of the fluid inside the extruder are obtained, which can provide theoretical basis and guidance for the design and processing technology of single-screw extrusion molding equipment.*

KEYWORDS*: Single screw extruder; Molding process; Numerical simulation; Fluid dynamics*

1 INTRODUCTION

China is a big country in the application of polymer materials[1], which is involved in all areas of life. Among the methods of processing materials, the extruder is the most widely used[2], and its extrusion molding processing technology can produce the required products with high efficiency and large output. Driven by demand, related technologies in China are also developing rapidly. Around 2010, plastic production was 58.38 million tons. In recent years, the output can reach about 80 million tons. However, compared with foreign high-precision equipment, Chinese extruders still have some shortcomings, and the phenomenon of dependence on imports still exists. Therefore, it is of great significance to produce an extruder that meets the needs of Chinese production, which will greatly reduce production costs.

The researchers systematically studied the screw extruder based on numerical simulation, and put forward a relatively complete mathematical model and many innovative ideas. For example, Liu Weiliang established a three-dimensional flow model of a single screw mixing unit for non-Newtonian isothermal viscous fluid[3]. Ma Dejun and Chen Jinnan established a three-dimensional non-Newtonian isothermal viscous fluid plasticization process model with or without threads in the head of an injection molding machine[4]. Dong Zhonghua, Jiang Bo and Guo Jian established a three-dimensional non-Newtonian non-isothermal viscous fluid flow and mixing model in a co-rotating twin-screw extruder[5]. Dong Zhonghua, Jiang Bo and Xu Shuhua established a three-dimensional non-Newtonian non-isothermal viscous fluid flow model in a co-rotating twin-screw extruder[6].

This article takes the single-screw extruder widely used in plastic production as the research object. Based on the Flow Simulation fluid dynamics analysis function in SolidWorks software, the simulation study of its molding process is carried out, and the temperature field, pressure field and velocity field of the fluid inside the extruder are obtained, which can provide theoretical basis and guidance for the design and processing technology of single-screw extrusion molding equipment.

2 STRUCTURE AND WORKING PRINCIPLE OF SINGLE SCREW EXTRUDER

2.1 Structure of single screw extruder

Transmission system, heating system and extrusion system are the three elements of single screw extruder[7], as shown in Figure 1. The task of the transmission system is to drive the screw to work, which is mainly composed of a motor, a belt drive, a reducer, etc, the extrusion system is composed of a screw, a barrel, etc, and the task of the heating system is to make the material reach the plasticizing temperature, which is mainly composed of electromagnetic heaters. The details are shown in Figure 2.

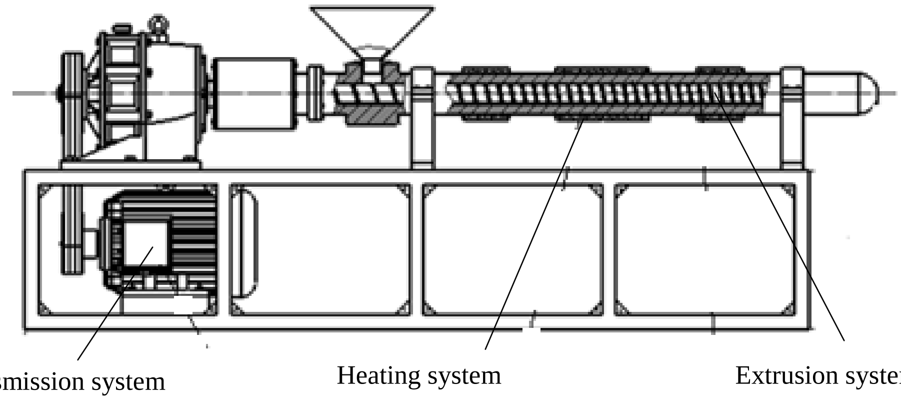
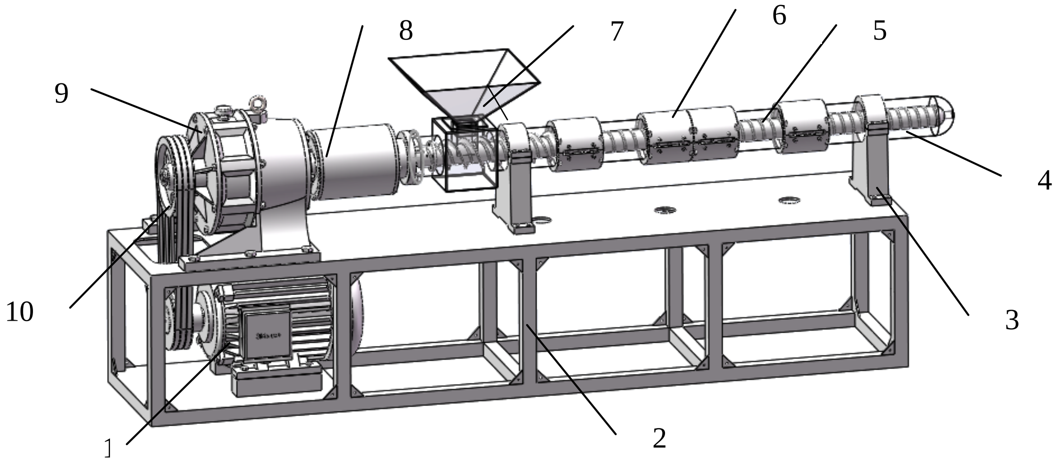


Fig.1 Plan view of single screw extruder



1.motor 2.frame 3.support frame 4.barrel 5.screw 6.electromagnetic heater 7.hopper 8.coupling 9.cycloid reducer 10.V belt drive

Fig.2 Three-dimensional view of single screw extruder

2.2 Working principle of single screw extruder

The power is transmitted from the motor to the cycloid reducer through the V-belt, and then the cycloid reducer drives the screw to rotate through the coupling. At this time, the material enters the barrel from the hopper. Firstly, enters the conveying section of the screw, secondly, enter the compression section, thirdly, enter the metering section, and finally squeeze out from the head evenly.

The single screw extruder is generally divided into three sections, each section accounting for about one third, they are the conveying section, compression section and metering section[8], as shown in Figure 3. In the first section of the conveying section, the material enters, preheats and compacts. It is transported to the second compression section through the movement of the screw, where the material will be heated and begin to plasticize, and then transported to the third metering section through the movement of the screw, the melted material will be melt more completely because of the further increase in pressure, and at this time the material will be quantitatively transported to the position of the machine head and the plastic will be extruded.

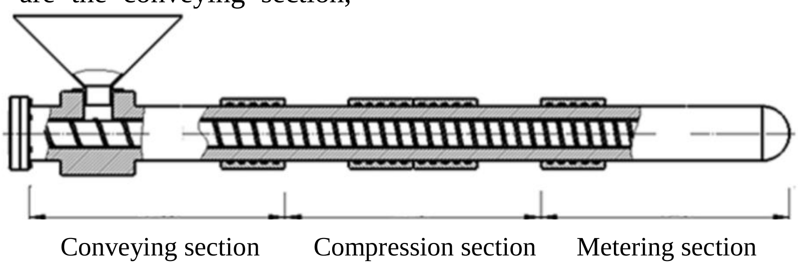


Fig.3 Segmentation of single screw extruder

3 SIMULATION OF SINGLE SCREW EXTRUDER MOLDING PROCESS

3.1 Preparation before solution

3.1.1 Determination of the unit

In order to facilitate calculation and observation, standard international units are used in this design. Length unit: mm, mass unit: g, time unit: s, pressure unit: MPa.

3.1.2 Analysis type

The analysis type selects internal and heat conduction in solids. The reference axis is the axis of the screw (Z axis), as shown in Figure 4.

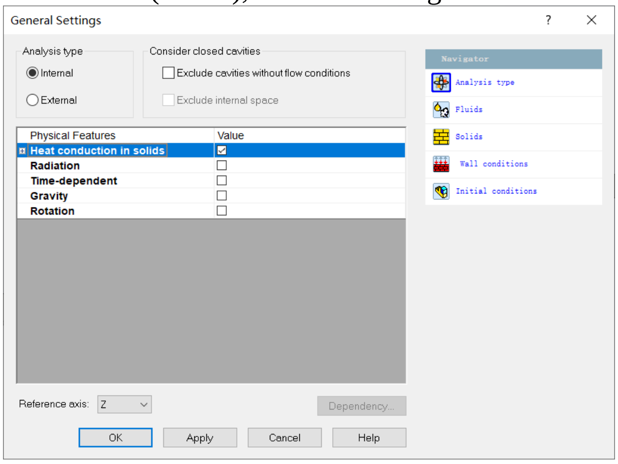


Fig.4 Analysis type

3.1.3 Setting of fluid and solid

The fluid used in this study is PVC (polyvinyl chloride), and the selected material of the barrel and its screw is 45 steel, the fluid and solid settings are shown in Figure 5.

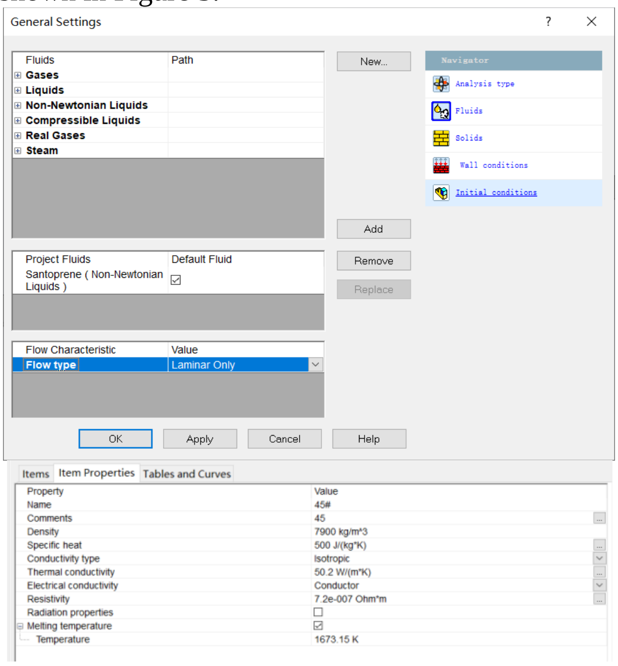


Fig.5 Settings of fluid and solid

3.2 Determination of boundary conditions

(1) Boundary conditions

SolidWorks Flow Simulation can set multiple boundary conditions, the inlet volume flow, inlet velocity, outlet volume flow, outlet velocity and various pressures inlet and outlet, wall conditions.

Since PVC (polyvinyl chloride) starts to change to viscous flow at 180°C, this simulation sets the barrel temperature to 180°C. Since the movement of the screw is a rotary movement, the rotation speed of the screw is selected as 50r/min in this simulation, so the rotation speed of 5rad/s is added to the inner wall of the screw. Add an inlet pressure of 2.0 MPa at the inlet, an atmospheric pressure of 0.1 MPa at the outlet, and an external temperature of 20°C. The specific boundary conditions can be seen in table 1.

Table 1 Setting of boundary conditions

Items	Thermal boundary conditions	Flow boundary conditions
Barrel	180°C	fixed
Screw		5rad/s
Inlet	180°C	2.0MPa
Outlet	20°C	0.1MPa

(2) Screw parameters

The main structural parameters of the screw are shown in table 2.

Table 2 Main structural parameters of screw

Screw speed	Screw length	Thread width	Groove depth	Screw diameter
5rad/s	2250mm	9mm	4.5mm	90mm

3.3 Grid division

SolidWorks Flow Simulation can automatically generate grids. In this study, the gap between the barrel and the screw is 0.45mm, the groove depth is 4.5mm, and the gap is too small, so the gap should be manually set, so the mesh refinement level at the fluid boundary is manually adjust to a higher level 4. The total number of grids reached 46,298, and the number of fluid grids reached 15,481. Part of the grid division diagram is shown in Figure 6, and the grid division data is shown in Figure 7.

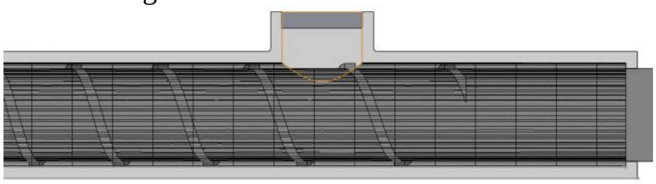


Fig.6 Part of the grid division diagram

Parameter	Value
Status	Mesh generation finished normally.
Total cells	1,601,160
Fluid cells	625,275
Solid cells	975,885
Fluid cells contacting solids	495,629
Cpu time	0:2:55
Calculation time left	
Run at	LAPTOP-MNB3J9E1

Warning	Comment
No warnings	

Fig.7 Grid division data

3.4 Model check

3.4.1 Interference check

Select the Check to perform interference inspection, the result is shown in Figure 8.

Check

Results
Status: SUCCESSFUL. Geometry is OK
Analysis type: Internal
Fluid volume: 2907710 mm^3
Solid volume: 4.285483e+007 mm^3

Fig.8 Interference check

3.4.2 Fluid check

Check the fluid area, everything is normal, the result is shown in Figure 9.

Fig.9 Fluid area

3.5 Wall setting

The screw is selected as the real wall, the rotation speed is 5rad/s, and the temperature is 20°C. The surface of the barrel is selected as the real wall surface, and the heating temperature is 180°C. The specific parameters are shown in Figure 10.

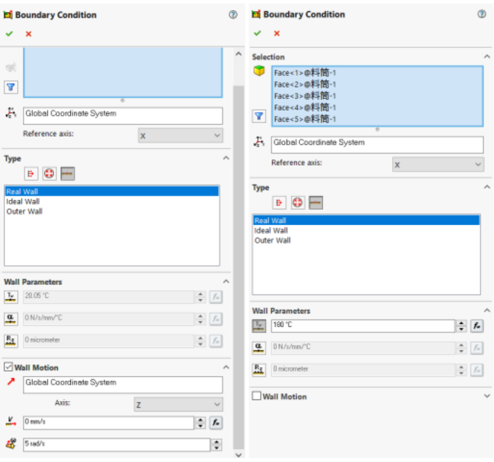


Fig.10 Wall setting

3.6 Solution results

3.6.1 Flow trace

Figure 11 is the diagram showing fluid traces inside the barrel.

Fig.11 Display of fluid traces inside the barrel

It can be clearly seen from Figure 11 that the fluid flow is relatively stable and uniform, and the fluid basically flows along the designed spiral groove, and the motion is a uniform rotary motion.

3.6.2 Temperature field

(1) Solid temperature distribution diagram of extruder

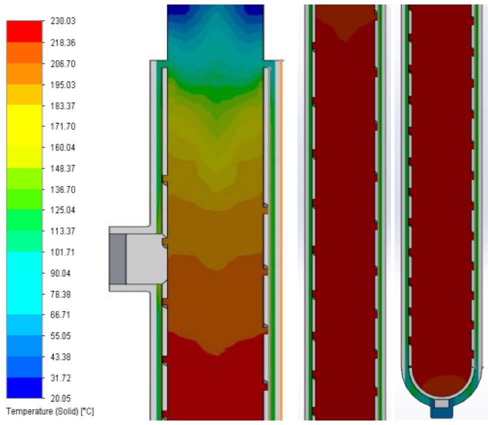


Fig.12 Solid temperature distribution diagram of extruder

The result can be obtained from Figure 12, when the fluid just enters the barrel, the solid temperature reaches 190°C due to the heating of the barrel. On the contrary, the temperature of the exposed part of the screw drops rapidly to 20°C. As the fluid flows from the conveying section into the compression section, the temperature gradually reaches 230°C, which is the result of the combined action of the rotary motion of the screw and the heating of the barrel.

(2) Fluid temperature distribution diagram

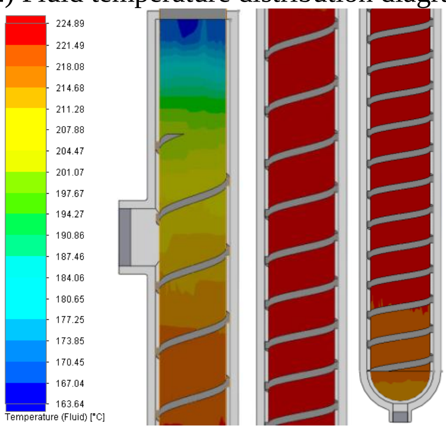


Fig.13 Fluid temperature distribution diagram

(3) XY line chart of fluid temperature

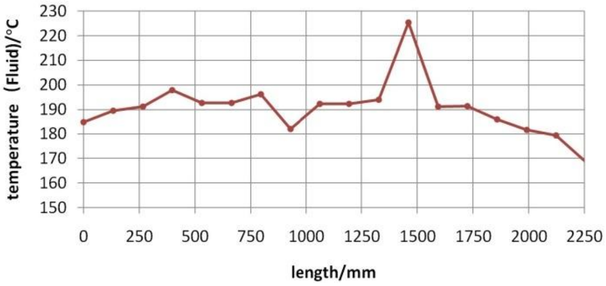


Fig.14 XY line chart of fluid temperature

It can be concluded from Figure 13 and Figure 14 that when the fluid just enters the barrel, the fluid temperature can reach 185°C due to the heating of the barrel. As the screw rotates and the barrel is heated, as the fluid flows from the conveying section into the compression section, the temperature gradually rises, reaching above 190°C, and the polyvinyl chloride has been heated to its melting point. Since the length of the compression section is also 750mm, the temperature gradually rises at 1250mm and reaches the peak of 225°C at 1500mm (just after the compression section), and then the fluid temperature gradually decreases to about 170°C due to the lower indoor temperature near the outlet.

3.6.3 Pressure field

(1) Surface pressure distribution diagram of screw

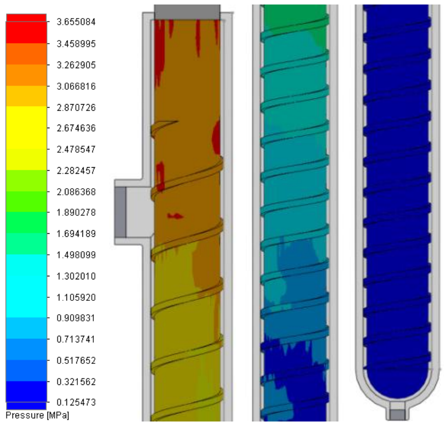


Fig.15 Surface pressure distribution diagram of screw

(2) XY line chart of static pressure

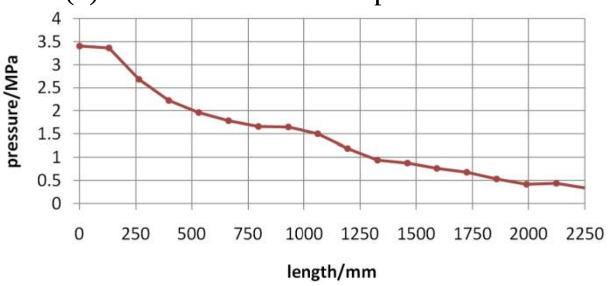


Fig.16 XY line chart of static pressure

From Figure 15 and Figure 16, it can be seen that the fluid can reach 3.4 MPa when it just enters. With the rotation of the screw, when the fluid enters the compression section from the conveying section, the pressure decreases to about 1.7 MPa. When the fluid enters the metering section from the compression section, it gradually decreases to 0.6 MPa, and finally closes to the atmospheric pressure of 0.3 MPa at the outlet.

3.6.4 Velocity field

(1) Fluid velocity distribution diagram

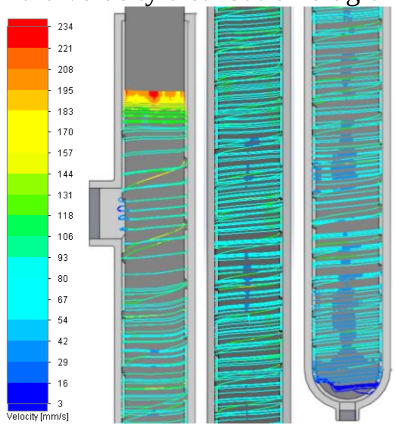


Fig.17 Fluid velocity distribution diagram

(2) XY line chart of velocity

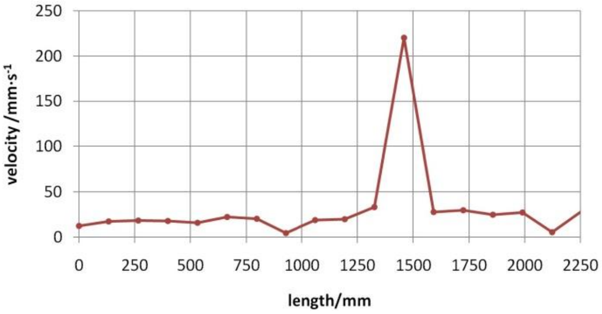


Fig.18 XY line chart of velocity

It can be seen from Figure 17 and Figure 18 that the fluid flow inside the barrel is more complicated and the speed is not stable. The velocity in the conveying section of inlet is low, and can reach the speed of about 20mm/s. Due to the rotation of the screw and the punching of the fluid, at the 1250mm position, when the fluid gradually flows from the compression section into the metering section, the speed gradually increases, reaching the peak of about 220mm/s at 1500mm. Then the speed drops to 30mm/s, and gradually stabilizes, and the fluid is output from the screw head steadily.

4 CONCLUSIONS

Taking the single screw extruder widely used in plastic production as the research object, the forming process of it was simulated and studied based on SolidWorks Flow Simulation, and the temperature field, pressure field and velocity field of the fluid inside the extruder were obtained. The relevant conclusions can provide theoretical basis and guidance for the design and processing technology of the single screw extruder.

5 ACKNOWLEDGEMENTS

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