# Development of medical PVC calendering single screw extrusion unit

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**Abstract:** This article introduces the research and development principles of the medical PVC calendering single-screw extrusion unit, lists its main performance indicators, and provides a detailed description and summary of its main components, the structure and characteristics of core parts, as well as design principles and guidelines.

**Key words:** medical PVC; calendering method; single screw extrusion unit; structure and characteristics; design principles and guidelines

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## 0 Preface

PVC is the third largest general-purpose plastic after PE and PP, primarily used in various industries such as construction materials, packaging, and medicine. Among these, it accounts for the largest proportion in the construction materials industry, approximately 60%, followed by the packaging industry, with the remaining being applied in several other niche industries. PVC can be divided into soft PVC and hard PVC, with the difference being the presence of softeners. Hard PVC accounts for approximately two-thirds of the market, while soft PVC accounts for one-third. Soft PVC is generally used for flooring, ceilings, and the surface layer of leather, as well as high-grade medical non-toxic PVC (free of toxins and meeting medical device standards), etc.

The development of modern medical technology has led to the widespread application of PVC in the medical field, and medical PVC has played a significant role in enhancing the level of medical technology. As China's healthcare system gradually improves, the demand for disposable PVC medical products has rapidly increased, posing higher requirements on their production equipment and processes. Due to the special requirements in the pharmaceutical field for hygiene and safety, surface smoothness, corrosion resistance, and other properties, the manufacturing level of equipment used in medical PVC production plays a pivotal role in the production process of its products. The level of this level largely determines the quality, efficiency, and new product development capabilities of the products.

Plastic calendering has always been one of the main categories in plastic molding processes due to its inherent advantages of high-speed, continuous production, as well as the wide application of its products and high thickness accuracy. In China's production of plastic films, leather, and sheets, calendering is widely used.

In order to align with the development of modern medical technology, domestic leading medical PVC production enterprises have joined forces with Dalian Rubber & Plastics Machinery Co., Ltd. (hereinafter referred to as "Dalian Rubber & Plastics") to absorb foreign advanced technologies, innovate plastic calendering production process methods and routes, and research and develop the "medical PVC calendering single screw extrusion unit". This unit fills the domestic gap in medical PVC calendering and is of great significance

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to Dalian Rubber & Plastics, marking its entry into a new field - the pharmaceutical industry. This article provides a detailed introduction to its basic composition, research and development principles, basic structure and characteristics, and core parameters.

## 1 Development principles of medical PVC calendering single screw extrusion unit

(1) The technical level has reached the domestic advanced level, suitable for the production of medical soft PVC through calendering.

(2) Adapt to the user's production process, with a production capacity of 300~450 kg/h;

(3) High degree of automation, suitable for the control of efficient and coordinated production across the entire line.

## 2 Main performance indicators and structural features

### 2.1 Main performance indicators

Basic process parameters:

Material: Soft PVC, granules, ~Φ5 mm

Material hardness: 80P

Plasticizer ~40 parts

Control time: ＜ 150℃

Crushed material: Irregular, ~20 mm×20 mm

Thickness: 0.1 mm~0.5 mm

Addition ratio: 0~30%

Basic performance indicators of the unit:

Nominal diameter of screw rod: Φ150 mm

Aspect ratio: 25

Production capacity: 300~450 (max) kg/h

### 2.2 Unit structure and characteristics

The medical PVC calendering single-screw extrusion unit primarily consists of a material conveying system, main motor, coupling, reduction gearbox and lubrication system, screw, barrel, cooling system, screen changer, die head, and electronic control system. To save space and facilitate operation, the medical PVC calendering single-screw extrusion unit adopts a "horizontal + V-shaped" layout. In addition to the stainless steel cladding of the transmission system, which meets the cleanliness requirements of the pharmaceutical industry, as shown in Figure 1. The screw, barrel, material conveying system, and electronic control system are the core components of the unit. The main structures and characteristics of the remaining components are as follows:

**Figure 1 Medical PVC calendering single screw extrusion unit**

The reduction gearbox adopts a cast box body and utilizes involute gears as the transmission pair. The gears undergo heat treatment and precision machining to achieve sufficient contact strength and load-bearing capacity, with a safety factor up to 1.5. The radial force of the screw is borne by thrust centripetal symmetrical spherical roller bearings, and all bearings are lubricated with forced thin oil lubrication.

The screen changer is mainly composed of a housing, a porous plate, seals, etc. It adopts a mechanical rapid screen change form. The main body is made of forged medium carbon steel, which undergoes normalizing and base note treatment. The surface in contact with the material is chrome plated to a certain thickness to enhance wear resistance, and the filtration accuracy is greater than 60μm. The transition distance between the screen changer and the die head should be designed as short as possible, while taking into account the influence of pressure fluctuations on extrusion. When applied in the pharmaceutical field, it is necessary to reduce material retention, avoid material yellowing and coking, and equip the front of the screen with melt pressure and temperature detection components to achieve online alarm, interlock upper limit detection and control, and protection functions.

The machine is mainly composed of a head body, a quick-opening structure, connecting pieces, etc. The outlet adopts a flat structure, allowing the molten material to further plasticize and extrude at low temperatures. The head body is made of forged medium carbon steel, which undergoes quenching and tempering after normalization. The surface in contact with the material is chrome-plated to a thickness of over 0.03mm, and

the slot opening is quenched to a hardness of over 35HRC, aiming to enhance wear resistance. The quick-opening structure utilizes mechanical locking buckles to achieve the function of quick opening and closing.

The cooling system consists of a heat exchanger, solenoid valve, and pipelines. A plate heat exchanger with high efficiency and large filtration area is used to achieve rapid heat exchange in the system. The flow rate is regulated by a control valve to maintain the required process temperature. All parts in contact with water are made of stainless steel to ensure the longevity of the system.

## 2.3 Main structures and characteristics, design principles and guidelines of core components of the unit

PVC is a non-crystalline polymer that exhibits three states at different temperatures: glassy, elastic, and viscous flow. These states occur over a wide temperature range, and its melting process completes within a relatively broad temperature spectrum. Consequently, the structural design and key parameter specifications of the core components of the machine unit become particularly crucial. The core components of the medical PVC calendering single-screw extrusion unit are as follows:

### 2.3.1 Screw

(1) Design principles and guidelines for screws

Due to the unique temperature-sensitive characteristics of PVC, the determination of core screw parameters is based on the collection and analysis of core data from different PVC machine models both domestically and internationally (see Table 1).

**Table 1 Screw data table for PVC machines at home and abroad**

| Project | Φ90×25 | Φ120×18 | Φ150×20 | Φ180×9 | Φ200×20 |
|---|---|---|---|---|---|
| Design capacity (kg/h) | 50~100 | 50~100 | 150~300 | 400~800 | 200~400 |
| Main motor power (kW) | 55 | 40 | 75 | 75 | 110 |
| Screw output speed (rpm) | 26~78 | 10~30 | 7~42 | 6~60 | 5~15 |
| Cooling hole size (mm) | φ25 | φ25 | φ35 | φ45 | φ45 |
| Screw lead (mm) | 90 | 120 | 150 | 160 | 200 |
| Rib width (mm) | 8 | 12 | 12 | 12 | 16 |
| Screw compression ratio | 2.154 | 3.37 | 3.83 | 2.25 | 2.57 |

Based on the characteristics of medical PVC materials and following the design principles outlined above, the core parameters of the screw for the medical PVC calendering single-screw extrusion unit are determined as follows:

Screw type: Regular type;

Nominal diameter of screw rod: Φ150 mm;

Aspect ratio: 25;

Screw speed: 6~60 r/min;

Screw lead: 150 mm.

After determining the screw specification, based on the design experience of the length of each segment of non-crystalline polymer, the detailed design principles for screw parameters are as follows:

$L_1$ is generally taken as 10~25% of L;

$L_2$ is generally taken as 50~60% of L;

$L_3$ is generally taken as 20~25% of L;

$H_3$ is generally taken as (0.025~0.06)D;

$e$ is generally taken as (0.08~0.12)D;

$l$ is generally taken as(0.08~0.1)D;

$\delta$ is generally taken as 0.2~0.4 mm.

The core parameters of the screw have been determined, and various performance indicators have been calculated. The specific performance parameters are shown in Table 2 below:

**Table 2 List of performance index parameters for medical PVC screws**

| Project | Φ150×25 |
|---|---|
| Depth-to-extension ratio-α (reflecting the degree of strain of fluid particles) | 0.89 |
| Shear rate γ | 9.9 |
| Mixing degree M (reflected in the degree of dispersion in the spiral groove) | 1 351 |
| Specific energy consumption e (J.cm-3) analyzes the degree of plasticization of the material in the screw channel, requiring force or work | 10.68 |
| Material temperature increase ΔT/℃ | 4.2 |
| Dwell time t/sec (analyzing the aging degree of the main components of the material) | 92.4 |
| Shear stress τ (g·cm^-3) | 57.5 |

(2) Screw structure and characteristics

It adopts an isometric gradual transition in a common three-segment form; the number of heads is mostly single, and the screw head adopts a 90~120° cone structure to avoid fluctuations due to production and pressure; the screw is internally drilled and cooled with water to reduce the impact of temperature sensitivity; the screw surface undergoes nitriding and mirror polishing treatment to control the residence time of materials and meet the cleanliness requirements in the pharmaceutical field.

### 2.3.2 Barrel

(1) Design principles and guidelines for the barrel:

Considering the compatibility with the screw, similarly, the determination of core parameters is based on the collection and analysis of core data from different PVC machine models both domestically and internationally (see Table 3).

**Table 3 Data table of barrel for PVC machines at home and abroad**

| Project | Φ90×25 | Φ120×18 | Φ150×20 | Φ180×9 | Φ200×20 |
|---|---|---|---|---|---|
| Barrel heating method | Electricity | Electricity | Electricity | Electricity | Electricity |
| Barrel cooling method | Water | Wind | Water | Water | Water |
| Cooling groove for barrel /mm | Φ12×13 | Nothing | Φ12×13 | Φ16×17 | Φ16×17 |
| Does the feeding section of the barrel have grooves | YES | Nothing | YES | Nothing | YES |
| Groove form of the feeding section of the barrel | Rectangle | Nothing | Triangle | Nothing | Triangle |

Based on the characteristics of medical PVC materials and following the design principles outlined above, the core parameters of the barrel for the medical PVC calendering single-screw extrusion unit are determined as follows:

Heating method of barrel: Electric;

Cooling method of barrel: Water;

Feeding section of barrel: With grooves, triangular in shape;

The nominal diameter of the barrel is Φ150 mm.

(2) Structure and characteristics of the barrel

Electric heating and water cooling are employed; the inner hole of the feeding section features triangular grooves to enhance conveying capacity; grooves are cut along the entire length of the outer wall, and the lead in the metering section is appropriately reduced to increase cooling capacity; the inner surface of the barrel undergoes nitriding and mirror polishing treatments to improve wear resistance, facilitate material flow, and meet the cleanliness requirements in the pharmaceutical industry.

### 2.3.3 Material conveying system

(1) Design principles and guidelines for material conveying system

The material conveying system needs to accommodate multiple material states and various proportions of additions, while considering factors such as cost, operation, and space. Its design adopts a main spiral conveyor structure. The material conveying system mainly consists of a main feeder, an auxiliary feeder, a conveyor, and a hopper (see Figure 2). The main feeder adopts a structure with large pitch and deep groove, with a design capacity of 450 kg/h, to complete the conveyance of granular materials. The auxiliary feeder adopts a structure with small pitch and shallow groove, with a design capacity of 150 kg/h, and is equipped with an anti-bridging mechanism to complete the conveyance of irregular and flaky broken materials.

(2) Structure and characteristics of material conveying system

All surfaces of the material conveying system that come into contact with the material are polished to a Ra0.8 or higher finish, and are made of stainless steel 316L, meeting the requirements of the pharmaceutical industry. The material conveying system is arranged in a staggered and stacked manner, with multi-stage reduction to achieve a matched transmission ratio. It features a small footprint and saves overall line length.

**Figure 2 Material conveying system**

### 2.3.4 Electronic control system

Design principles and guidelines for the electronic control system: Adhering to the control principles of high automation, adapting to efficient and coordinated production across the entire line, the system primarily comprises three parts: drive, temperature control, and feeding.

(1) drive

Considering cost-effectiveness, we have adopted

PROFINET communication for the entire line drive, and the motor drive utilizes the NE300 frequency converter from Nidec CT. We have added a .GSD file to the program to facilitate drive network configuration with the main system.

（2）temperature control

Utilizing a temperature control meter and solid-state relay in conjunction, the system achieves heating and cooling outputs.

（3）blanking

Multiple motors can be individually manually adjusted in speed through knobs and program logic, and can also be switched to a linkage mode based on manual mode to achieve synchronous speed increase and decrease.

## 3 Conclusion

Currently, DXS has developed the "Medical PVC Calendering Single Screw Extrusion Unit" and has delivered it to users for use. Through formal production operation, it meets process requirements, achieves stable conveying and uniform plasticization, and its capacity and appearance are suitable for producing medical soft PVC calendering production lines. Its performance meets expected goals. It can be adapted to downstream calendering production lines, meeting the requirements of calendered products with a maximum width of 800 mm, thickness ranging from 0.1 to 0.5 mm, and thickness accuracy of ±0.015 mm. It coordinates efficiently and continuously with upstream and downstream equipment. Overall, the unit is evaluated as reasonable and advanced, reaching the domestic advanced level. Users have provided feedback on its high degree of automation and good economy. Dalian Rubber & Plastics has formed independent intellectual property rights for this unit, which has opened up new product areas in the pharmaceutical industry for the company and become a new economic growth point.