

Paddle design based on continuous low-temperature vacuum drying system in fishmeal production

Shu Wu, Yaping Gong^{a, *}, Shuaijun Wang *, Yanxin Zhang, Quan Shi,
Di Zhang, Hui Chen

ZheJiang Ocean University, Zhejiang, China

^a 981545300@qq.com

Abstract. With the rapid development of aquaculture, fishmeal is gradually processed into high-quality aquafeed, and there is a great demand for fishmeal in China. In order to solve the problems in the traditional processing process, the process research, focusing on the fishmeal processing process of the most critical link - drying paddle research. This paper mainly focuses on the continuous low-temperature vacuum drying equipment research, on the basis of the existing process to improve the design of the paddle structure. Compared with the current process, the fishmeal produced by continuous low-temperature vacuum dryer, under the same raw materials and the same time conditions, the transport capacity of the dryer per unit of time and the drying area of the paddle have been effectively improved.

Keywords: fishmeal; vacuum dryer; paddle structure.

1. Introduction

Most of the fishmeal available on the market comes from marine organisms such as fish and shrimps, which have a relatively low economic value, and is industrially dried and processed to produce high-protein organic feeds favourable to the feeding industry. Fishmeal has a high protein content and contains a variety of nutrients, i.e. 18 amino acids, minerals (calcium, phosphorus, magnesium), vitamin B, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). [1] EPA and Docosahexenoic Acid (DHA).

In recent years, the consumption and demand of fishmeal in the feed industry has been rising year by year, and the domestic market demand for fishmeal is about 2 million tonnes, but the amount of self-produced fishmeal in China is only 14% of the global production. According to statistics, Peru exported about 1,487,200 tonnes of fishmeal in 2009, China imported 730,000 tonnes of Peruvian fishmeal, 340,000 tonnes of Chilean fishmeal, and 238,000 tonnes of fishmeal from other countries. [2, 3] The total amount of fishmeal from other countries is 238,000 tonnes. Therefore, high quality fishmeal dryer has a greater demand in our industrial market. So the use of continuous low-temperature vacuum drying system in fishmeal is also becoming more and more popular in the industry.

In the whole industrial field, people are concerned about how to improve the drying efficiency, for example: French scholars FERRASSE and so on.[4] Further research on paddle dryer, through the experiment mainly studied the stirring speed, temperature and other effects on drying efficiency. A. Iguaz[5] Designed a rotary dryer hot air circulation system, and its simulation analysis, the results show that the hot air circulation system can save 28% ~ 63% of energy. Germany, Switzerland, Japan and other countries have been developing vacuum belt drying devices for more than 20 years, and have developed some large and medium-sized and experimental machines[6]. All the work described in the previous section has focused on the modification of the whole system, while less research has been done on the stirring paddles. In this paper, based on the method of numerical simulation, the transport of fishmeal in the double-shaft hollow paddle and by improving the diameter length of the paddle, after the data comparison, the results show that, under the same conditions, the capacity of the drying system per unit of time has been improved after the paddle improvement.

2. Introduction to continuous low temperature vacuum drying

2.1 Production process

The current process of fishmeal: it is produced by cooking, pressing, (degreasing), drying, crushing and other processes, as shown in Figure 1. Since the fishmeal production industry, its production process has gone through from the direct fire drying method, dry drying method, wet drying method, to the current vacuum low-temperature drying four method of four processes. In addition, there are low-temperature vacuum drying method, freeze-drying method and other new processes of continuous research and exploration efforts, have also carried out the corresponding research, design and development. Through these research, design and development, so that the new process in the cooking effect and efficiency, drying effect, amino acid content and protein absorption rate, etc., have obvious advantages over the current process of production of similar products. [7] The new process has obvious advantages over the similar products produced by the current process.

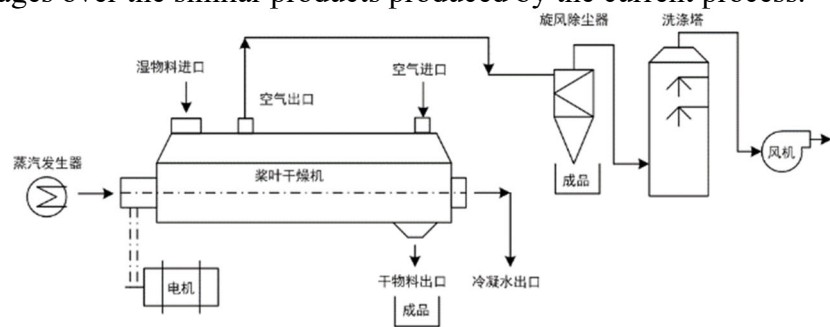


Figure 1. Continuous low temperature vacuum drying flow chart

2.2 Advantages of Continuous Low Temperature Vacuum Dryer

The essence of the continuous low-temperature vacuum drying process is the transfer of moisture from the surface of the material to the gas phase, because the surface moisture continues to evaporate, so that the internal moisture of the material can continue to diffuse to the surface. Under low-temperature vacuum drying conditions, there is almost no condensed gas in the gas phase, such as air, whose composition is dominated by low-pressure water vapour, which is pumped away by a vacuum pump (see Table 1). The advantages over air drying are [8, 9]:

It is suitable for a wide range of materials, and can be applied to heat-sensitive materials as well as materials that require high-temperature treatment. With both continuous and intermittent performance, this system is suitable for a wide range of applications.

Stable performance: Because of the expansion of the paddles, the material components come into contact with the heat-conducting surfaces to achieve heat transfer. In the axial zone, the material temperature, humidity and mixing temperature gradients are very small, thus ensuring the operational stability of the process.

Low drying temperature: the drying has the low-temperature characteristic, which can reduce or avoid the loss of heat-sensitive components in the material, and is conducive to retaining the active components in the material and improving the quality of the dried products.

Fast drying speed: under the same heat conduction temperature, heat conduction structure and fabric condition, because the low pressure condition is the boiling point of water becomes low in the apparatus. Therefore, under the condition of the same drying basis, compared with normal pressure drying, the time and effect of vacuum drying can play a qualitative improvement.

Table 1. Material Drying Data for Paddle Dryer

Material Name	Vapour pressure /MPa	RPM /(r/min)	Feed moisture content /%	Water content of discharged material /%	Drying strength /[kg/(m ² - h)]
fishmeal			40	1	8

3. Hollow Blade Structural Performance Analysis

3.1 Basic structure of the paddle

Stirring paddle is the key part of this dryer, and its special structure makes this dryer different from ordinary stirring heat transfer dryer. The function of the paddle is heat transfer, its general form: radial symmetric wedge, axial fan, for the hollow sheet structure, shown in Figure 3, including the outer arc panel, wedge-shaped big end end plate, fan-shaped side plate and welded to the end of the plate head of the stirring rake plate, is an all-welded structure, welded to the spindle as a whole, the appearance of the weld grinding and polishing, the interior can withstand the pressure of the steam pressure or the hot medium pumping pressure for the pressurised container. In the working process, the two symmetrically arranged paddles rotate in opposite directions, the surrounding material through the Figure 3 paddle structure sketch shear, extrusion, stirring, dispersion and heating effect, so that the material along the radial non-stop changes in the position of the layer of material back to the mixing of the strong, very high heat and mass transfer efficiency. [10] The efficiency of heat and mass transfer is very high.

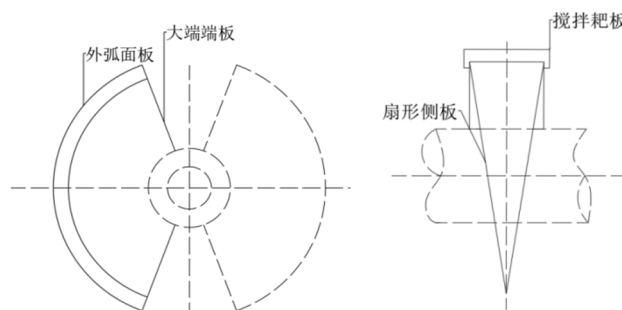


Figure 2. Sketch of paddle structure

3.2 Geometry of the paddle

The geometry of the paddle and the heating area, stirring intensity, stirring power, heat transfer effect is directly related to the paddle cone angle most of the design into a symmetrical form, on both sides of the material extrusion, cutting effect is equivalent, but there are also asymmetric type, on the material production Figure 4 paddle spacing and the relevant angle of the unidirectional thrust effect. Vacancy angle between the two paddles β is generally 40° , the value of the change on the drying performance.

The main heating area of the paddle dryer is the paddle, so the proper arrangement of the paddle on the main shaft is very important, and should try to improve the assembly precision and increase the number of paddles. Usually the paddle outer diameter and wedge angle is determined, the paddle width of the big end that is determined, the number of paddles can be arranged only with the paddle gap. Need to take into account the paddle and rake plate processing accuracy and paddle positioning and rotary accuracy, as well as the two rotary axis of different axial movement, usually not less than 5mm. [11] Usually not less than 5mm.

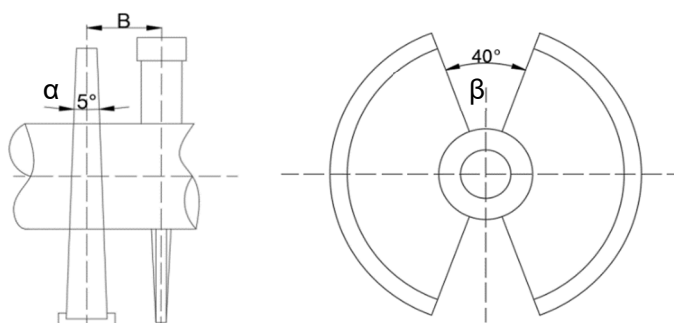


Fig. 3 Paddle pitch and associated angle

3.3 Distribution of paddles on the main shaft

Paddle shaft from both sides of the head, shaft tube, hollow blade, stirring paddle, spiral blade group welding and become (see Figure 5), a single hollow paddle shaft welded 64 groups of paddles[12] The shaft paddles are hollow fan ring structure and helical direction of the opposite, hollow paddles and the heating shaft between the angle of 82-90 °, the propeller blade staggered in turn set to the hollow shaft into the heat carrier, hollow shaft is densely arranged wedge-type hollow paddles, the hot medium through the hollow shaft flow through the paddles. The heat transfer area per effective volume is very large, and the hot medium (saturated steam) flows through the rotary joint, the jacket of the shell and the hollow mixing shaft, which has different internal structures according to the type of hot medium to ensure that the heat is transferred to the fishmeal through the rotation of the mixing blades.

When the heating shaft rotates, the inclined set of hollow paddles give the fish material a thrust in the forward direction, which can effectively improve the pushing speed of the fish material in the dryer and shorten the production running time. According to the moisture content of the material to control the heating steam pressure to control the temperature between 70 °C and 100 °C. Together with the end suction device, low temperature, rapid and efficient drying and transport of materials can be achieved. Because there are a large number of blades in the jacket and hollow shaft for heating, the heat transfer area of each piece is large, and there is forced stirring and violent agitation, so the equipment occupies very little space, and the drying efficiency is also very high. When the agitator blades form a certain inclined angle with the shaft centre, it can accelerate the advancement of the material.

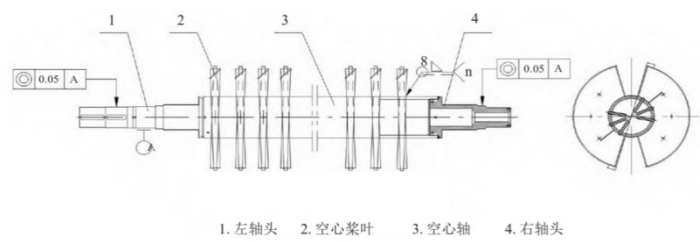


Fig. 4 Schematic structure of hollow shaft paddle shaft

4. Calculation of conveying capacity of hollow paddle mixing equipment

In the selection and structural design of the hollow paddle mixing equipment, the heat exchanger area is first calculated through the heat balance method, and the heat exchanger is selected. However, in the process of actual use, it often encounters the situation that the transmission capacity of the selected device is not enough. Its transport capacity can be estimated by using the formula of the spiral transporter.

$$Q = 47D^2 \times N \times S \times \gamma \times \psi \times C \quad (1)$$

Where Q --- conveyor conveying capacity, t/h;
D - outer diameter of the spiral leaf, m;
N - rotational speed of the spiral shaft, r/min;
S - Pitch of the spiral blade, m;
 γ - pile density of the material, t/m³;
 ψ - the filling factor of the material in the equipment;
C - Inclination factor for equipment installation.

Since the conveying capacity of the hollow paddle type mixing equipment is for heat transfer, its screw structure is not exactly the same as that of the screw conveyor, and the conveying capacity

should be corrected. According to the hollow paddle arrangement on the hollow shaft structure (see Figure 2), combined with our experience, the correction factor is

$$K = 1.17 \times D \times \sin(90^\circ - \alpha) / H \quad (2)$$

Where D - blade diameter, m; α - blade body relative to the axis of the axial tube acute angle, ($^\circ$);
 H - distance between two adjacent blades, m.

Then the corrected conveying capacity of the hollow paddle equipment is:

$$Q1 = (n) K \times Q \quad (3)$$

Where $Q1$ - corrected conveying capacity, t / h; n - the number of spiral shaft.

$$\text{Then } Q1 = (n) K \times 47D^2 \times N \times S \times \gamma \times \psi \times C \quad (4)$$

Factors affecting conveyance capacity are:

Blade diameter D ; 2) axial tube speed N ; 3) pitch of the blade S (about $2D \times \sin(90^\circ - \alpha) \times \sin 70^\circ$);
4) material filling coefficient ψ ; 5) installation slope of the equipment C ; 6) blade body relative to the axial tube axis of the acute pinch angle α ; 7) the distance between two adjacent blades H .

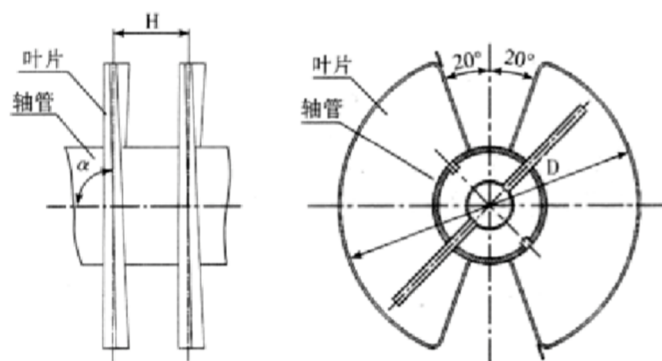


Fig. 5 Arrangement of hollow blade on hollow shaft

Table 2. Known product design specifications

Material Name:	fishmeal
Material withstand temperature:	70-100°C
treatment capacity	$W = 200$ tonnes/day; (based on a 24-hour day)
Content before drying:	$W_{\text{initial}} = 80$ per cent;
Rate of content after drying:	$W_{\text{end}} \approx 30$ per cent;
Drying medium:	Conduction heating;
Equipment Material:	Equipment materials through the Division of stainless steel production, material sus304;
Control systems:	The control cabinet is centrally controlled;
Material temperature:	$\theta_1 = 15^\circ\text{C}$ (based on average annual temperature)
Set the product temperature:	$\theta_2 = 40\text{-}50^\circ\text{C}$ (typically product temperature is $10\text{-}15^\circ\text{C}$ lower than exhaust air temperature)
Set up the product adiabatic specific heat:	$C_s = 0.4 \text{ Kcal/kg} \cdot ^\circ\text{C}$

4.1 Calculation of transport volume before correction

Assuming that a factory with a hollow paddle equipment to cool fishmeal, process requirements are as follows: 200 tonnes / day; (24 hours a day in accordance with the design), the initial temperature of 15°C , the product temperature of 45°C , the medium of soft water, the medium temperature at room temperature. Selected equipment parameters: heat transfer area A 200 m^2 , effective volume 15

m³, motor power 160 k W, shaft speed N12 r/min, blade diameter D 0.8 m, blade pitch H 0.2 m, blade acute angle of 88 °, equipment installation slope 2 ° (check the inclination coefficient C = 1.1).

After the equipment was put into operation, it was found that its delivery capacity was not up to the requirements.

Applying equation (4) to calculate where:

$$K = 1.17 \times D \times \sin(90^\circ - \alpha) / H$$

$$= 1.17 \times 0.8 \times \sin(90^\circ - 88^\circ) / 0.2 = 0.163$$

$$S = 2D \times \sin(90^\circ - \alpha) \times \sin 70^\circ$$

$$= 2 \times 0.8 \times \sin(90^\circ - 88^\circ) \times \sin 70^\circ = 0.0526 \text{ m}$$

Fishmeal $\gamma = 0.61 \text{ t/m}^3$; the filling coefficient ψ of the material in the equipment is taken as 1.4, then the conveying capacity is:

$$Q_1 = 2 \times 0.163 \times 47 \times 0.82 \times 12 \times 0.0526 \times 0.61 \times 1.4 \times 1.1 = 4.76 \text{ t/h}$$

From the calculation, it can be seen that the conveying capacity of the equipment is much smaller than the requirements of 8.3t / h, and need to be modified to amend.

After the modification and correction, calculate its conveying capacity without changing the energy consumption (blade shaft speed is unchanged) and the blade pitch is unchanged (has been welded), first of all, the equipment body part of the installation of the slope increased to 3 ° ~ 5 °, and then in the outer circle of the blade to increase the guide rib plate in order to increase the guide of the blade, see Figure 6.

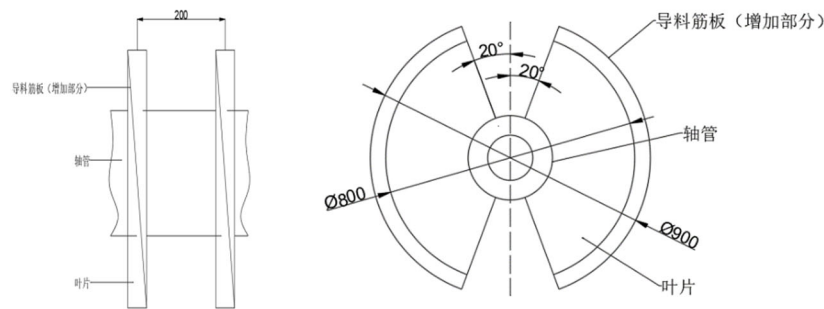


Fig. 6 Structure of hollow blade with added guide rib plate on the outer circle of the blade

After adjustment, the equipment part of the structural parameters are: blade diameter D 0.9 m, blade pitch H 0.2 m, blade (equivalent) acute angle 87.5 °, equipment installation inclination of 2.5 ° (check the inclination coefficient C = 1.2).

Calculate the equipment conveying capacity [substituting into equation (4)] as:

$$Q_1 = 2 \times 0.276 \times 47 \times 0.92 \times 12 \times 0.059 \times 0.61 \times 1.4 \times 1.2$$

$$= 15.94 \text{ t/h}$$

$$K = 1.17 \times D \times \sin(90^\circ - \alpha) / H$$

$$= 1.17 \times 0.9 \times \sin(90^\circ - 87.5^\circ) / 0.2 = 0.23$$

$$S = 2D \times \sin(90^\circ - \alpha) \times \sin 70^\circ$$

$$= 2 \times 0.9 \times \sin(90^\circ - 87.5^\circ) \times \sin 70^\circ = 0.074$$

After the modification, the equipment conveying capacity $Q_1 = 15.94 \text{ t/h}$ is greater than 8.33 t / h, the conveying capacity to meet the requirements. Although the conveying capacity to meet the requirements, but the hollow paddle cooler also need to meet the cooling performance requirements, so the heat exchange effect must be accounted for.

Take the integrated heat transfer coefficient of 125.8W / (m² - °C), accounting for the product temperature can be cooled to less than 100 °C. Calibration results, conveying capacity of 19.9 t / h, the material can be cooled to 97.63 °C, while the actual conveying capacity is less than 19.9 t / h, so the discharge temperature should be lower than the calculated value.

4.2 Paddle drying area

In paddle dryer, the heat transfer area A_2 of the body is about 30 per cent of the total heat transfer area, i.e. $A_2 = 200 \text{ (m}^2\text{)}$. On this basis, the proposed body size of the dryer is as follows:

Paddle outer diameter: $D = 900 \text{ (mm)}$;

Box length: $L_0 = 8600 \text{ (mm)}$;

Hollow shaft specification: $\Phi 426 \times 25 \text{ (mm)}$

Spindle centre distance: $S = 900 \text{ (mm)}$;

Mainframe upper cover size: the part is not subject to force and does not contact with the material, only to ensure the sealing of the drying process and enough operating space, mainly on the interface orientation and size design.

The diameter of the paddle will affect the distribution of the paddle and the size of the paddle, and ultimately affect the heat transfer area of the paddle, affecting the drying efficiency. In the calculation, assuming that the shape of the paddle is symmetrical about the shaft cross-section, the angle of the paddle package is 160° , the distance between the two ends of the paddle and the end plate is 20 mm , and the width of the auxiliary blade is 10 mm larger than that of the paddle, then the paddle drying area of the shaft of the paddle of the single blade is calculated by the formula:

$$S = n [\alpha (R_1^2 - r_1^2) + bp] \quad (5)$$

Where: R_1 - paddle spread outer radius (mm);

r_1 - inner radius of paddle spread (mm);

b - Radial length of paddle (mm), $b = (D-d)/2$;

α - The fan angle (radian) at which the paddle unfolds;

p - width of paddle end (mm), $p = (L_0 - 40)/n - 10$;

n - number of paddles.

Fan angle of paddle deployment α

$$\alpha = \frac{8(L_1 - l_1)}{9(D - d)} \quad (6)$$

Outer helix expansion dimension L_1

$$L_1 = \sqrt{(\pi D)^2 + \left(\frac{9}{8}p\right)^2} \quad (7)$$

Inner Helix Expansion Dimensions l_1

$$l_1 = \sqrt{(\pi d)^2 + \left(\frac{9}{8}p\right)^2} \quad (8)$$

Outer radius of paddle spread R_1

$$R_1 = \frac{4L_1}{9\alpha} \quad (9)$$

The inner radius of the paddle spread r_1

$$r_1 = R_1 - b \quad (10)$$

From equation (3-1) to equation (3-6), it can be seen that the heat transfer area S is an equation about the number n of paddles. In order to ensure reliable heat transfer, take the corresponding number of paddles n rounded to $n = 64$, the total number of paddles is 128 , the angle of the paddle for 2° .

On the basis of determining the number of paddles of a single paddle shaft as 64 , it can be obtained:

Paddle end width $p = (L_0 - 40)/n - 10 = 160 \text{ mm}$;

Find: $D=800\text{mm}$ when $p=159\text{mm}$, $L1=2518\text{mm}$, $l1=1361\text{mm}$, $d=426\text{mm}$, $R1=407$, $b=235$, $r1=172$, $S=27.5\text{m}^3$,

At $D=900$, $L1=2832\text{mm}$, $l1=1350\text{mm}$, $d=426\text{mm}$, $R1=420$, $b=237$, $r1=183$, $S=29.7\text{m}^3$

It can be obtained that after the increase of paddle diameter, the transport capacity of the hollow paddle mixer per unit time increases from 4.76t/h to 15.94t/h , and the drying area increases from 27.5m^3 to 29.7m^3 .

5. reach a verdict

It can be obtained that after the increase of paddle diameter, the transport capacity of hollow paddle mixer in unit time grows from 4.76t/h to 15.94t/h , and the drying area grows from 27.5m^3 to 29.7m^3 . According to the manufacturer's data, comparing with the current process, the fishmeal produced by continuous low-temperature vacuum dryer, under the same raw material conditions, the drying system in unit time after the improvement of paddle Under the condition of the same raw material, the processing capacity of the drying system per unit time after the improvement of the paddle has been improved. The content of amino acid is increased by $0.1\text{-}0.2\%$, and the content of protein is not changed much, but the digestibility and bio-availability of protein can be increased by 2% , which can make the nutritional value of fishmeal products and the quality of the products be improved. It can produce good economic effect and is an important part of aquaculture industry.

Acknowledgment

Provincial first-class courses, Turbine Automation. 11184083123YP.

References

- [1] WANG Yongding, TIAN Chenxi, DONG Yalong. Research on high quality fishmeal processing device. Fishery Modernisation [J]. 2017, 44(04): 68-72.
- [2] Tian S. Fishmeal processing and its effect on quality. Food Safety Guide [J]. 2015, 36): 143.
- [3] WU Daiwu, TANG Feng, HU Bin. Effects of different raw materials and drying processes on the quality of fishmeal. Feed Industry [J]. 2020, 41(04): 29-34.
- [4] Applet-2023-08-13-Heat, momentum, and mass transfer measurements in indirect agitated sludge dryer. [J].
- [5] A. Iguaz. Influence of air recycling on the performance of a continuous rotary dryer for vegetable wholesale by-products of a continuous rotary dryer for vegetable wholesale by-products. [J].
- [6] WANG Juan, LI Yuanzhi, YANG Gongming. Processing of banana powder by continuous belt vacuum drying. Food Science [J]. 2006, 09): 163-7.
- [7] Zheng Yinping. Research on efficient continuous vacuum low temperature type fishmeal drying equipment [D]; Zhejiang Ocean University, 2015.
- [8] Wang Juan, Chen Renren, Yang Gongming. Introduction of vacuum belt continuous drying equipment with high efficiency and energy saving. Journal of Agricultural Engineering [J]. 2007, 03): 117-20.
- [9] Li Fuhu. Experiment on the application of vacuum paddle dryer in high viscosity materials. Chemical Design Newsletter [J]. 2017, 43(10): 116-7+35.
- [10] YU Caiyuan, WANG Baohe, WANG Xizhong. Design Manual of Drying Equipment. [J]. Chemical Industry Press, 2005.2
- [11] Zhang JJ, Yang DC. Disc dryer and new conduction drying technology. [J]. Chemical Industry Press, 2015.3
- [12] Xu Koon, Yu Guofeng. Optimisation of manufacturing process of W-shaped paddle blade sludge dryer %J China Petroleum and Chemical Standard and Quality [J]. 2022, 42(20): 187-9.