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Structural design and experimental research on vacuum drying box for poultry feathers

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Abstract: *The extrusion technology of waste poultry feathers is a common feather deep processing technology. Making waste feathers into feed feather meals can greatly improve the utilization rate of poultry feathers. It is for dry feathers, and wet feathers must be dried before further processing. This paper completes the structural design of a drying box for wet feather drying and uses the principle of vacuum drying to realize the conversion of wet feathers to dry feathers.*

Keywords: *poultry feathers; vacuum drying; structure design.*

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In today's world, the global intensive animal husbandry is developing rapidly, but the current situation of shortage of protein resources in the traditional sense seriously affects and restricts the further development of my country's animal husbandry, and the sources of protein resources need to be broadened. As a big country in animal husbandry, my country will produce a large number of waste feathers in the process of centralized or free-range breeding of common poultry such as chickens, ducks, and geese. Among the large number of waste feathers produced, only a small part of the feathers with excellent quality will be used in the clothing industry, and most of the inferior feathers that are selected will have nowhere to go. Some of them are buried or burned in situ and allowed to rot and degrade, which causes great pollution and damage to the environment. Another small part, about 20,000 tons of feathers per year[1], is added to livestock animal feed after simple crushing treatment. However, due to the immature technology, the keratin protein in feathers cannot be used by livestock and poultry. Absorption results in a low utilization rate and a serious waste of a large number of amino acids. According to statistics, the weight of discarded feathers in China is as high as 1.5 million tons every year, and these discarded feathers are rich in protein resources and a large number of amino acids, and the crude protein content in feathers is as high as 80%[2]. At present, there are many methods for processing waste feathers as feed, which can convert the keratin protein and amino acids in feathers into forms that can be directly absorbed by livestock, to improve product quality, turn waste into treasure, and make waste products more valuable. Feathers become feather meals that can be added directly to livestock feed. Currently commonly used processing methods include physical methods, chemical methods, and biotechnology methods[3,4,5,6,7,8,9]. Among them, the most widely used is the extrusion method in the physical method.

However, all the feather extrusion machines currently used in society are basically dry feather extruders that use dry feathers as raw materials, and the moisture content generally does not exceed 20%. But for fresh feathers with moisture content as high as 70%-80% that have just been taken off from livestock, they are helpless. Therefore, this paper focuses on the structural design of the feather drying system in the wet feather extruder.

1. Development of traditional drying and new drying technology

At present, there are many drying types of equipment in the world for drying most materials, and the performance is good. However, not all technologies are perfect in many aspects, such as energy consumption, product quality, operational safety, dryer control, optimized operation, environmental pollution, etc. Among them, most of the previous drying technologies were developed based on the production experience of a certain period of time[10]. Most of the developers were small suppliers of this drying equipment, and did not consider too many issues of energy, environmental and product quality. With the maturity of legal regulations and the development of competition among peers, many original dryers have been optimized and improved, and have more advanced new technologies for drying wet materials of different physical forms. See Table 1.1[11].

Table 1.1 Comparison of conventional and innovative drying technologies

raw material type	normal type	new technology
liquid suspension	dryer	Inert particle fluidized bed/spouted bed drying
	spray	Combined spray/fluidized bed drying vacuum belt drying Pulse combustion drying
Paste/Sludge	spray	Inert example spouted bed drying
	drum	Fluidized Bed (Solid Particle Back Mixing) Drying
	paddle stirring	superheated steam drying
particles	turn around	Superheated steam fluidized drying
	airflow	Vibrating bed drying
	Fluid bed drying (hot air or combustion gas)	annular air drying pulsating fluidized bed drying Jet zone drying Y AMATO rotary drying
serial	Multi-Cylinder Contact Drying	Combined shock/radiation drying
	Shock (air) drying	Combined impact and through drying (fabrics, low basis weight papers) Shock and microwave/HF combined drying

2. Working principle and characteristics of vacuum drying

2.1 Principle of vacuum drying

A process of removing moisture from materials under ambient conditions below 1 standard atmospheric pressure (the number of gas molecules per cubic centimeter is 2.687 × 1019 in standard conditions). Vacuum drying is the same as atmospheric drying, the basic principle is the theory of heat and mass transfer[12]. The difference is that in the vacuum drying process, the surrounding environment of the dried material is a closed low-pressure space[13].

In the process of vacuum drying, the vacuum system continuously heats the material to be dried while evacuating[14], so that the moisture inside the material diffuses to the surface through the pressure difference or concentration difference, and the water molecules obtain enough kinetic energy on the surface of the material to overcome the mutual interaction between the molecules. Attractive force, fly into the low-pressure space of the vacuum chamber and then be pumped away by the vacuum pump[15,16].

In the vacuum drying process, the pressure in the drying chamber is always lower than the atmospheric pressure, the number of gas molecules is small, the density is low, and the content of oxygen molecules is low, so it can dry substances that are easy to oxidize and deteriorate and flammable and explosive dangerous goods[17]. It can play a certain role in the disinfection and sterilization of medicines, food, and biological products, and can control and reduce the contamination of materials or inhibit the growth of certain bacteria.

Because the temperature required for water to vaporize is proportional to the pressure, the relationship between vaporization temperature and vapor pressure for several different substances is shown in Figure 2.1. Therefore, the moisture in the material can be vaporized at low temperature during vacuum drying, which can realize low-temperature drying, greatly reduce energy consumption, and the utilization rate of heat energy is also reasonable.

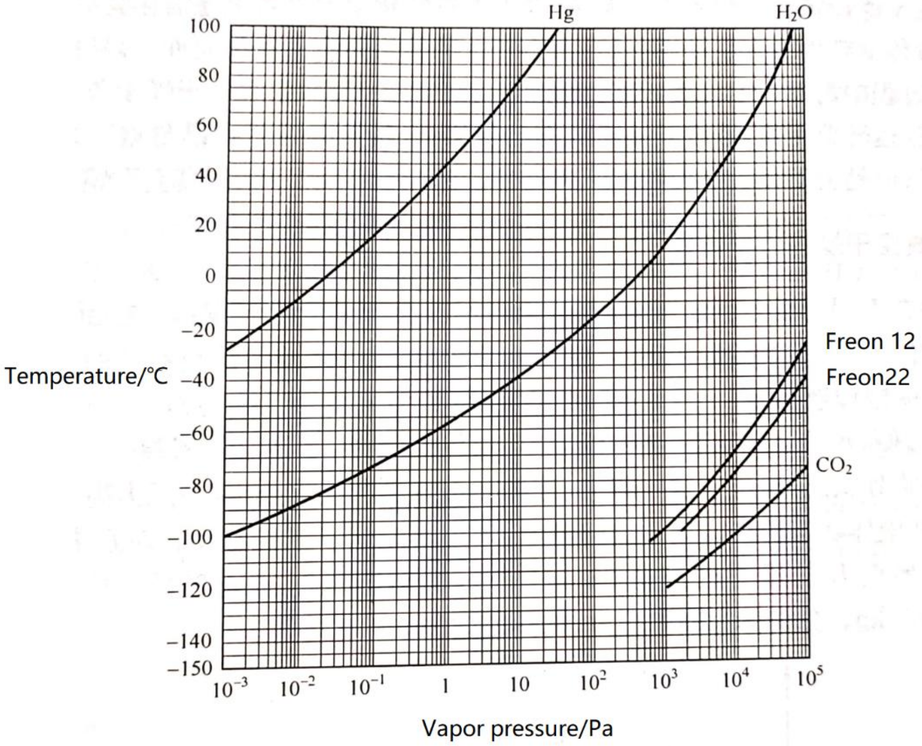


Figure 2.1 _ The relationship between the vaporization temperature and vapor pressure of several different substances

Vacuum drying can eliminate the surface hardening phenomenon that is easy to occur in the case of atmospheric drying. Atmospheric pressure hot air drying forms a fluid boundary layer on the surface of the material to be dried, and the vaporized water vapor diffuses into the air through the fluid boundary layer, and the moisture inside the dried material must move to the surface. The boundary layer water film will be broken, and local dry cracks will appear on the surface of the dried object, and then expand to the entire surface to form surface hardening[18]. The pressure difference between the inside and the surface of the vacuum drying material is large. Under the action of the pressure gradient, the water will move to the surface quickly without surface hardening. At the same time, the drying speed can be increased, the drying time can be shortened, and the operating cost of the equipment can be reduced.

Vacuum drying can overcome the solute dispersion phenomenon caused by hot air drying. Hot air drying causes a large temperature gradient to be formed inside and on the surface of the material to be dried, which promotes the emission of certain components in the material to be dried. In vacuum drying, the temperature gradient inside and outside is small, and the water as a solvent moves independently by reverse osmosis, which overcomes the phenomenon of solute dispersion. Some materials to be dried contain valuable or useful substances, which need to be recycled after drying; some materials contain toxic and harmful substances that endanger human health, which are not allowed to be discharged into the space environment after drying and require centralized treatment. Only vacuum drying can easily recover these useful and harmful substances and can achieve good sealing. Therefore, in the sense of environmental protection, some people call vacuum drying "green drying"[19].

2.2 Study on the characteristics of vacuum drying

When water evaporates at different pressures, the process can be represented by a p-v curve. In the p-v curve shown in Figure 2.2, the ordinate is the pressure p and the abscissa is the specific volume v (volume per unit mass of substance). Curve AB is a saturated liquid, on the left side of AB, water is in a liquid state; curve BC is a saturated steam line, on the right side of BC line, water is in a vapor state; below the curve ABC, water is a liquid state Coexistence of vapor phase.

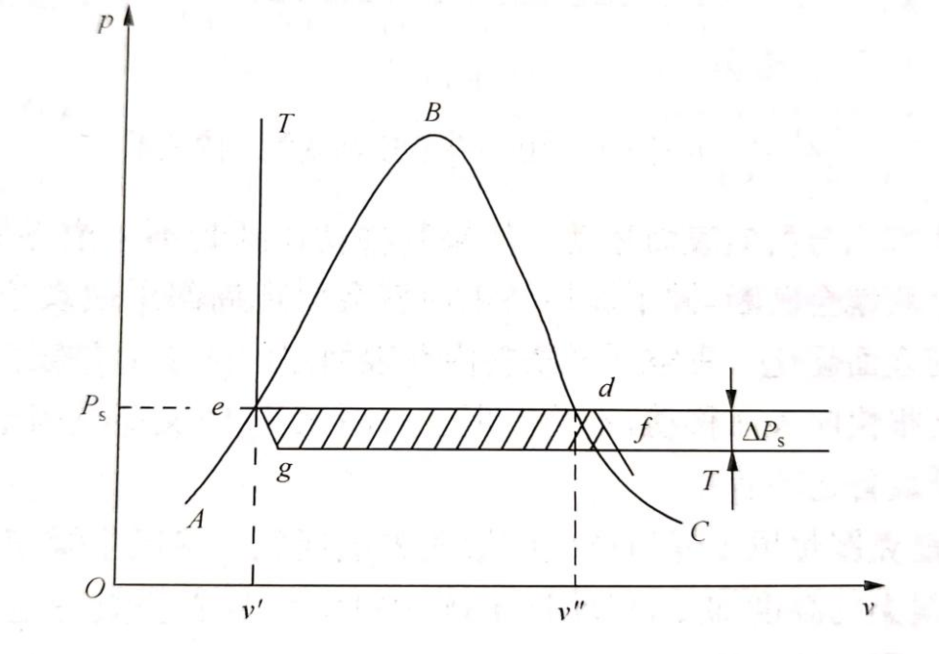


Figure 2.2 Vaporization characteristic curve of water

In order to qualitatively derive their interrelationships, the Carnot cycle in the analysis p -v system is composed of four processes: isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression. Set at the pressure p, under the condition of adiabatic with the outside world, isobaric heating, the system expands isothermally, the volume increases, the system absorbs energy from the heat source to e point to boiling, the liquid begins to vaporize, and the volume of t increases from v' to v”, when it reaches point d, the vaporization of all liquids ends. Then the adiabatic expansion to point f is still an isothermal process, but the pressure is not equal, and the pressure drops by Δps. After condensing at point f, the system begins to liquefy and release heat And keep the pressure and temperature unchanged, the volume is reduced from v ″ to v ', when it changes to g, and then adiabatically compressed to point e, a cycle is completed. The attack made by this cycle can be represented by the area edfg. Because the pressure changes Δps and the temperature changes ΔT is small, its area can be represented by a rectangle Δps (v ” - v '), namely

$$dA = (v'' - v') \cdot dp_s \tag{2.1}$$

from thermodynamics

$$dA = L\frac{dT}{T} \tag{2.2}$$

thus get

$$\frac{dp_s}{dT} = \frac{4.1868L}{T(v''-v')} \tag{2.3}$$

formula (2.3), v " and v ' are the specific volumes of gas and liquid water, respectively, m^3/kg; L is the latent heat of vaporization, kj/kg ; ps is the saturated vapor pressure at temperature T, MPa; T is the thermodynamic temperature, K.

Equation (2.3) is integrated to get

$$p_s = 4.1868\frac{L}{v'-v'}\ln T + C \tag{2.4}$$

From the (2.4) Clapeyron - Clausius formula, it can be known that:

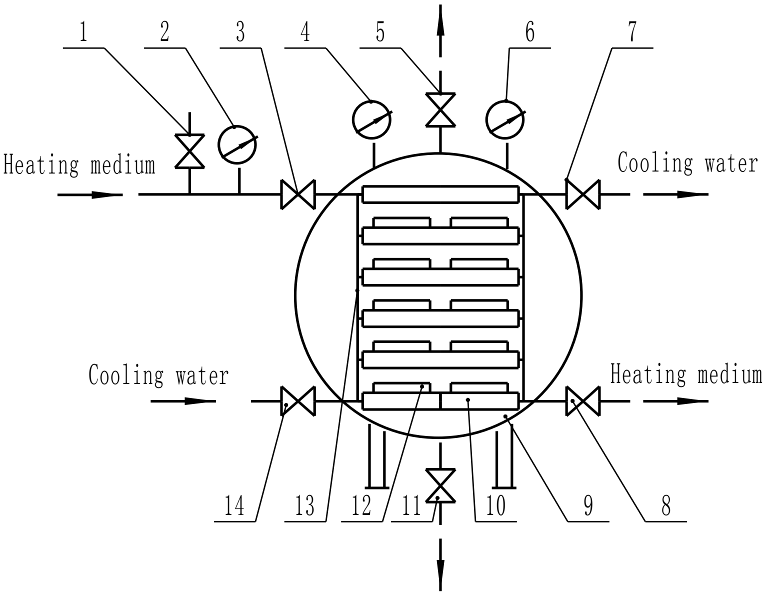
(1) The vaporization temperature of water decreases as the pressure decreases, and low-temperature vaporization can be achieved under vacuum, which is the theoretical basis of vacuum drying.

(2) In the case of constant pressure ps, heating the system, in order to maintain the balance of the formula, there must be more liquid vaporization to speed up the drying speed.

(3) If T remains unchanged and P s is reduced, more liquid will also be converted into steam, which is also one of the methods to speed up vacuum drying[15].

3. Design of vacuum drying box structure

The vacuum drying box is composed of a safety valve, thermometer, heating box, shelf, material tray, pressure gauge, exhaust valve, and other components. The size of the vacuum drying box is a tank with a length of 1008 mm and an outer diameter of 608 mm. The front and rear doors are elliptical heads with a thickness of 4 mm, and the thickness of the middlebox is also 4 mm. The material of the entire vacuum drying box is a stainless steel material. There are 6 layers of shelves in the box, of which 5 layers have a total of 10 material trays, the distance between the shelves is 60 mm, and the empty vacuum degree in the box is 1333 Pa. The structure of the vacuum drying box is shown in Figure 3.1.



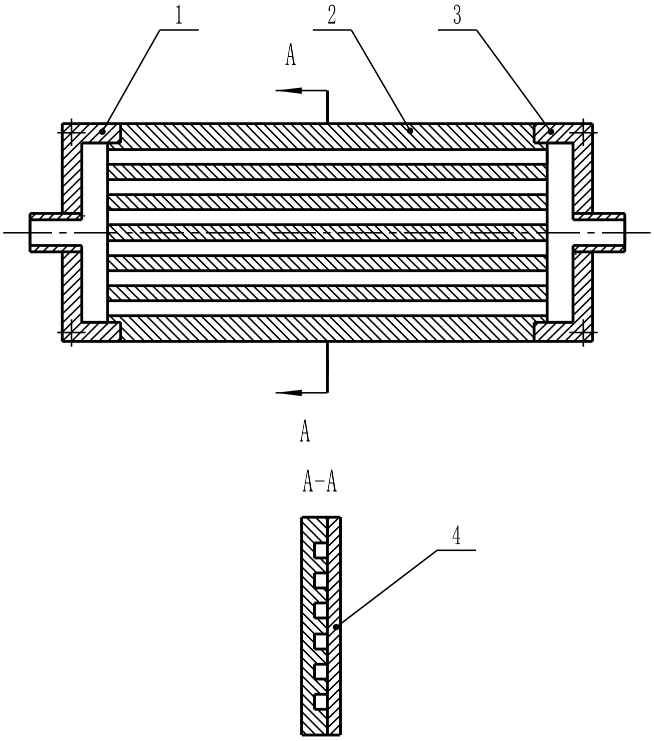
1 - safety valve; 2 - pressure gauge; 3 - heating medium inlet valve; 4 - vacuum gauge; 5 - air extraction valve; 6 - temperature gauge; 7 - cooling water discharge valve; 8 - heating medium discharge valve; 9 - box; 10 - shelf; 11 - trap; 12 - material tray; 13- cluster pipe; 14- cooling water inlet valve

Figure 3.1 Vacuum drying oven

Spread the wet feathers evenly on the tray and place the tray on the shelf. The heating medium enters the shelf through a specific channel, and the feathers placed on the tray receive heat to warm up and evaporate the moisture attached to the surface of the feathers. The selected heating medium is steam. During the drying process, the air in the vacuum box and the water vapor formed by the vaporization of moisture are extracted by the suction valve. When the moisture content of the feathers is reduced to a predetermined standard, the entire drying process is completed. After the drying process, in order to make the feathers and the drying box cool in time, all the heating medium is discharged, and then cooling water is input into the channel for the cooling process. During the drying process, the vacuum degree, temperature, and pressure of the heating medium in the drying box are displayed by the corresponding vacuum gauge, temperature gauge, and pressure gauge. After the drying process is over, the residual water in the drying box is discharged through the trap. Now design several main components of the vacuum drying box.

3.1 Design of the shelf

The shelf acts as heating in the vacuum drying oven. The tray responsible for holding the material is placed on the surface of the shelf. The heating medium flows through the shelf for heating and heating. The upper surface of the shelf is responsible for carrying the tray and conducting heat, and the lower surface radiates heat to the material. The shelf can conduct heating medium and cooling medium in the temperature range of -35 ℃ —150 ℃. There are 6 channels in the shelf, which can be used for heating and cooling medium to flow through, heating and cooling the partition. The design of the shelf is shown in Figure 3.2.

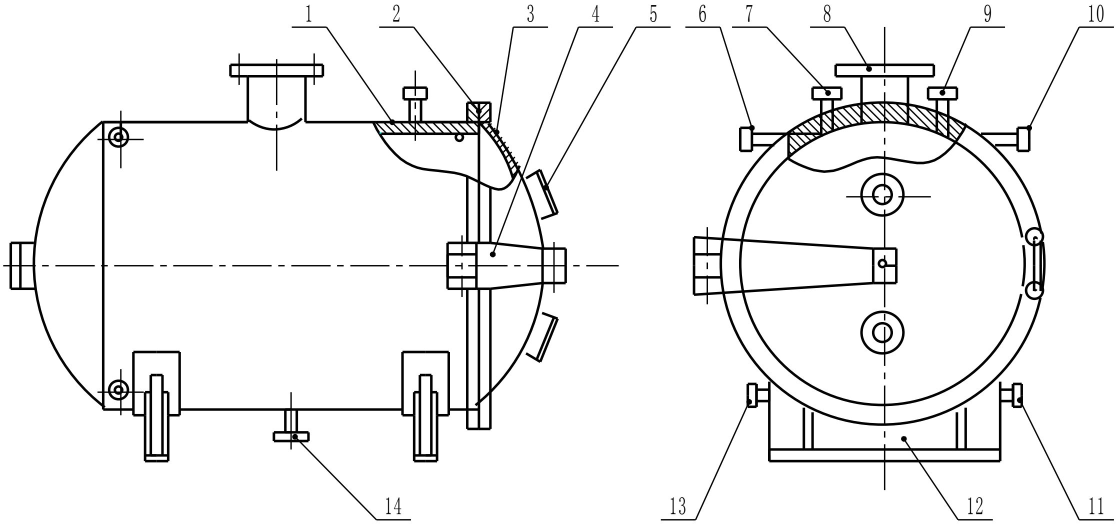


1-left collector; 2-shelf body; 3-right collector; 4-cover
Figure 3.2 Shelf structure

There are two common structures for heating shelves: heating tube type and channel type. The heating medium transmits heat to the shelf through heating pipes and channels respectively, so that the temperature of the shelf is increased and reaches a predetermined temperature. In order to make the temperature of the shelf even after heating up, the heating tube type shelf is to weld the heating pipe on the heating shelf. Due to the uneven uniformity of the welding seam and the inconsistent welding contact between the heating pipe and the shelf, etc., so choose channel-type shelves in structure. In order to ensure that the heating medium flowing through each channel of the shelf has the same temperature and flow rate, a collector structure is added at both ends of the shelf, so that the heating medium flows in parallel and one-way through each channel, and the shelf is heated evenly. Therefore, not only can the flow rate of the heating medium entering each channel be equal, but also the temperature difference of the heating medium at the inlet and outlet of the channel can be reduced.

3.2 Design of the cabinet

The box body is mainly composed of the box body, sealing ring, gate, and gate opening mechanism, observation window, heating medium inlet, and outlet, cooling water inlet and outlet, vacuum table seat, temperature table seat, suction flange port, feet and drain valve seat, etc. composition. The structure is shown in Figure 3.3.



1-box body; 2-sealing ring; 3-gate; 4-gate opening mechanism; 5-observation window; 6-heating medium inlet; 7-vacuum meter seat; 8-air exhaust port flange; 9-temperature meter seat;
10-cooling water outlet; 11-heating medium outlet; 12-feet; 13-cooling water inlet; 14-trap seat; 15-insulation layer
Figure 3.3 Box structure

The door opening mechanism of the box is a door that is opened and closed by rotating around the hinge axis. Since the box of the drying box is a negative pressure airtight container, there are strict requirements on its air leakage rate, outgassing rate, and stability. In order to ensure a low leakage rate of the box, it is necessary to ensure that its dynamic seal, static seal, and welds have high airtightness. The pressing force of the rubber sealing ring at the door of the box should be uniform and ensure that the pressing amount during sealing is not less than 1/4 of the characteristic size of the rubber sealing ring. All weld structures on the box should conform to the vacuum technology. It is required that the welding quality should be strictly controlled to ensure high weld strength and low air leakage rate, such as one welding of one weld as far as possible. In order to ensure a small outgassing rate on the inner surface of the drying box, there are very strict requirements on the roughness of the inner surface of the box. The smoother the surface of the box, the less gas is adsorbed on the surface, and the less gas is released during heating and drying. Therefore, in order to improve the anti-corrosion ability of the inner wall of the box, the smoothness of the surface should be improved for the metal surface working in the environment of a large amount of condensable steam. Since the negative pressure container is most likely to be destabilized and deformed by external pressure, there are great requirements for the reliability of the vacuum drying oven during the vacuum drying process.

3.3 Design of the tray

The tray is the key component for placing the feathers on the shelf for vacuum drying. Because the tray needs to transmit the heat brought by the shelf, the tray needs to have good thermal conductivity, that is, it should have high thermal conductivity and good heat transfer performance. Flatness and low roughness. The material of the tray is made of aluminum alloy or stainless steel sheet stamping. Using this material to make the tray not only has good thermal conductivity, but also has good corrosion resistance, and meets the requirements of hygiene standards. There are 10 trays in 5 layers, with a length of 900 mm, a width of 180 mm, and a height of 65 mm. The feathers are placed in the tray.

4. Performance test research of drying oven

In order to check whether the vacuum drying box designed and produced in this paper meets the requirements of the established twin-screw extruding machine, whether the drying amount of wet feathers per unit time in the vacuum drying box is greater than the feeding amount of the machine during normal production, and the vacuum drying Whether the box can supply the feeding requirements of the twin-screw extruder, the designed vacuum drying box is tested by taking slaughtered chicken feathers as the test object.

Required instruments: vacuum drying oven, XY-110MW moisture meter, drying tray.

Measurement method: Prepare an appropriate amount of freshly slaughtered chicken feathers with a moisture content of about 80 %, and simulate the raw materials transported to the factory for extrusion and puffing. Among the prepared slaughtered chicken feathers, three groups of samples were randomly selected for pre-experiment. Fill one group of chicken feather samples extracted evenly into each tray in the vacuum drying box, close the door of the box, and the suction valve starts to work. Observe the vacuum gauge when the pressure in the drying box reaches about 1 333Pa a., stop the pumping work. At the same time, the heating medium steam is input into the vacuum box through the channel for heating and drying. After drying for 5 minutes, stop the input of the heating medium, and after a little cooling, input cooling water at the channel for cooling treatment. After the chicken feathers in the drying box are completely cooled, the input of cooling water is stopped, the door of the box is opened, the chicken feathers are taken out and the moisture content is measured with a moisture analyzer. Subsequently, drying for 1 min, cooling, and moisture content measurement were repeated until the moisture content of chicken feathers was measured to be less than 20 %. Three sets of experiments were repeated. The time to reduce the moisture content of the chicken feathers to the specified value and the moisture content of the chicken feathers after drying were recorded for the three sets of experiments. The test results of this test are shown in Table 4.1.

Table 4.1 Time required for sample drying

group	time/min	Moisture content/%
1	6	1 8.62
2	6	1 8.37
3	5	1 9.50

from Table 4.1 that when the vacuum drying box is fully loaded and dried, the average time required to reduce the moisture content of such chicken feather samples to below 20 % is 5.5 min, and the dried chicken feather samples have an average time of 5.5 min. The average moisture content is 18.83 %. The volume of feather samples that this fully loaded vacuum box can hold is:

$$V = a \times b \times h \times n \tag{4.1}$$

In the formula, a—the length of the tray, m;
b—the width of the pallet, m;
h - the height of the pallet, m;
n—the number of trays.

The volume of chicken feather samples that a fully loaded vacuum box can hold is 0.1053 m3.

In order to know the quality of the chicken feather samples piled up after drying in the vacuum box, it is also necessary to measure the bulk density of the feathers.

Required instruments: 500 ml graduated cylinder, electronic scale (1000 g/0.1 g).

Determination method: The mass-volume method was used for determination. First, put the 500 ml measuring cylinder on the electronic scale, let it stand, and then zero the electronic scale. Three groups of dried chicken feather samples were randomly selected and dropped freely into a 500 ml measuring cylinder through a funnel, wherein the lower mouth of the funnel was about 5-8 cm away from the mouth of the measuring cylinder. When the volume of chicken feathers slightly exceeds the 500 ml mark, stop adding chicken feathers, and gently remove a small number of chicken feathers with tweezers until it just reaches the 500 ml mark. At this time, record the weight m displayed by the electronic scale. Then the bulk density ρ of the chicken feather sample is calculated as:

$$\rho = \frac{m}{V} \tag{4.2}$$

In the formula, ρ—the bulk density of the tested chicken feathers, g /cm^3;
m—the mass of chicken feathers to be tested, g;
V—the volume of the graduated cylinder, cm^3.

Of the chicken feather sample was measured to be below 20 %, the bulk density was 84.62 kg / m3, and the dry mass of the chicken feather sample contained in the vacuum box was calculated to be 8.91 kg when the vacuum box was fully loaded. It can be seen from Table 4.1 that the average time required to reduce the moisture content of the chicken feather samples to below 20% is 5.5 min when the vacuum box is working, and the drying rate of the vacuum drying box can be calculated to be 1.62 kg/min. The feed rate of the currently matched twin-screw extruder is known to be 2.7 kg/min. Therefore, adding a drying oven in front of the twin-screw extruder cannot meet the feeding requirements of the twin-screw extruder, and two identical vacuum drying ovens need to be connected in series, that is, when the drying speed is 3.24 kg/min, only It can meet the normal working requirements of the twin-screw extruder.

5. Conclusion

Processing waste feathers into feed feather meal is an effective way to increase the added value of feathers, and drying is a key step before feathers are processed into feather meal. Different drying technologies have their own advantages and disadvantages. After optimization and comparison, this paper selects and designs a vacuum drying equipment. Vacuum drying has the advantages of improving production efficiency, saving production costs, etc., and can greatly improve the efficiency of feather extrusion and puffing into feather meal. Tests have shown that two identical vacuum drying boxes are connected in series at the feeding port of the twin-screw extruder, which can meet the normal working requirements of the twin-screw extruder and realize the transition from wet feathers to dry feathers.

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