

# System Design of Microcrystal Freezing Sleeping Equipment and Research on Effect of Foie Gras Fast Cooling Equipment

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**Abstract:** The purpose of this paper is to design the heat exchanger copper tube in the microcrystalline freezing sleeping equipment system and explore the freezing effect of the foie gras fast cooling equipment. By using SOLID WORKS 2021 to design the heat exchanger of the copper tube, it is applied to the microcrystalline freezing sleeping equipment. Exploring the cooling time of microcrystal freezing sleeping equipment and freezing refrigerator; The extraction rate of foie gras juice at different temperatures after being treated by microcrystalline freezing equipment was investigated, and the optimum freezing temperature was obtained. Compare the juice leaching rate, cooked meat loss rate, color difference, shear force physicochemical properties of foie gras after different treatment methods. The results show that it takes 12.5 min for the body temperature to reach -18°C by using the frozen sleeping equipment, which is better than 240 min in the refrigerator. When the temperature of the instrument is set at -20°C, the juice leaching rate is the least. There was no significant difference in the cooking loss rate and SAP leaching rate between the treatment group and the liquid nitrogen treatment group. There was no significant difference in color difference among the three freezing groups. There was no significant difference between the tenderness of foie gras treated by microcrystalline freezing device and that of fresh meat group. Thus, the feasibility of changing the copper tube of heat exchanger to improve the efficiency of the equipment is verified, which provides a theoretical basis for the comprehensive utilization of the rapid cooling equipment in the future.

**Keywords:** Microcrystalline Freezing; Crushing Degree; Foie Gras; Heat Exchanger Copper Tube; Freeze Effect.

## 1. Preface

As one of the common meat consumed by people, foie liver is deeply loved by the majority of people, which is rich in protein, fat, vitamin B, niacin, calcium, phosphorus, iron, cholesterol and other ingredients, and has the effect of nourishing qi and stomach, promoting rehabilitation and weight loss[1][2]. According to statistics, in 2020, the global foie gras consumption 59.57 million tons, China's foie gras consumption 8.84 million tons, accounting for 16.1% ranked second, only second to the United States (21.3%), but China's foie gras per capita consumption is only 6.29 kg / person · year, far lower than the world average level. The production of foie gras in 2022 was 7.18 million tons, an increase of 3.0% over 2021 [3]

Secondly, with the development of the current catering industry, people's demand for fresh meat products has greatly increased. In order to ensure the quality of meat products and the supply and demand of meat products, rapid freezing technology is an appropriate and effective solution. But at present, rapid freezing is mostly air freezing, dry ice freezing and liquid nitrogen freezing[4]. Rapid freezing machinery is mostly frozen in liquid nitrogen, while liquid nitrogen is extremely volatile, difficult to recover and expensive. When applied to food, it will greatly improve its storage and use cost[5][6]. Therefore, in the 1990s by Japan's Yamada, President invented and pioneered the frozen sleep technology, Guangdong Pacific Nick technology co., LTD to further improve the technology and optimization, and put forward the frozen sleep technology freezing speed is about 1 / 20, is liquid nitrogen freezing time about 1 / 8 of the operating cost,

greatly improve the production efficiency and the added value of products [7]. Frozen sleep technology is a kind of liquid as the medium of high-speed freezing technology, often use a variety of refrigerant as the medium, more edible liquid, and put forward the frozen sleep technology frozen food, because cell tissue is not destroyed, color, flavor will not change, after thawing can restore the original freshness, but there are solute penetration problems. Li Xiaoyan et al. proposed to improve the refrigerant composition and combine the magnetic field auxiliary technology with liquid fluidization technology, use magnetic field technology to control or inhibit the growth of ice crystals, break the "boundary layer" of the food surface of the boundary with the high-speed turbulent flow of liquid fluid freezing technology, reduce the boundary heat resistance and enhance the heat transfer rate. This approach is undoubtedly complicated in terms of technology and its cost [8]. Based on this, some scholars have put forward the microcrystal frozen sleep technology again.

In the field of microcrystal frozen sleep technology, most of the liquid high-speed freezing technology, can make food ice grains smaller. However, a new problem will arise. If ethanol is used as a refrigerant, as the temperature continues to drop and the freezing point of ethanol is very low, ethanol will become very sticky, which will cause the original cooling rate to slow down [9][11].

In addition, when improving the refrigeration equipment to improve the cooling efficiency, most of the research is focused on the improvement of the refrigeration compressor, or studying the improvement of the cooling pipeline. Xian Zhijian et al. proposed that the heat exchange effect of 5 mm copper tube heat exchanger is better than that of 7 mm copper tube heat exchanger, which can save a lot of copper and

aluminum, and reduce the refrigerant charge [12][13]. Zhang Peng proposed the forming process of wing heat exchanger and further pointed out that with the technical development of refrigeration industry and the further strict control of environmental protection regulations, improving the heat transfer coefficient of heat transfer unit structure is a necessary means to improve the overall heat transfer performance of heat exchanger and make up for the low performance of alternative refrigerant[14]. However, few studies have been done to improve the refrigeration efficiency by directly increasing the contact area through the number of heat exchanger rings.

Therefore, the purpose of this research is to develop a core component for the refrigerator to solve the above problems-copper tube heat exchanger. In the application of this copper pipe, the freezing efficiency will be greatly improved, and the problem of slow refrigeration rate when ethanol is used as a refrigerant will be solved. By comparing the effect with the refrigeration refrigerator and liquid nitrogen freezing, the

physical and chemical properties of the sample are analyzed and analyzed, so as to verify its efficient ability, which once again proves the feasibility of liquid circulation rapid freezing technology.

## 2. Experimental Materials

### 2.1. Raw Material Preparation

The foie gras used in the experiment were all bovine tendon meat, removed from oil and fascia, and evenly divided into 100.00 g ( $\pm 0.20$  g) for each group.

### 2.2. Experimental Reagents and Instruments

Table 1. Main chemical reagents

reagent	rank	vender
absolute ethyl alcohol	AR	Tianjin Fuyu Fine Chemical Co., Ltd

Table 2. Main Instruments and Equipment

instrument	model	vender
electronic analytical balance	Type AL104	Mettler-Toldo Instruments Ltd
Vacuum sealing insurer	Type of QH-66	Zhejiang Qunhai Electronic Technology Co., LTD
Color difference instrument	The WR-10QC type	Shenzhen Weiwei Optoelectronic Technology Co., LTD
UK SMS Proformer	TA. Type XT Plus C	UK Stable Micro Systems Inc
Vacuum packaging bag	Of the 30cm 20cm type	Foshan Hongchen Packaging Materials Co., LTD
Low temperature constant temperature sink	And DC-30 type 10	Changzhou Guowang Instrument Manufacturing Co., LTD
ice box	The BCD-471 WDCD type	Haier
nitrogen canister	The YDS-15 type	East Asia Electromechanical Co., Ltd
Probe thermometer	Type 8807	The Deli Group Company Limited

## 3. Experimental Method

### 3.1. Heat Exchanger Copper Pipe Model Establishment and Instrument and Equipment Development

#### 3.1.1. Drawing of the Basic Sketch

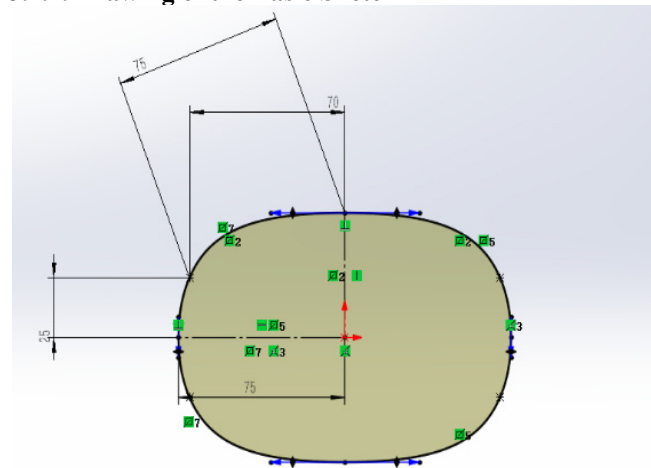


Figure 1. The basic sketch

First, the basic sketch is drawn. The copper tube design is based on the rounded rectangle. In order to facilitate the subsequent scanning auxiliary line from the inside of the rotating body, the establishment of the rounded rectangle adopts the mirror image technique. The origin is selected on the basic surface of the upper view, and two vertical auxiliary lines are constructed, and two auxiliary lines are connected in

the form of spline curve. In order to ensure the symmetry of the subsequent mirror image, the endpoints of the spline are tangent to the two auxiliary lines respectively, and the 1 / 4 image is fully defined. With the vertical auxiliary line as the base line, mirror the 1 / 4 figure to get the 1 / 2 base figure. Take the horizontal auxiliary line as the base line and mirror the 1 / 2 image to obtain the rounded rectangular base figure.

#### 3.1.2. Surface Stretching and Scanning

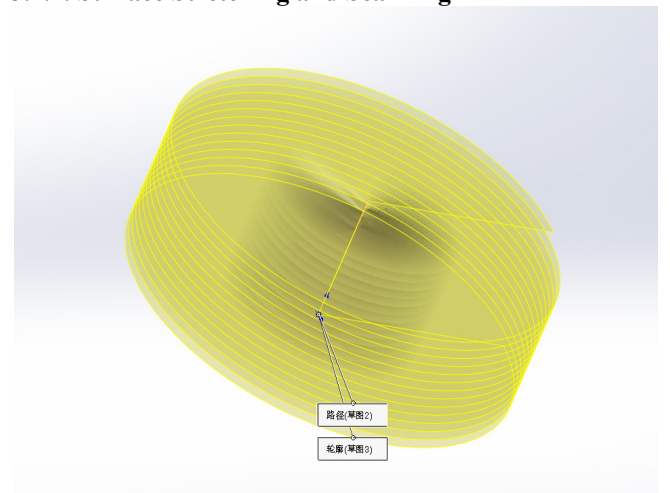


Figure 2. Stretch scan

The auxiliary line in the basic sketch is changed to the construction line, so that the graph forms a closed loop, and the graph convex platform is stretched in the features to obtain the cylinder with rounded rectangle as the bottom surface. Switch the view to the front view, take the midpoint above the front view graph as the starting point, and make the vertical line down. Switch the view to the right view, the following

midpoint is the starting point, the right extension, and the extension length is greater than the rotation diameter of the cylinder when the midline is used as the rotation line. Then the surface was scanned, and the sketch outline was selected, taking the new two auxiliary lines as the path, selecting the contour orientation changing with the path, setting the contour torsion value, and the torsion control was set as the number of circles. According to the previous research of Japanese scholars, the circle ratio was set as 14 circles with the optimal liquid ratio and volume ratio as the reference to generate the scanning image.

Select the image in the conversion entity, and select all the faces to cross, and get the intersection curve. To facilitate the subsequent operation, only to keep the intersecting curve, hide all the rotating faces, and only keep the curve. Scan the intersection curve to the surface, set the outline to the circular outline, change the path to 3D sketch, select the inner diameter is tentatively 5 mm to obtain the 3D diagram of copper pipe.

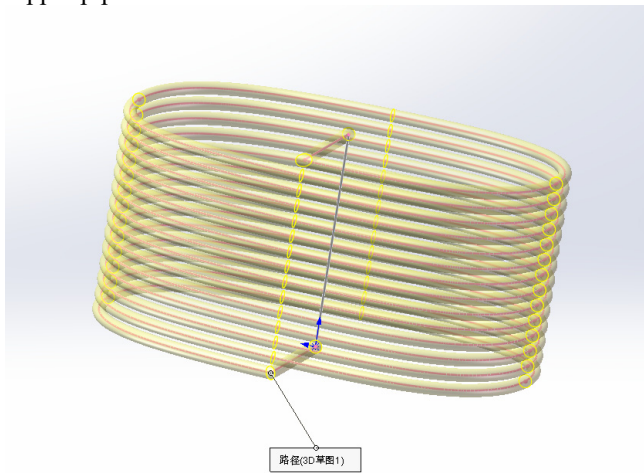


Figure 3. 3D Composition of copper pipe of heat exchanger

### 3.1.3. Development of Microcrystal Frozen Sleep Equipment

The copper tube of the heat exchanger is transferred to the external professionals for stability measurement and development, and the microcrystal frozen sleep instrument is applied. The instrument is compact structure, the shell is high quality steel plate spray, the liner is made of stainless-steel

material, add pulley foot with locking device, can be easily moved and fixed. The minimum temperature control range can reach-30°C, the volume is 10 L, and the data is set by CNC panel. As shown in Figure 4, Figure 5.



Figure 4. Overall diagram of microcrystalline cryosleep equipment



Figure 5. Internal diagram of microcrystal frozen sleep equipment

## 3.2. Effect Verification

### 3.2.1. Comparative Measurement of Cooling Time between Different Treatment Groups

**Table 3.** Instrument selection

Processing group	brand	model
Refrigerator (-18°C)	Haier	The BCD-471 WDCD type
Microcrystalline equipment (-18°C)	Chang Wang	And DC-30 type 10

20 Turn on the power supply, add the refrigerant alcohol to the instrument, and record the time taken to drop from room temperature to-18°C and-25°C. When the temperature of the instrument and the refrigerator reaches-18°C, take 6 groups of 100.00 g (± 0g) foie gras in each group, each 3 groups are a large group, placed in the instrument and the refrigerator, record the time when the meat temperature reaches-18°C, and contrast with the refrigeration time of the refrigerator.

### 3.2.2. The Instrument is Optimal for Refrigeration Temperature Measurement

#### 3.2.2.1 Sample Preparation.1

Take 18 groups, each group is 100.00 g (± 0.20 g) of beef tendon meat, remove oil, and remove the shape as consistent as possible, each 3 groups are a large group, numbered 1~18, vacuum package.

#### 3.2.2.2 Sample Determination

The instrument is pre-cooled in advance, and the temperature gradient is-10°C, -14°C, -18°C, -20°C, -22°C and-25°C. To be frozen, freeze the water and freeze for 15 min, wipe the surface moisture, and weigh the balance to calculate the juice leaching rate [15]. Comparing the average juice aching rate in each group to obtain the optimal temperature. Sap leaching rate is calculated according to formula (1):

$$P = \frac{W_1 - W_2}{W_1} \times 100\% \quad (1)$$

In formula: P —— sap leaching rate, %

W<sub>1</sub> —— Mass of foie gras before freezing, g  
W<sub>2</sub> —— Mass of foie gras after freezing, g

### 3.2.3. Determination of the Color Difference

#### 3.2.3.1 Sample Preparation.1

Take 12 groups, each group 100.00 g ( $\pm 0.20$  g) of beef tendon meat, oil, tendon, shape as much as possible, each 3 groups for 1 group, number 1~12, vacuum packaging, each group was recorded as, original foie gras, -18°C refrigerator frozen foie gras, frozen sleep equipment optimal temperature treatment foie gras, liquid nitrogen treatment foie gras. Numbers A, B, C, and D.

#### 3.2.3.2 Sample Determination

Freeze the frozen sample, stand still for 15 min, wipe the surface moisture, carefully placed under the color difference meter, read a value, b value, L value, calculate the total color difference  $\Delta E$ , and compare the total color difference of foie gras in different treatment methods [16].  $\Delta E$  is calculated according to formula (2):

$$\Delta E = \sqrt{(a-a_0)^2 + (b-b_0)^2 + (L-L_0)^2} \quad (2)$$

### 3.2.4. Determination of Cooking Loss Rate and Juice Leaching Rate

#### 3.2.4.1 Sample Preparation.1

Sun Hongxia, Zheng Jiaxu and others judged the water holding ability of meat by the cooking loss rate and the juice leaching rate [17][18]. Take 24 groups, each group 100.00 g ( $\pm 0.20$  g) bovine tendon meat, oil, tendon, shape as far as possible, each 3 groups for 1 group, number 1~24, of which 1~12 groups used to determine cooking loss rate, 13~24 groups measured juice leaching rate, vacuum packaging, the original goose liver, -18°C refrigerator frozen treatment foie

gras, frozen sleep equipment optimal temperature treatment foie gras, liquid nitrogen treatment foie gras recorded as A, B, C, D.

#### 3.2.4.2 Sample Determination.1

The processed foie gras was thawed, steamed in boiling water for 30 min, and then wiped away, the cooking loss rate is calculated by the following formula (3), and the juice leaching rate is calculated according to the above formula (1):

$$\rho = \frac{M_1 - M_2}{M_1} \times 100\% \quad (3)$$

In formula:  $\rho$  — Cooking loss rate, %

$M_1$  — Quality of foie gras before steaming, g

$M_2$  — Goose of goose after quality, g

### 3.2.5. Determination of the Shear Force

#### 3.2.5.1 Sample Preparation.1

Take 12 groups, each group 100.00 g ( $\pm 0.20$  g) of beef tendon meat, oil, tendon, shape as much as possible, each 3 groups for 1 group, number 1~12, vacuum packaging, each group was recorded as, original foie gras, -18°C refrigerator frozen foie gras, frozen sleep equipment optimal temperature treatment foie gras, liquid nitrogen treatment foie gras. Numbers A, B, C, and D.

#### 3.2.5.2 Sample Determination.2

The treated foie gras was chilled, dried, and several 2 cm 2 cm 2 cm meat cubes were taken for each small sample [19] [20] In three sets of parallel tests, the head of the knife and the texture direction of the meat were vertical [21].

Table 4. Shear force parameter setting

method	Probe model	Pre-measurement rate	Measure the rate	Post-test rate	Determination distance	Initial excitation force
Warner-Bratzler	HDP/BSW	2.0 mm/s	1.0 mm/s	2.0 mm/s	33 mm	10 g

### 3.3. Data Processing

Data were processed with SPSS 26.0 and Origin 2021 analysis.

## 4. Results Analysis

### 4.1. Analysis of the Instrument Refrigeration Time

The cooling time can have a better reaction refrigeration efficiency. The data intuitively shows that with the gradual decrease of the target temperature range, the cooling time and the total time increase accordingly. To reach lower temperatures, it takes longer to reach the predetermined temperature, which is the commonality of the freezing equipment. From the perspective of refrigeration time, the time required for the equipment to drop from room temperature of 25°C to -18°C is 26.5 min. By consulting the refrigerator instructions, the time required for the refrigerator to drop from room temperature to -18°C is 32 min, which is not much difference between the two. The time required for cooling increases significantly at the target temperature near or below -23°C. Especially below -23°C, the cooling time takes more than 10 minutes. Therefore, when using the instrument, consider opening the refrigeration function early before operation to ensure that the desired temperature is reached if necessary.

Table 5. Refrigeration time of the instrument Figure 5 Instrument cooling time

temperature range (°C)	time consuming (min)	Total time (min)
25~0	10	10
0~-10	5.5	15.5
-10~-11	0.5	16
-11~-12	0.5	16.5
-12~-13	1	17.5
-13~-14	1	18.5
-14~-15	1.5	20
-15~-16	1.5	21.5
-16~-17	2	23.5
-17~-18	3	26.5
-18~-19	3	29.5
-19~-20	3.5	33
-20~-21	4	37
-21~-22	4	41
-22~-23	6.5	47.5
-23~-24	7	54.5
-24~-25	10	64.5

In terms of the freezing performance of the meat samples, the freezing temperature was set to -18°C, and the preheating was completely. The meat samples were placed in the instrument and the refrigerator respectively, and the complete freezing time was 12.5 min and 240.0 min respectively, which is far better than the freezing effect of the refrigerator.

According to the analysis, because the refrigerator takes air as the medium and the cooling air circulation is not good, the cooling system inside the refrigerator may have "hot zone" and "cold zone", resulting in different temperatures in different positions, affecting the cooling rate of the sample.

#### 4.2. The Instrument is Most Suitable for Refrigeration Temperature Analysis

With the juice immersion rate, the device optimal refrigeration temperature is obtained indirectly. This test study shows that as the temperature decreases, the juice loss rate gradually decreases and then increases, when at-10°C, -12°C and-24°C, the immersion rate is not different ( $p > 0$ ); at-18°C and-22°C, but not significant from other groups; at-20°C, the juice immersion rate is the least, reaching 3%, significant difference with other groups ( $p < 0$ ). According to the juice leaching rate, it is generally believed that the shorter the freezing time, the faster the water content in meat products froze, and the less the leaching rate.05.77.05 [22]

#### 4.3. Color Difference Analysis

Color difference is an important indicator to evaluate sensory, and also as an important indicator to measure the freshness of meat [23][24]. The results of this test showed that after thawing ( $p < 0$ ). No significant difference in groups B, C and D ( $p > 0.05$ ). 05 According to Figure 2, the total color difference of frozen meat will increase. The main reason is that the freezing of foie gras leads to the surface water loss, and the surface brightness of the meat increases, thus increasing the L \* value. Although there was no significant difference in the total color difference value in groups B, C and D, the a \* value and b \* had different changes. For the reasons, the meat was exposed to air and caused the reaction of myoglobin with oxygen and microbial metabolites on the surface in goose liver[24]. In general, the microcrystal equipment handles meat samples in color sense and other freezing methods.

#### 4.4. Analysis of Cooking Loss Rate and Juice Leaching Rate

The juice leaching rate and the cooking loss rate reflect the water retention of meat, and also reflect the quality of meat to some extent[25].05.05. The results of this experiment showed that when the meat samples were treated with different freezing methods, the cooking loss rate of group B compared with group A, C and D ( $p < 0$ ), and the cooking loss rate of group A compared with group B, C and D ( $p < 0$ ). Current theory is that in traditional freezing, the formation of large crystals inside food can cause damage to the cell wall, making the food tissue loose and seeping water[26], Thus resulting in a higher cooking loss rate. Rapid freezing prevents the formation of these large crystals, so that the cellular structure of the food is not destroyed, leading to potentially lower cooking losses. The result can be analyzed from Figure 8 to fit the common theory. It can be found that the cooking loss rate and juice leaching rate are affected by the freezing mode and greatly affected. The freezing sleeping equipment is better in controlling the cooking loss rate and juice leaching rate than the refrigerator freezing, which is not different from the liquid nitrogen freezing.

#### 4.5. Shear Force Analysis

Muscle fiber, muscle connective tissue, and intramuscular fat are the most important factors affecting the tenderness of

meat, and the shear force can more directly reflect the tenderness of meat [27]. 05. The results of this experiment prove that the shear force level in group B is significantly different compared with the other groups ( $p < 0$ ). Group D has significant shear force compared to other groups ( $p < 0$ ). There was no significant difference in the shear force level in groups A and C ( $p > 0$ ). 05.05.

Goose liver samples after the refrigerator-18°C frozen, shear force rise significantly, analyze the reason, after freezing and water thawing treatment, goose liver muscle fibers become irregular, protein molecules may degeneration or condensation, moisture loss degree, makes the goose liver internal become more dry, tight, thus increasing its shear force. As a result, foie gras frozen before thawed may be more difficult to chew and digest than fresh foie gras, and can vary in taste and texture.

After the goose liver sample is frozen by liquid nitrogen, the shear force decreases. The reasons are analyzed. One is that the liquid nitrogen freezing temperature of liquid nitrogen is very low, the water in the goose liver sample is crystallized quickly, and then formed a larger crystal, but these crystals will destroy the tissue structure of the goose liver. And the very low temperature makes the foie gras produce liquid nitrogen frostbite, its performance is that when the freezing is finished, when the freezing is completed, the foie gras tissue is frozen, so the probe is easier to divide the foie gras, thus showing the decrease of shear force. The second is oxidation. In the process of liquid nitrogen freezing, although the vacuum encapsulation sample is used when freezing, the freezing resistance of the packaging material cannot withstand the freezing temperature of liquid ammonia-196°C, making the packaging material brittle, and when freezing and freezing, the oxygen in the air will oxidize with the fat and other components in foie gras. This oxidation accelerates the rancidity of the goose liver fat, which causes it to become soft and affect the shear force.

In conclusion, the shear force index effect of goose liver samples frozen by microcrystal equipment is better than that of refrigerator freezing and liquid nitrogen freezing, that is, the preservation effect is good.

### 5. Conclusion

In this experiment, the model is designed by S OLID WORKS 2021 software. The basic image is mirror, and the stereo image designs a heat exchanger copper tube in the way of convex body stretching and curved surface scanning. With the help of external personnel, it is measured and applied to obtain the microcrystal frozen sleep equipment. The cooling preheating time at different set temperatures is obtained by operation. The appropriate freezing temperature of the freezing instrument was obtained by comparing the juice leaching rate of goose liver samples at different cold temperatures. Comparing the juice leaching rate, cooking loss rate, color difference and shear force of the goose liver samples under different freezing methods, so as to verify the feasibility of the heat exchanger copper tube and the advantages of freezing effect over other freezing.

77.05 The test results show that from the refrigeration time, the time required for the equipment to drop from room temperature of 25°C to-18°C is 26.5 min, and the time required for the refrigeration refrigerator to drop from room temperature to-18°C is 32 min, with little difference between the two. In terms of the freezing performance of meat samples, the freezing temperature is set to-18°C, and in the

microcrystal freezing equipment and the refrigerator, the complete freezing time is better than the freezing effect of the refrigerator. From the optimal freezing temperature of the instrument, the juice immersion rate was the least to 3% at-20°C, which was significantly different from the other groups. From the perspective of the total color difference of the sample, there was a significant difference between the original goose liver compared with the other groups. There was no significant difference between the refrigerator-18°C freezing group, microcrystal-20°C freezing group, and liquid nitrogen freezing groups ( $p > 0$ ). From the perspective of juice leaching rate and cooking loss rate, there is a significant difference between the cooking loss rate of samples after refrigerator-18°C freezing treatment compared with-20°C treatment and liquid nitrogen freezing treatment. In terms of shear force, there were significant differences in group B compared with other groups. The shear force of the liquid nitrogen freezing group varied significantly compared with the other groups. There was no significant difference in the shear force level between the original goose liver group and the microcrystal device-20°C frozen group ( $p > 0.05$ ).

To sum up, the copper tube of the heat exchanger has a good freezing effect when applied to the instrument, which provides a theoretical basis for the comprehensive utilization of the subsequent circulation refrigeration instrument. Compared with the ordinary freezing equipment, the freezing time is shortened, thus greatly improving the efficiency of rapid freezing. In terms of refrigerant, it achieves low loss and recycling, reduces the cost of quick-freezing, improves its commercial value, and further meets the demand for rapid freezing in the current industry environment.

## 6. Looking Forward

Rapid freezing has a wide range of application fields both now and in the future, which can not only be applied to agricultural and livestock products, but also to other fields such as medical treatment (such as blood, semen freezing, animal samples, etc.). Therefore, a good quick-freezing technology is the basis for the development of excellent products and food industries. The design of the heat exchanger copper pipe and its practical application, to a certain extent to achieve the corresponding effect. However, in terms of experiments, it is a pity that there are some problems in the liquid nitrogen freezing group. For example, when freezing, there is no packaging materials that can withstand ultra-low temperature. After freezing, the materials become brittle and cannot achieve the vacuum effect, which makes the sample contact with air and liquid nitrogen, resulting in sample pollution and error in the results. There are also some problems in the setting of the freezing temperature of the microcrystal instrument. When the temperature is too low or when the sample is placed in the instrument, in the precooling and freezing, the internal temperature is difficult to reach the set temperature, there is a certain deviation, which is related to the designed copper tube of the heat exchanger. This will be the focus and difficult direction of follow-up research. The development of rapid freezing technology is related to the aspects of frozen prepared food, catering chain industry, fresh fruit tea and the central kitchen of pension institutions, hospitals and schools. Therefore, the development of rapid freezing technology has a long way to go.

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