Investigation Report on the Development of Refrigerated Display Cabinet Industry

University of Shanghai for Science and Technology
Institute of Refrigeration Technology

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Abstract

In recent years, with the strengthening of consumption level of residents and the promotion of Internet penetration, especially with the rise of mobile payment, e-commerce has become the main way of shopping for many people. Online shopping products have gradually developed from 3D digital household appliances, clothing, Cosmetics to fresh products such as flowers, meat, vegetables and fruits. Chinese fresh market has developed rapidly. In 2017, the transaction scale of Chinese fresh e-commerce market was about 139.13 billion Yuan, an increase of 59.7% compared with the previous year. The rise of fresh e-commerce has led to the rapid development of cold chain logistics and the increasing demand for refrigerated display cabinets.

Refrigeration display cabinet is an important part of the food cold chain, and also an important part of the food cold chain transportation market. Refrigeration display cabinet is an indispensable device for the preservation and sale of food in modern commercial and catering industries. It plays an important role in improving the quality of food, booming the sales market and improving quality of life. The refrigeration display cabinet industry will occupy a considerable proportion in the future domestic and foreign commodity cold chain market.

This paper introduces the development status of cold chain logistics and display cabinet industry in China, as well as the development of refrigeration technology in display cabinet, as well as the importance of evaporator and condenser in refrigeration cabinet technology. The importance and prospects of substitution of 5 mm small diameter heat exchanger in refrigeration display cabinet were analyzed, and the feasibility of practical research was analyzed theoretically. Based on the current development of refrigeration display cabinets and the assumption of the Shanghai Office of the International Copper Professional Association of the United States on the application and promotion of 5 mm small diameter copper tubes, further experimental studies are planned.

Key word Refrigerated Display Cabinet, 5mm Copper Tube, Heat Exchanger

Catalog

Chapter I. Research Background

1.1 Development status of cold chain logistics market

Cold chain logistics generally refers to a system engineering in which the production, storage, transportation and sale of products are always in a prescribed temperature range until consumption, so as to ensure product quality and reduce process losses. With the progress of science and technology and the development of refrigeration technology, it is a low-temperature logistics process based on refrigeration technology and means of refrigeration technology.

China is a big country in the production, consumption and trade of agricultural and sideline products. The upgrading of production and management mode of agricultural and sideline products, the effective connection of agricultural and sideline production with modern circulation and urban market are important guarantees for the realization of food safety and the comprehensive development of agricultural modernization in China. Fresh products are easy to rot and deteriorate in transportation and distribution at room temperature, which results in low quality and high wastage rate of fresh products. There are higher requirements for logistics and distribution objectively. Developing cold chain logistics is an important way to solve the distribution of fresh products.

Before 2013, there was little capital investment in the cold chain of fresh food, especially in the early stage of circulation of fresh food. From 2014 to 2015, investment in early links increased substantially, and investment in later links also slowly followed up.

The reasons are mainly due to the rise of fresh e-commerce, specifically: in 2009, capital began to pay attention to fresh e-commerce; in the five years from 2009 to 2013, a total of 620 million Yuan of financing was completed; in 2014, the total amount of financing was 1.4 billion Yuan; in 2015, the total amount of financing was 4.3 billion Yuan in the first three quarters.

In recent years, the government attaches great importance to the development of domestic cold chain logistics market, and has promulgated a number of documents to encourage the healthy development of cold chain logistics market from supporting the construction of cold chain logistics infrastructure, planning cold chain logistics operation process, and supporting the rapid development of fresh e-commerce. With the rapid development of e-commerce and the improvement of residents; income, the freshness of food is increasingly demanded. The major e-commerce platforms have also increased the supply

of fresh products. According to the data of research institutes, the transaction scale of fresh e-commerce market in 2017 is 141.8 billion Yuan, and it is estimated that the transaction scale will reach 215.8 billion Yuan in 2018.In recent years, Ali, Tencent, Jingdong and other e-commerce platforms have entered one after another, increasing the number and fresh investment, making the fresh e-commerce industry develop rapidly. Data show that in the next three to five years, Chinese market will reach 470 billion Yuan. Cold Chain Logistics Supply Chain Cold Chain Logistics

The transaction scale of domestic fresh e-commerce market is shown in Figure 1-1.

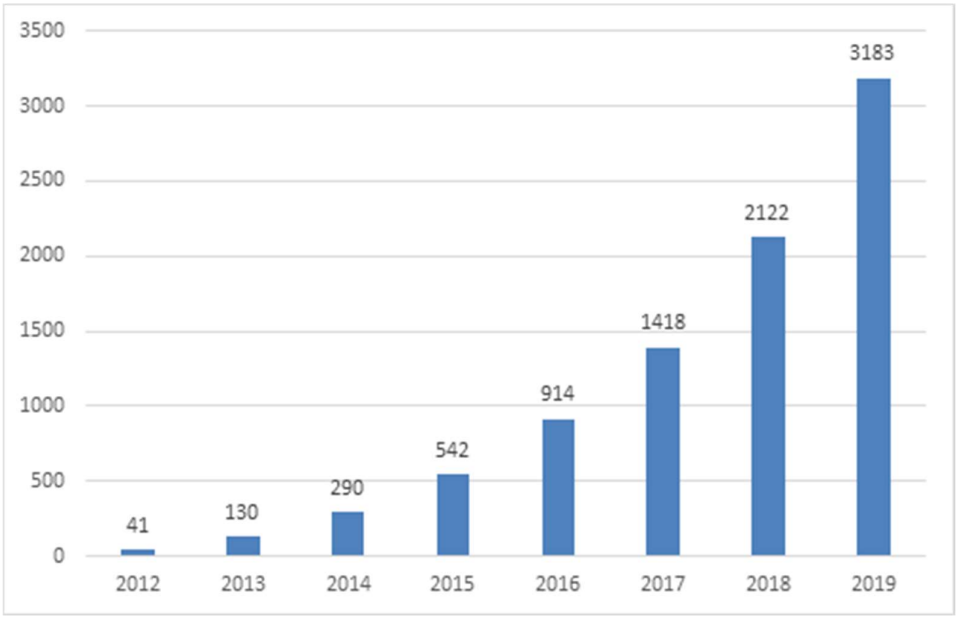


Figure 1-1 Size of Domestic Fresh E-commerce Market

At the same time, according to statistics, since 2010, the number and amount of mergers and acquisitions in cold chain logistics industry have shown a growth trend. Especially in 2016, mergers and acquisitions have grown by leaps and bounds, with the capital scale reaching 5.2 billion Yuan. In 2017, mergers and acquisitions involving more than 8 billion Yuan.

Multidisciplinary cross-border cold chain logistics will lead to a new competitive pattern. In the future, Cold chain industry of China will enter a new fast lane of integration, mergers and acquisitions, and restructuring.

1.2 Development status of refrigerators market

As the main equipment in the later stage of fresh food cold chain, food refrigeration display cabinet has a variety of types and types. Among them, open food refrigeration display

cabinet can not only provide suitable refrigeration temperature for food, but also display food, beautify shopping environment and stimulate consumption. After years of development, it has become an indispensable equipment in supermarkets. According to incomplete statistics, the energy consumption of food refrigeration display cabinets in supermarkets accounts for about 50% of the total energy consumption of supermarkets. Therefore, the performance of food refrigeration display cabinets not only has an important impact on the quality of food, but also on the energy saving of supermarkets.

From a global market perspective, since 2012, with the recovery of the global economy, The field of global refrigeration market has entered a stable stage of development. According to the data of refrigeration display cabinet industry provided by China Industry Online, the global refrigeration display cabinet sales have been on the rise since 2015.In 2017, 174 million units were sold, an increase of 0.8% year on year, sales of 72.2 billion US dollars, an increase of 3% year on year. Sales increased more than sales growth year on year, the average price of products increased, and the effect of high-end transformation began to show. The changing trend of global refrigerated display cabinet sales in 2012-2017 is shown in the figure 1-2.

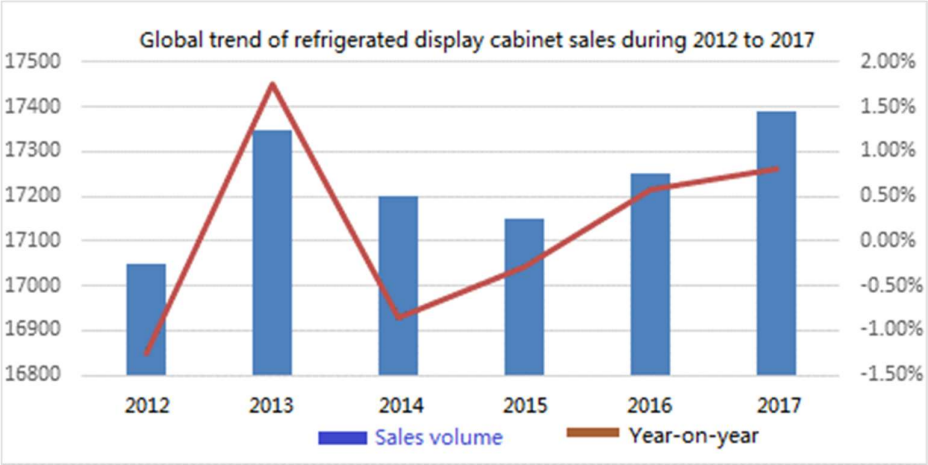


Figure 1-2 Trends in global refrigerated display cabinet sales from 2012 to 2017

As can be seen from the picture, sales of refrigerated display cabinets reached their peak in nearly six years in 2013, slightly declined in 2014 and 2015, and continued to climb steadily for two years in 2016. Overall, the global refrigerated display cabinet sales market rose slightly from 2012 to 2017.

Although the global refrigeration display cabinet market has recovered as a whole, there are great differences in regional market performance. In view of the general good growth momentum of the developed economies in the world, the growth rate of emerging and

developing economies has steadily rebounded, and the performance of refrigerators and display cabinets in continents has also shown corresponding characteristics. Sales of refrigerated display cabinets in major continents and countries are shown in Figure 1-3.

Figure 1-3 Sales of refrigerators in major continents and countries

Asia is the largest producer and consumer of refrigerators and display cabinets in the world, accounting for nearly 60% share. In 2017, the refrigerated display cabinet Market in Asia grew by 0.5% year-on-year. Except for China, Israel, the United Arab Emirates and a few other countries, the rest of the world showed strong performance, including Pakistan, India, Iraq, Vietnam and other countries. Japan and South Korea have obvious brand advantages in Southeast Asia, and Chinese investment in Southeast Asia and South Asia has been active in recent years.

Europe is the second largest refrigeration display cabinet market in the world. In 2017, thanks to the strong domestic demand, the cyclical warming of the global economy and the recession of populism, the euro zone countries emerged from the crisis, and the market demand for refrigerators and display cabinets in Europe was released. The market size increased by 1.7% year on year, with the growth of Eastern Europe growing relatively faster.

The size of the American market as a whole has grown. Among them, North America is driven by the rising demand of the United States, the market size of refrigerated display cabinets increased by 1.8% year-on-year, and affected by high permeability and low population growth, most of the sales of refrigerated display cabinets in North America come from renewal. After two consecutive years of contraction, South American economy shows a weak growth trend. Although demand in Argentina, Colombia and other countries is still

depressed, Brazil, the main consumer country of South America, has recovered, which has led to a slight recovery in the refrigeration display cabinet market.

The decline in market size in Africa has deepened. After the trough of 2016, Africa's economy bottomed out in 2017, with sub-Saharan economic growth expected to be 2.4%. Although consumption in this region has rebounded, but due to sluggish consumption in Nigeria and other places, the refrigeration display cabinet Market in Africa has been dragged down.

Australia is the main market in Oceanic continent. In 2017, Australian Economy continued to grow, unexpected drop in unemployment rate, and the growth of home ownership brought about by the First New Deal of Home Purchase, to a certain extent, stimulated the consumption of refrigerators and display cabinets. After the closure of the Ilex Refrigerator Factory in Australia, there are no refrigeration display cabinet factories in the continent, which basically rely on imports. The main source of imports is China, and Chinese products account for more than half of market share in Australia.

However, from the domestic sales market, the refrigerated display cabinet industry is currently in a critical turning point: Chinese data show that from 2008 to 2017, the sales volume of the refrigerated display cabinet industry in China has continued to rise, but the growth rate has slowed down slightly. But sales volume is not the only criterion to measure an industry. Technology, innovation and sustainable development are indispensable. Domestic enterprises continue to invest in research and development, product innovation and replacement, frequency conversion, intelligent, multi-door, air-cooled frost-free, ultra-thin embedded and other new concepts and products emerge in endlessly. According to the annual research report of China refrigerated display cabinet industry in 2017, the sales trend of China refrigerated display cabinet industry in 2008-2017 is shown in Figure 1-4.Industry Online

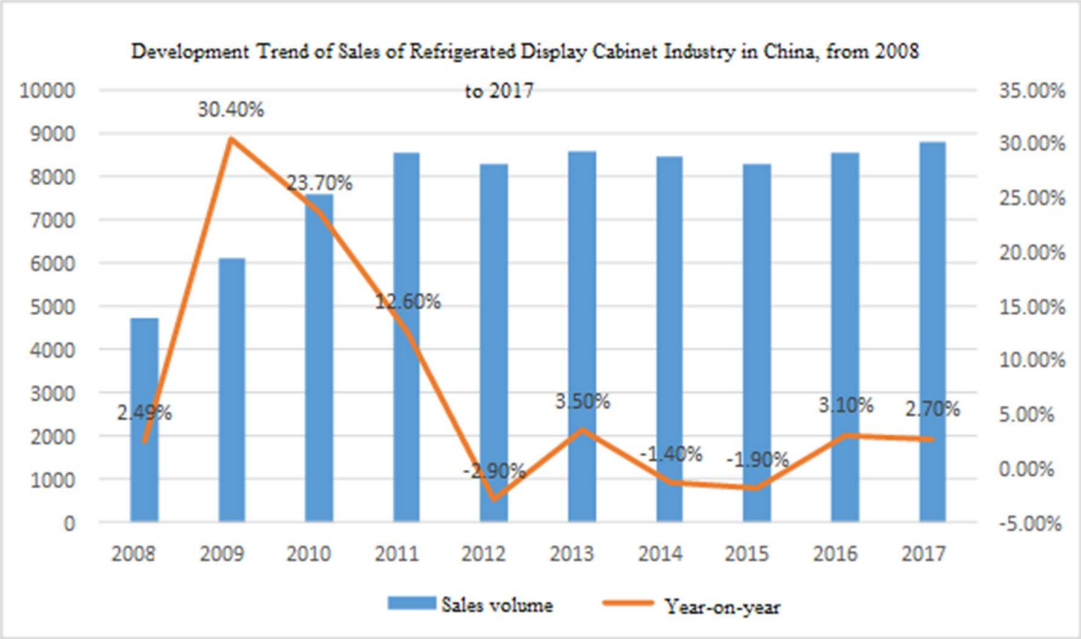


Figure 1-4 Development Trend of Sales of Refrigerated Display Cabinet Industry in China, from 2008 to 2017

Refrigeration display cabinet is the last link equipment in the food refrigeration chain, which plays an important role in the sale of fresh food. The improvement of people's demand for food consumption and the diversification of commercial sales have greatly promoted the development of refrigerated display cabinets. In summary, it can be seen that the refrigerated display cabinet industry will occupy a considerable proportion in the domestic and foreign markets in the future. Therefore, technological innovation and cost reduction of refrigerated display cabinets have a far-reaching impact on the sustainable development of the industry.

Chapter II. Summary of Refrigerated Display Cabinet

2.1 Characteristics of refrigerated display cabinets

Refrigerated display cabinets are usually used in shops and supermarkets. They not only have the function of preserving perishable goods or food at low temperature, but also have the function of displaying and selling goods or food. The refrigerated display cabinet has various structures and shapes according to its use, temperature and place of use. Its purpose is to maintain appropriate temperature and humidity in the cabinet to ensure the freshness of food. Therefore, the design requirements for refrigerated display cabinets are as follows:

(1) Maintaining proper temperature and humidity in the cabinet can maintain the quality of food well during storage.

(2) It should have the function of displaying commodities, and its structure and shape should make it easy for customers to see and take food.

(3) It is convenient to replenish food in the cabinet without spending too much time on the salesman.

(4) Because it is used in stores, it should be in harmony with the structure of stores and the shape and appearance of other sales equipment to give people a sense of beauty.

(5) The inside structure of the cabinet should be easy to clean and made of materials that meet the hygienic requirements.

(6) Due to contacts with customers, attention should be paid to preventing leakage and bruising of customers, and safety should be high.

(7) Structures should be firm and not easily deformed by external forces.

(8) The operation is simple and easy to repair.

(9) Low manufacturing cost and low power consumption in operation.

2.2 Classification and structure of refrigerated display cabinets

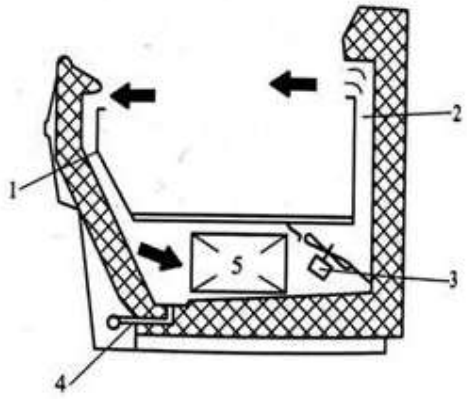
2.2.1 Classification of refrigerated display cabinets

According to the structure of refrigerated display cabinet, it can be divided into open type and closed type. Open type is divided into horizontal open type and vertical multi-store open type; closed type is divided into horizontal closed type and vertical multi-store closed type.

(1)Horizontal open refrigerated display cabinet

Horizontal open refrigerated display cabinet is shown in Figure 2-1.The upper part of the refrigeration display cabinet is open, and the opening is provided with an air curtain

formed by circulating cold air. The heat intruded by the maintenance structure is also absorbed by circulating cold air without affecting the quality of food. The influence on food quality is mainly caused by the hot air and radiation heat invaded by the opening part, especially for the refrigerated display cabinet for frozen food, the radiation heat flow is larger



1-Inhalation duct 2-Outlet duct
3-Ventilator unit 4-Drainage outlet
5-Evaporator

Figure 2-1 Horizontal open refrigerated display cabinet

When the outside wet air invades the refrigerated display cabinet, it is easy to frost in the evaporator. With the increase of frost layer, the cooling capacity decreases. Therefore, at least one automatic defrosting must be carried out within 24 hours. The amount of air intrusion from outside air is related to the wind speed. When the wind speed exceeds 0.3m/s, the amount of air intrusion will increase significantly. Therefore, the relative position with indoor air conditioning should be considered when arranging open refrigerated display cabinets.

(2) Vertical multi-stored open refrigerated display cabinet

Vertical multi-stored open refrigerated display cabinet is shown in Fig. 2-2.Compared with horizontal display cabinet, vertical multi-stored display cabinet unit occupies a large area, and the height of goods placed is similar to human height. It has good display effect and is convenient for customers to shop. However, the cold air inside the display cabinet with this structure is easier to escape from the cabinet, thus the amount of air invaded by the outside is more. In order to prevent the mixing of cold air and outside air, an air curtain consisting of one or two layers of non-cold air is set on the outside of the cold air curtain. At the same time, it is equipped with larger refrigeration capacity and cold air volume. Because the air curtain of the vertical refrigeration display cabinet is vertical, the amount of outside

air intruding into the cabinet is more affected by the air velocity. From the point of view of energy saving, it is required that the outside air velocity of the control cabinet should be less than 0.15m/s, the temperature should be less than 25 C, and the humidity should be less than 55%.

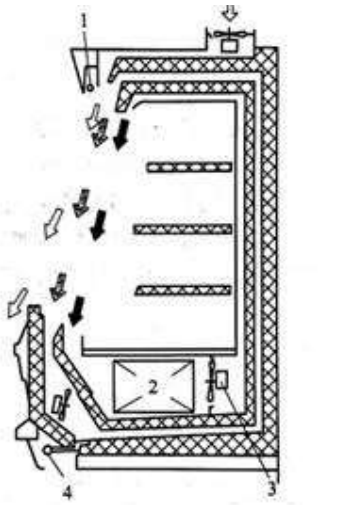
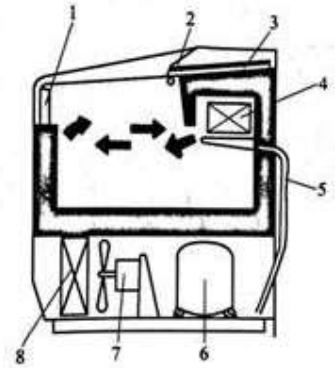


Figure 2-2 Vertical multi-stored open refrigerated display cabinet

(3) Horizontal closed refrigerated display cabinet

Its structure is similar to that of the open type. The structure of the horizontal closed refrigerated display cabinet is shown in Figure 2-3.The sliding cover is composed of two or three layers of glass at the opening, and the air in the glass interlayer acts as heat insulation. In addition, the cold air curtain is replaced by the cooling exhaust pipe buried on the cabinet wall, and the heat transferred through the outer wall is absorbed by the cooling exhaust pipe. In order to improve the refrigeration performance, a cooler can be installed above the rear of the refrigeration display cabinet, so that the cold air can be forced to circulate like a horizontal lid. Its disadvantage is that the quantity of goods loaded is small and the efficiency of sales is low.

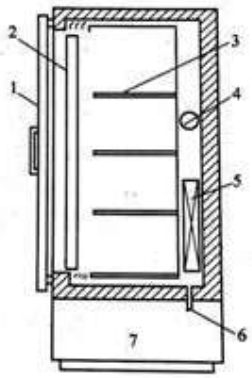


1-Front window 2- Fluorescent lamp
3- Night lid 4- Upper cooler 5- Drain pipe
6- Compressor 7- Fan 8- Condenser

Figure 2-3 Horizontal closed refrigerated display cabinet

(4) Vertical closed refrigeration display cabinet

The vertical enclosed refrigeration display cabinet, shown in Figure 2-4, has a cold air circulation passage on the back wall of the cabinet. The cold air is forced to circulate in the cabinet under the action of a fan. The cabinet door is made of two or three layers of glass, and the air in the glass interlayer has the function of heat insulation. Because of the low infrared transmittance of glass, although the cabinet door is large, the incoming radiation heat is not much.



1-Cabinet door
2- Fluorescent lamp
3- Shelf 4- Ventilator
5- Cooler 6- Drain pipe
7- Refrigeration unit

Figure 2-4 Vertical closed refrigeration display cabinet

2.2.2 The structure of refrigerated display cabinet

The inner and outer walls of refrigeration display cabinets are mostly made of color aluminium plate, stainless steel plate, color steel plate, galvanized steel plate, and, ABS

plastic and high strength fiberboard. Stainless steel plate packaging (decoration and anti-collision device) is used in the main bulge part of the outer wall to reduce external force damage and protect the refrigerated display cabinet.

Glass wool, polystyrene and rigid polyurethane can be used as heat insulation materials. Polyurethane foams are widely used in the middle of the inner and outer walls, which have the characteristics of good thermal insulation and durability. The choice of insulation thickness can be referred to household refrigerators.

2.3 Requirements for the use of refrigerated display cabinets

(1) Method of preventing dew from outside surface of cabinet

Because of the lower temperature in the cabinet, it is necessary to prevent the wall temperature of the refrigerated display cabinet from being lower than the dew point temperature of the air in the shop so as to avoid condensation.

The easily exposed parts on the outside wall of refrigeration display cabinet are: the bottom and back of the unit separated display cabinet; the glass surface, door surface and door frame of the closed refrigeration display cabinet; and the forced convection refrigeration display cabinet is near the air blowing out and suction port. Soft wire heater for preventing condensation consumes about 10W power per meter, and the actual power needs to be determined by experiments. Heaters are also used to prevent condensation in doors and glass surfaces of refrigerated display cabinets.

(2) Discharge of defrosting water and cleaning water

Refrigeration display cabinet must have discharge pipes to guide defrosting water and cleaning water. The discharge pipes are easy to clog, so the discharge pipe aperture should be as large as possible. At the same time, filters can be installed at the orifice to prevent pipe clogging.

The refrigeration display cabinet of the internal refrigeration unit usually has a good structure for dealing with defrosting water in order to move easily. It can be put back once a day to drain water regularly, or it can be heated by evaporating water plate, heat discharged from condenser, heat dissipation from compressor exhaust pipe or electric heater.

(3) Fan configuration

With forced convection cooling refrigeration display cabinet, the refrigerated air in the cabinet usually uses a small axial flow fan with power of 4 ~ 30W. One fan is usually used in small refrigeration display cabinet, while in multi-layer open refrigeration display cabinet with separate units, the number of fans can be as many as 7-9.

The air curtain of horizontal refrigerated display cabinet is basically horizontal, while that of vertical multi-stored refrigerated display cabinet is nearly vertical. The thickness of the wind curtain and the wind speed at the outlet must be calculated according to the experiment. Honeycomb type is often used in air blowers.

(4) Requirements for glass facades

In order to improve the display effect of refrigerated display cabinet, glass is mostly installed in the display area or on the door, which also plays a role of thermal insulation, increases thermal resistance and ensures that the important display surface of refrigerated display cabinet does not dew. According to the temperature in the cabinet, the glass is divided into single, two and three layers. Generally, high temperature refrigerated display cabinets use single-layer glass facade, while low temperature refrigerated display cabinets need to install two or three layers of glass, and vacuum or fill inert gas between the glasses. In addition to glass, transparent plastics such as acrylic resin can also be used. As the expansion coefficient of plastics varies with temperature, special attention should be paid to preventing its deformation.

(5) Lighting requirements in cabinets

One of the functions of refrigerated display cabinet is to display and sell goods. Only when you can see clearly the displayed goods, the sales effect is good. Therefore, the lighting of refrigerated display cabinet is very important. Because of the heat release of the lighting, the temperature of the articles rises considerably, so the fluorescent lamp is more suitable for the lighting of the refrigerated display cabinet. For the same illumination, the fluorescent lamp has the least temperature rise. To maintain the quality of goods, no lighting is the best, but too dark light sales effect is poor. When illuminated by fluorescent lamp, the illumination of commodity surface can be as high as 15001x.The general refrigeration display rack is equipped with a row of fluorescent lamps on each floor.

In addition, the American Association of Commercial Refrigerator Manufacturers (CRMA) has made many relevant regulations on the structure of refrigeration display cabinets. If a thermometer is installed in the cabinet, the display part should not have sharp metal ends, otherwise it is easy to bruise fingers and make cleaning more difficult. The inner bending part should have an inner radius of more than 3 mm; the lower frame of sliding door should be easily wiped and cleaned; the loading limit should be clearly indicated, etc.

2.4 Refrigeration system of refrigeration display cabinet

(1) Unit form

The refrigeration unit of refrigeration display cabinet can be built-in unit or separate unit. Most built-in units adopt air-cooled fully enclosed compression condensation units or semi-enclosed compression condensation units, as shown in Figure 2-5.Air-cooled or water-cooled semi-enclosed compression condensation units are commonly used in separating units. In addition, the installation requirements of separate units are higher.

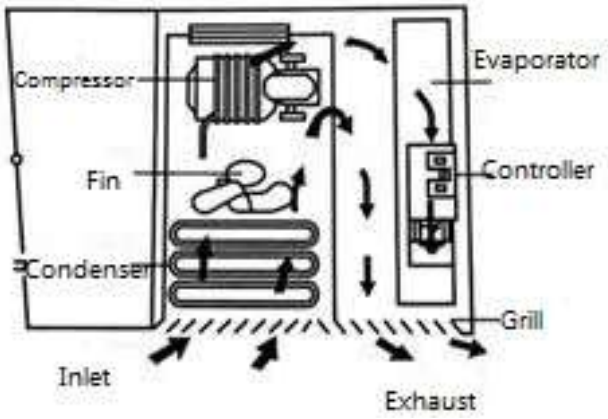


Figure 2-5 Treatment of Cooling Air in Condenser of Built-in Unit

In order to expand the storage capacity of refrigerated display cabinets, the resettlement space of units must be reduced. Therefore, great attention should be paid to ensuring the heat dissipation effect of the condenser and the treatment of its heat exhaust. In order to ensure the smooth passage of cooling air in the condenser, a distance must be made between the refrigeration display cabinet and the surrounding wall. When forced convection fin-coil condenser is used in refrigeration display cabinet, the dust deposited on the condenser should reduce the heat dissipation performance, so many filters are used before the condenser in refrigeration display cabinet. In addition, because the built-in units are located in a smaller space, it is necessary to consider the repair in case of failure, and the movable installation structure is preferable.

Large refrigeration display cabinets used in supermarkets and other large stores are equipped with machine rooms to install refrigeration units. The power of the units is about 1.5-30 kW. The refrigeration display cabinets of separate units are generally 1800-3600 mm in length. Refrigeration display cabinets can share a set of refrigeration units from several to more than a dozen, while refrigeration compressors mainly use semi-closed units (generally 2-4 compressor units in parallel).One of the advantages of the separated unit is that it can realize the rational allocation of refrigeration capacity and reduce energy consumption, and adjust the cooling load of the refrigeration display cabinet according to the change of the

environment temperature in the shop accordingly; at the same time, it can improve the economy, reliability and durability of the refrigeration unit greatly while guaranteeing the quality of the goods.

(2) Selection of evaporator

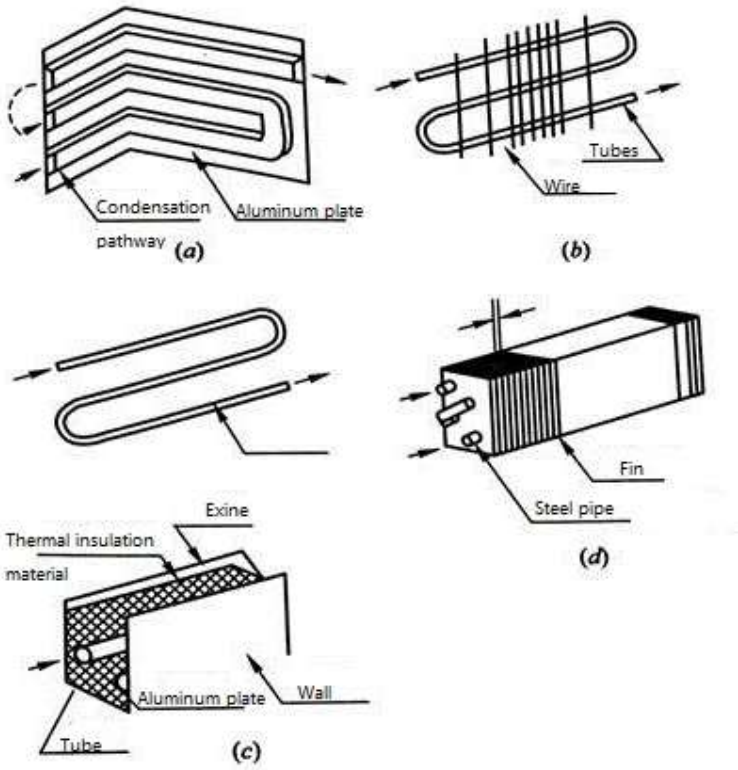


Figure 2-6 Various evaporators for display cabinets

(a) Aluminum plate type; (b) steel wire coil type; (c) optical coil type; (d) finned coil type

The evaporators used in refrigeration display cabinets are aluminium plate type, metal finned snake coil type, light snake row type, cross finned coil type and tube plate type, etc. (see Figure 2-6), and the application of these evaporators is shown in Table 2-1.The determination of cross-fin-coil fin spacing is usually calculated when the middle distance of the display cabinet with lower temperature is larger, and the cooling area is calculated when the difference between the temperature in the cabinet and the evaporation temperature is about 10 C.

Table 2-1 Evaporators for Display Cabinets

Types of evaporators	Applicable cooling mode	Applicable Showcase	Remarks
Aluminum plate type	Natural convection	Small Ice Cream Showcase	Both evaporator itself and cabinet inner wall
Tube sheet type	Natural convection	Small Ice Cream Showcase	Arbitrary evaporator for cabinet inner wall
Metal Winged Snake Coil	Natural convection	Small desktop display cabinet	Special purpose for wall top and refrigeration
Cobra barrel	Natural convection	Reception-type Under-rack assistance	Not many
Cross-finned coil type	Forced Convection and Natural Convection	Applicable to various types of display cabinets	The Display Cabinet of Separating Unit is Used More

(3) Defrosting method

When using the closed refrigerated display cabinet, the external air with the door switch intrudes into the cabinet, causing humidity to increase. Similarly, for open refrigerated display cabinets, more water is brought into the cabinet by the outside air, which makes the evaporator frost more serious. When the frost layer is over 1mm, the cooling effect begins to decrease, and the temperature in the cabinet is not easy to maintain, so the frost must be defrosted. Because the temperature in the cabinet must rise to above 0 C when defrosting, the quality of goods in the refrigerated display cabinet will be affected to a certain extent. The defrosting method is shown in Table 2-2.

Table 2-2 Ways of defrosting display cabinets

Defrosting method	Defrosting method	Applicable cabinet temperature	Defrosting time (min)	Explain
Cut off refrigeration cycle	Refrigerant stop frost melts naturally	Above -2℃	30~50	When defrosting, the frost needs to absorb the heat of dissolution and defrost for a long time.
Electric heating type	Electricity is supplied to the heater while the refrigeration stops.	Full temperature range	Refrigeration: 15-30 Freezing: 20-40	The defrosting time is short, so the heating cost and defrosting electricity cost should be increased.
Hot air type	Lead compressor exhaust into evaporator to defrost	Full temperature range	Refrigeration: 5-15 Freezing: 15-25	The frost melting time is short. The refrigeration display cabinet should be assisted by a low-power heater.

Cut-off refrigeration cycle is the simplest defrosting method, so it is widely used. Most refrigerated display cabinets for vegetables, fruits, dairy products and drinks are in this way. When defrosting, the air outside the cabinet can enter the cabinet to speed up defrosting.

Electrically heated defrosting method is widely used in low temperature refrigeration display cabinets (such as refrigeration display cabinets for meat and fish).The heater can be combined with the evaporator. The forced convection evaporator can be installed in other places. The power of the heater is generally less than or equal to the power of the compressor. At the same time, the heater should have overheating protection device.

Hot gas defrosting mode adopts reverse circulation mode in display cabinet of refrigeration unit. In the centralized combined refrigeration display cabinet system, the refrigeration display cabinet can be divided into more than three groups. When defrosting is needed, some compressors can be stopped and defrosted one by one.

The start-stop of defrosting operation is usually controlled by a timer. In recent years, there are many automatic defrosting methods according to the frosting conditions when necessary (Fig. 2-7).According to the air temperature difference at the entrance and exit of forced convection evaporator, defrosting is carried out when necessary by using the corresponding frost change. Because the change of environment has a great influence on frosting amount, the reasonable regular defrosting time should be adjusted according to the frosting condition when using the timer. In addition to using timer to control the duration of a defrost melting, it can also use the phenomenon that the temperature rises sharply after defrosting, and use thermostat to control the end time of defrosting. The refrigeration display cabinet using tube sheet evaporator (evaporator aluminium plate is the inner wall of the cabinet usually has no defrosting device. In this case, all the goods are taken out once a month, and defrost after removal.

Temperature control mostly uses thermostats. Temperature induction action type evaporator pressure regulating valve can also be used (but less), and low pressure controller can also be used.

As far as humidity control is concerned, most of the goods in refrigerated display cabinets are packaged goods, so humidity control cannot be carried out. The evaporator pressure regulating valve is used to keep the temperature of the evaporator above a certain value in the refrigerated display cabinet where the unpackaged goods are stored in order to prevent the temperature from decreasing. Sometimes humidifying devices are also used. Because of the high humidity requirement of refrigerated display cabinets for vegetable storage, many places adopt the method of spraying vegetable water mist directly.

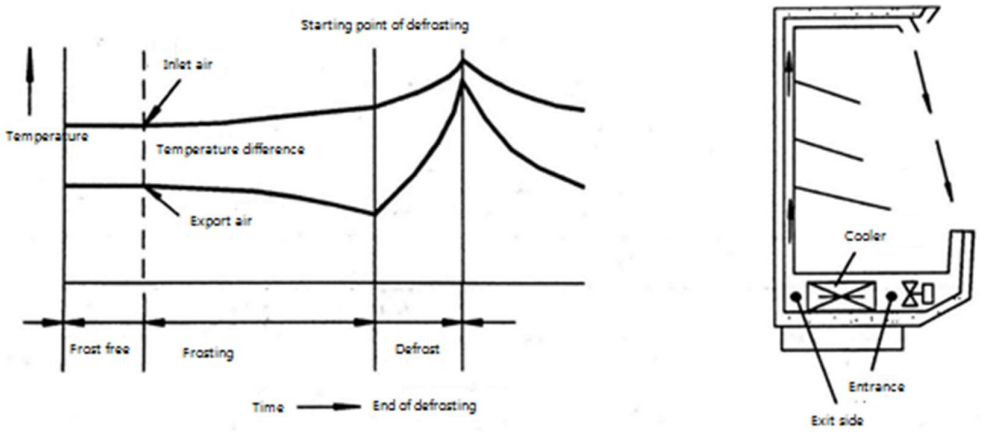


Figure 2-7 Detect Defrost Controller

Throttle mechanisms usually use thermal expansion valves, and small refrigeration cabinets in units also use capillaries as throttle mechanisms. When using capillary, the charge of refrigerant should be strictly controlled.

Although the shape of the refrigerated display cabinet used for flower display and sticking is similar to that of the above display cabinet, it has the following three characteristics:

(1) The temperature in the cabinet is higher, usually between 3 and 4 degrees Celsius.

(2) Because of the small temperature difference between inside and outside the cabinet, the thickness of the insulation layer is only 25-50 mm.

(3) The cabinet is often equipped with large glass doors or windows to improve the display effect of flowers.

In addition, the humidity in the flower cabinet is very important to the quality of flowers. The optimum humidity is 90%~95%, and the minimum cannot be less than 80%.This is to prevent excessive evaporation of water on the surface of flowers, leaves and flowers. Therefore, the evaporator has a larger evaporation area. Generally, the natural convection cooling mode is used to maintain and improve the humidity in the cabinet as far as possible. Moreover, more precise electrical control should be adopted to minimize the temperature fluctuation in the cabinet, because the large temperature fluctuation will also lead to excessive evaporation of water in flowers.

Some flower cabinets are equipped with deodorizing devices to prevent flowers from being polluted. Commonly used deodorization devices, such as activated carbon, contain potassium permanganate solution, which can be used to slow down the growth of odor sources and limit the formation of ethylene. The odor released by flowers is also absorbed by

it. In order to ensure the efficiency of deodorization device, it is necessary to ensure a certain speed of air flow, so special circulating fans should be set up.

2.5 Relevant standards for refrigerated display cabinet products in China

There are 14 relevant standards for refrigerated display cabinets in China, as detailed in Table 2-3.Compressors, expansion valves, evaporators, condensers, fans and other key components of refrigeration system of refrigeration display cabinets and accessories products are in accordance with the relevant standards of small refrigeration devices.

Table 2-3 Summary of Relevant Standards for Automotive Air Conditioning in China

1	SB/T 10794.1-2012	Commercial refrigerators Part 1: Terminology	Active	2012-12-01 Implementation
2	SB/T 10794.2-2012	Commercial refrigerators Part 2: Classification, requirements and test conditions	Active	2012-12-01 Implementation
3	SB/T 10794.3-2012	Commercial refrigerators Part 3: Beverage refrigeration display cabinets	Active	2012-12-01 Implementation
4	DB31/647-2012	ENERGY EFFICIENCY LIMITED VALUE AND ENERGY EFFICIENCY GRADE OF COMMERCIAL REFRIGERATOR	Active	2013-02-01 Implementation
5	GB 26920.2-2015	Energy efficiency limits and energy efficiency grades for commercial refrigerators Part 2: commercial refrigerators for self-contained condensing units	Active	Implementation of 2017-01-01
6	JB/T 7244-1994	Food freezer	Active	1995-07-01 Implementation
7	GB/T 21001.1-2015	Refrigeration display cabinets Part 1: Terminology	Active	Implementation of 2016-04-01
8	GB/T 21001.2-2015	Refrigeration display cabinets Part 2: Classification, requirements and test conditions	Active	Implementation of 2016-04-01
9	GB/T 21001.3-2015	Refrigeration display cabinets Part 3: Test evaluation	Active	Implementation of 2016-04-01
10	GB/T 24986.2-2010	Reliability evaluation methods for household and similar electrical appliances	Active	2010-12-01 Implementation

		Part 2: Special requirements for refrigerators (freezers)		
11	QB/T 2964-2008	Requirements for Recycling and Utilization of Household Refrigerators (Refrigerators)	Active	Implementation of 2008-09-01
12	GB/T 26689-2011	Rigid polyurethane foam for refrigerators and freezers	Active	Implementation of 2011-12-01
13	HG/T 4960~4961-2016	Rigid polyurethane foam for insulation board and polyurethane rigid foam combination polyether for refrigerator and freezer	Active	Implementation of 2016-09-01
14	HG/T 4961-2016	Polyurethane rigid foam composite polyether for refrigerators and freezers	Active	Implementation of 2016-09-01

Chapter Ⅲ. Research Significance

At present, the scale of cold chain logistics in our country is expanding rapidly, and the demand for refrigerated display cabinets has been greatly increased by all social units. Therefore, improving the performance of refrigeration system of refrigeration display cabinet and saving production cost are of great significance to the whole industry.

3.1 Energy-saving ways of refrigerated display cabinets

With the continuous development of large supermarkets, the use of refrigerated display cabinets is increasing, and the energy saving of refrigerated display cabinets becomes more and more important. Taking a standard supermarket in Japan as an example, the electricity consumption for refrigerated display cabinets will account for more than half of the total supermarket, as shown in Figure 3-1.But the energy saving of refrigerated display cabinet needs not only the development of refrigerated display cabinet technology, but also a series of matching technology development with the use and operation of refrigerated display cabinet.

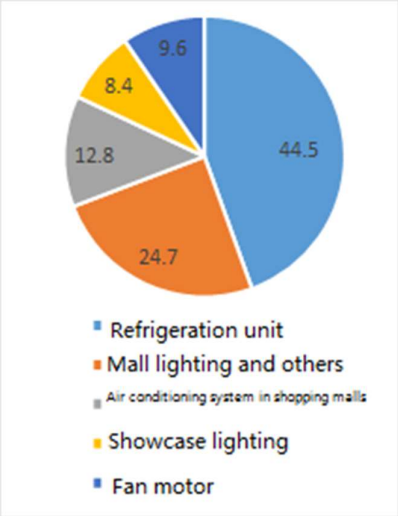


Figure 3-1 the electricity consumption of supermarket

Energy consumption is an important indicator for the development of refrigerated display cabinets. Over the years, domestic and foreign manufacturers have attached great importance to energy saving of display cabinets. Many measures have been taken to reduce energy consumption and promote the renewal of display cabinets. The most important one is the optimization of refrigeration system. Other related indicators are summarized as follows:
Figure 3-1 Percentage of electricity consumption in supermarkets

(1) The use of high-efficiency honeycomb outlet makes the air distribution of the cold air curtain uniform, reduces the load in the cabinet, and reduces the required air flow of the circulating fan by 40%.

(2) Increasing the evaporator area of refrigerated display cabinet can not only increase the evaporator temperature, but also prolong defrosting time and reduce defrosting times.

(3) Installation of the transformer of the fluorescent lamp in the cabinet from inside to outside can reduce the calorific value. Usually, the calorific value of the transformer of 40W fluorescent lamp is 8-10W.The energy consumption can be saved by 20% by replacing the illumination inside the cabinet with the illumination outside the cabinet.

(4) Double (or multiple) air curtain is used in vertical multi-stored refrigeration display cabinet. As shown in Fig. 3-2 and Fig. 3-3, double air curtain has two independent air supply loops, and generally only the inner loop has a cooler.

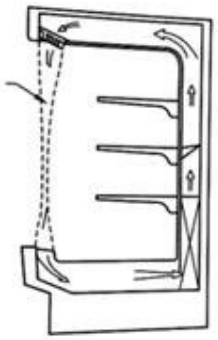


Figure 3-2 Single air curtain

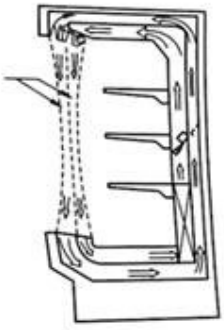


Figure 3-3 double air curtain

The cold air outlet of the single air curtain structure is generally in the front and upper part of the display cabinet and the whole back of the cabinet. In order to prevent overflow,

the air velocity of the cold air is low. The thickness of the air outlet in the front and upper part of the cabinet is usually 50-80 mm, and the cold air surrounds all the display goods.

The double air curtain can increase the wind speed and the thickness of the air curtain can be doubled. It is an active cooling structure. It can produce the following effects:

1) Refrigeration system optimization of refrigeration display cabinet.

2) The increase of air velocity in outlet can reduce the difference between air temperature in cabinet and commodity temperature.

3) The air curtain is relatively stable, little affected by the outside world, and the heat of intrusion decreases with it. At the same time, the number of defrosting decreases.

It can be seen from the above that the use of double air curtain can reduce the refrigeration required to maintain a constant cabinet temperature (see Table 3-1), save energy for refrigerated display cabinets, and also improve the freshness of goods.

Table 3-1 Comparison of Refrigeration Load of Single and Double Structure Refrigeration Display Cabinet

Stored food	Types of air curtain		Stored food	Types of air curtain	
	Single weight	double		Single weight	double
Commodities and dairy products	100W	53W	Fine meat and fresh fish	100W	55W

The freezing load of the single reconfigurable cabinet is 100W (environmental conditions: temperature is 25˚C; humidity is 60%; Japan Refrigeration and Air Conditioning Industry Association).The cost of using double air curtain is only a little higher than that of using single air curtain for refrigeration display cabinet, but the required power of refrigeration machine is reduced accordingly. Therefore, the original cost of the whole refrigerated display cabinet is basically the same. The use of double air curtain is conducive to saving operating costs, which makes the long-term operation more economical.

(5) According to the change of day and night temperature, illumination and the heat load of goods in the cabinet, the temperature of forced flow of cold air is controlled. By using automatic temperature controller, the temperature of circulating air can be increased appropriately at night, or the shutdown can be interrupted to prevent the air from passing through the cold, so as to save energy and reduce the frequency of defrosting.

(6) Prevent shell from condensation. In addition to structural research and improvement, according to the seasonal variation of air temperature and humidity, the power-on time of the heater is controlled.

(7) Defrost regularly. It can improve the efficiency of evaporator, reduce the temperature difference between air and refrigerant in cabinet, increasing the temperature of evaporator and save the power consumption of compressor.

(8) Hot steam defrosting with uninterrupted refrigeration is adopted. This defrosting method uses two evaporators, one evaporator for refrigeration, the other evaporator for defrosting, so that the refrigeration display cabinet can be continuously refrigerated. At the same time, in order to ensure the cooling fan cycle of the evaporator in refrigeration, switching valve, solenoid valve and automatic control circuit are installed in the pipeline, and the two evaporators can also refrigerate at the same time. Another way is to have three evaporators to defrost or set the main evaporator one by one, and the main evaporator is refrigerated by the auxiliary evaporator when defrosting.

Table 3-2 Comparisons of closed refrigerated display cabinets and open refrigerated display cabinets

Types of display cabinets	**Open refrigerated display cabinet**		**Closed refrigerated display cabinet**
	Vertical multilayer	**horizontal**	
Effective Content Volume/Power Consumption	**30**	**65**	**100**
Display area/power consumption	**40**	**90**	**100**
Frequency of defrosting (times/day)	**4~6**	**2~3**	**1~2**

(9) Choose the appropriate structure of refrigerated display cabinet. Refrigeration display cabinets in supermarkets generally use shelf mode, which is convenient for customers to choose, but also can effectively use the area of the shopping mall. Therefore, vertical multi-stored open refrigeration display cabinet occupies the mainstream in supermarkets, but from the point of view of energy saving and maintaining constant temperature in the cabinet, horizontal refrigeration display cabinet and closed refrigeration display cabinet are better

than multi-stored open refrigeration display cabinet. Therefore, for goods with high energy consumption and low sales, closed refrigeration display cabinet or combined refrigeration display cabinet with upper closed and lower horizontal open can be used. Table 3-2 compares the effective content area and display area per unit power consumption from the perspective of energy conservation and the frequency of defrosting from the perspective of freshness (temperature fluctuation).

(10) Intelligent refrigeration display cabinet with computer

The refrigeration display cabinet with computer calculates, compares and judges the signal data given by sensors placed in different parts of the refrigeration display cabinet according to the changes of the surrounding environment of the refrigeration display cabinet such as seasons, days and nights, setting places and so on, so as to control the most suitable refrigerant flow, temperature in the cabinet and the number of defrosting times of the refrigeration display cabinet. At the same time, it is equipped with a monitor. To improve food freshness and energy-saving effect.

Refrigerant flow control is to replace the usual thermal expansion valve with high precision electronic expansion valve. The temperature of the evaporator is sensed by sensors, and the most suitable superheat and opening degree of the valve are calculated and determined by computer. Thus, the refrigerant flow can be accurately controlled and the evaporator can be used most effectively to save energy.

Temperature control in the cabinet is to judge the temperature, humidity, illumination status and the surrounding environment of the new shopping mall by computer according to the sensor data of each part, and calculate the appropriate temperature of air curtain, so that the refrigerated display cabinet can keep a certain temperature for a long time. It improves the freshness of food from the point of preventing the overcooling of the cabinet and makes the cabinet run energy-saving.

The defrosting control is to monitor the temperature of defrosting by computer and control the defrosting time according to the frost state, so as to ensure that the temperature in the cabinet does not rise excessively. Due to the precise control of refrigerant flow and temperature in the cabinet, the defrosting capacity of the evaporator is significantly reduced, which also reduces the temperature fluctuation of the refrigerated display cabinet (improves freshness), and makes the refrigerated display cabinet energy-saving. The monitor can be expressed by either data signal or glimpse. Therefore, it is easy to realize the freshness management of food in cabinet and the occurrence of abnormal phenomena in early treatment.

(11) Using reflective covers

Shopping mall lighting produces a lot of radiation heat to refrigerated display cabinets, which will affect the quality and shelf life of display goods. Refrigeration cover plate installed in refrigeration display cabinet can save energy consumption by 20%~30%, and improve the storage quality of goods.

(12) Using heat recovery system

In large supermarkets, the cooling of refrigeration display cabinets can be recovered in summer and the condensation heat produced by refrigeration units can be recovered in winter. If the cold air escaped from the front of the refrigeration display cabinet can be recycled, filtered and flowed into the air conditioner, it can also be used directly as air conditioning in shopping malls. During the transition period between winter and summer, the recycled cooling air can be properly controlled to dehumidify the shopping mall.

Most of the refrigeration display cabinets in supermarkets are open refrigeration display cabinets, so they are easily affected by the market environment. Especially with the increase of the temperature of the market, the power consumption increases, the temperature inside the cabinet is unstable, and the number of defrosting increases. Therefore, the appropriate environment and heat recovery system in the market can not only save energy effectively, but also bring benefits to the freshness management.

(13) Parallel operation of multiple units

In winter, the load is only 20%~60% in summer because of the different operating temperature. If a unit is used, the unit will be in partial load operation for most of the year. In contrast, the parallel operation system of multiple compressors can stop the compressor operation in turn according to the refrigeration display cabinet compound, and concentrate the load on the compressor still in operation, which can not only ensure higher evaporation temperature but also improve efficiency. Table 3-3 lists the energy-saving effects of many units operating throughout the year.

Units assembled according to need can also run in parallel with more units. At the same time, compared with the principle of the combination system mentioned above, the parallel operation of multiple units can be replaced by other compressors even if one compressor fails, so the reliability of operation can be improved.

Table 3-3 Energy-saving Effect of Multiple Refrigerators

Cabinet type	2 sets / single station		3 sets / single station	
	Consumer electricity ratio (%)	Decline rate (%)	Consumer electricity ratio (%)	Decline rate (%)
Fruits and vegetables	84.0	16.0	77.8	22.2
Meat and fish	93.2	6.8	84.2	15.8
Cold drinks and snacks	99.9	0.1	96.9	3.1
Average	91.7	8.3	84.1	15.9

3.2 Refrigeration system optimization

The most important component of refrigeration display cabinet is its refrigeration system. Its performance is closely related to the performance of refrigeration display cabinet. According to Figure 3.1, 62.5% of the energy consumption in supermarkets is caused by refrigerated display cabinets, and 44.5% of the energy consumption is concentrated in refrigeration system of refrigerated display cabinets. It can be seen that the optimization of refrigeration system plays a vital role in improving the performance of refrigerated display cabinets and energy saving.

To improve the performance of refrigeration system of refrigeration display cabinet, the following five aspects can be optimized. Firstly, the optimization of refrigeration compressor; secondly, the upgrading of refrigeration system; thirdly, the optimization of system matching; fourthly, refrigerant updating; fifthly, the optimization of heat exchanger.

3.2.1 Refrigeration compressor optimization

Refrigeration compressor optimization mainly through

1) Improve the compression efficiency, such as reducing suction overheating, reducing relative clearance volume, reducing leakage, reducing pipeline pressure loss;

2) Improving the mechanical efficiency, such as improving the processing accuracy;

3) Improve the efficiency of motor and apply frequency conversion technology.

The selection of refrigeration compressor is mainly based on the exhaust volume, input power and refrigeration capacity of the compressor in operation, that is, the performance requirements of the refrigeration system for the compressor.

3.2.2 Refrigeration system upgrade

The refrigeration system upgrading of refrigeration display cabinet mainly includes the following means:

(1) The evaporator is divided into two stages. Because the air temperature and humidity of the first stage are higher, the first stage refrigerator with higher evaporation temperature can be used for pre-cooling; the second stage refrigerator with lower evaporation temperature can make the air temperature lower than the required temperature enter the cabinet. It not only saves 8%~10% of electricity consumption, but also reduces the number of defrosting, which is beneficial to commodity quality management.

(2) Multi-stage compression freezer. As mentioned above, the evaporator is divided into two stages, which can be composed of two different suction pressures, and can control different evaporation temperatures according to different requirements of commodity quality and shelf life, so as to save energy.

3.2.3 Optimal matching of systems

The optimum matching of the system can start from four aspects.

(1) The climate type in the design of refrigerators should be matched with the climate in the use area, otherwise the power consumption will increase.

(2) The matching of refrigeration dosage in refrigeration system will affect the refrigeration effect.

(3) The matching of capillary length, diameter and flow rate, if the length of capillary is too long or the diameter of capillary is small, the pressure difference will be larger when throttling, the flow rate of refrigerant will be smaller, the evaporation temperature will be lower, and the exhaust volume of compressor will be smaller, which will reduce the refrigeration capacity of refrigeration system.

(4) In the design of refrigerators, the selection of working time coefficient is also very important. Compressor working time is too short and start frequently, it will lead to higher energy consumption because of high starting power; if the working time is too long, the compressor always works at a lower evaporation temperature, the compressor working efficiency is too low, and energy consumption will also rise.

3.2.4 Refrigerant renewal

With the destruction of ozone layer by Freon refrigerants becoming more and more serious, the society pays more and more attention to environmental protection, and a series of regulations on the use of Freon refrigerants have been issued internationally. In October 1984, the United Nations adopted the Trend Memorandum of Understanding, requiring countries to substantially reduce the production and demand of Freon. In March 1985, the United Nations adopted the Vienna Convention for the Protection of the Ozone Layer, which

clearly pointed out the possible harm to human health and the environment caused by the depletion of the atmospheric ozone layer. Governments were called upon to take cooperative action to protect the ozone layer, and HCFCs were first introduced as monitored chemicals. In September 1987, the Montreal Agreement was adopted, which specifically proposed to limit the production and sale of CFCs such as R11, R22, R113, R114 and R115. By 1998, the production of CFCs would be gradually reduced to 50% of the production level in 1986, and such products would be eliminated as far as possible at the beginning of the next century. The convention also provides for a complete ban on widely used HFCs refrigerants such as R22, which must be completely banned in developed countries by 2030 and no later than 2040.At the beginning of 1999, China introduced a measure aimed at protecting the ozone layer, which included the following plan: "By 2010, China will completely prohibit the production and use of ozone-depleting substance, Freon." According to this plan, China should freeze the production and consumption level of CFCs from July 1, 1999 to the average level in 1995-1997, and then decrease year by year. By January 1, 2010, CFCs were banned. On September 27, 2010, the Ministry of Industry and Information Technology and other three departments jointly issued the announcement of the List of Controlled Ozone-Depleting Substances in China, which stipulates that the production of CFC, HCFC and other substances should be stopped or restricted. Development and Reform Commission of the Ministry of Environmental Protection of Developing Countries

At the same time, the research of new refrigerants and the research of new refrigeration systems for refrigeration display cabinets are also developing.

For this reason, the refrigerant R404A is widely used in the medium and low temperature system, such as new commercial refrigeration equipment and transportation refrigeration equipment. Non-azeotropic refrigerant R404A has the characteristics of cleanliness, low toxicity, non-flammability and good refrigeration effect. Its refrigeration capacity per unit volume and saturation pressure are equal to those of R22, and it has good thermodynamic characteristics. Its ODP is 0, so R404A is an environmentally friendly refrigeration that does not destroy the ozone layer in the atmosphere.R404A is also the main refrigerant used to replace R22 and R502 in the current market.

3.2.5 The optimization of heat exchanger

Heat exchanger occupies an important position in refrigeration system of refrigeration display cabinet in volume and weight, and its weight occupies more than 50% of the whole refrigeration device. Its characteristics also have a direct impact on the refrigeration system

and the overall performance of refrigeration display cabinets. In recent years, copper prices have risen rapidly, and the research of heat exchangers with small diameter has attracted more and more attention. Considering cost saving, energy efficiency improvement and environmental protection, the application of smaller diameter heat exchangers in refrigerated display cabinets can significantly reduce copper consumption and effectively reduce the cost of heat exchangers. At present, the products of refrigerated display cabinet mainly use 9.52mm or 7mm copper tubes. If the diameter of the pipe is reduced from 9.52 mm to 5 mm, the surface area of the copper pipe per unit length decreases, and the copper consumption per unit length decreases. In fact, due to the increase of compressive strength, the wall thickness of copper tubes can also be thinned, and the use of copper materials will be greatly reduced. At the same time, the small volume also greatly reduces the refrigerant charge, saves the cost and reduces the harm to the environment.

Figure 3-4 9.52mm copper tube heat exchanger and 5mm copper tube heat exchanger

From the proportion of various optimization methods to improve the performance of refrigerators, we know that the optimization of heat exchangers accounts for more than 50%. It is conceivable that reducing the diameter of copper tubes of heat exchangers can bring new opportunities to the refrigeration display cabinet market. Therefore, the research of 5 mm small diameter heat exchanger in refrigeration display cabinet replacing the original large diameter heat exchanger has far-reaching significance, and has a far-reaching impact on the sustainable development of the industry.

ChapterⅣ. Feasibility Analysis and Calculation of Small Diameter of Heat Exchanger in Refrigeration Display Cabinet

The main heat transfer and pressure drop performance of the heat exchanger with small-diameter copper tube also change, which leads to the change of the system performance. After the pipe diameter is reduced, because of the limitation of processing technology, it also brings new challenges to the application of small diameter. In order to analyze the necessity and feasibility of substituting small-diameter copper tubes for small-diameter copper tubes in refrigeration display cabinets, it is necessary to systematically analyze the advantages of small-diameter copper tubes, as well as the effects of small-diameter copper tubes on heat transfer performance, pressure drop performance and system performance of heat exchangers. Based on theoretical analysis and experimental results, the difficulties faced by the application and promotion of small-diameter copper tubes are studied, and is there a feasible solution?

4.1 Theoretical analysis

4.1.1 The influence of reducing diameter on the performance of heat exchanger

When the heat exchanger of refrigeration display cabinet adopts smaller tube diameter heat exchanger, the direct influence on the heat exchanger is that if the original structure is adopted, the heat transfer area in the tube decreases, and the heat transfer coefficient and pressure drop on the refrigerant side of the tube increase. The increase of heat transfer coefficient at refrigerant side can improve the heat transfer performance of heat exchanger, but the decrease of heat transfer area and the increase of pressure drop can reduce the heat transfer performance of heat exchanger and the energy efficiency of the system. Therefore, it is necessary to evaluate comprehensively the effect of small-diameter heat exchanger tubes on the performance of refrigerated display cabinets in theory.

4.1.2 The influence of reducing diameter on heat transfer coefficient in pipe

(1) In narrow channels, the thickness of flow boundary layer decreases greatly, so the heat conduction resistance of fluid decreases greatly and the heat transfer rate increases greatly.

(2) At the same time, because of the small diameter, the contact surface area of fluid and channel per unit volume is much larger than that of fluid and channel per unit volume in conventional channel, so that the heat transfer capacity per unit volume of channel is higher than that of conventional heat exchanger.

4.1.3 The influence of diameter reduction on pressure drop of heat exchanger

According to Darcy's formula (Formula 4-1) of resistance loss along turbulent flow, it can be obtained from a large number of experiments that the greater the velocity in the pipe, the greater the resistance loss along the pipe. At the same time, the smaller the diameter of the pipe, the greater the restraint effect of the pipe wall on the fluid and the greater the flow resistance, so the smaller the diameter of the pipe, the greater the resistance loss along the way. These trends have also been verified by a large number of experiments. Therefore, under the same refrigerant flow rate, the flow resistance of small diameter tube is much higher than that of large diameter tube, and the pressure drop of refrigerant side in tube is too large.

$$\frac{\Delta P}{L}=\left[f_m+\left(\frac{x_o-x_i}{x_m}\right)\frac{D_i}{L}\right]G\left(\frac{4m}{\pi D_i^2}\right)^2\frac{v_m}{D_i} \tag{4-1}$$

Formula:ΔP Pressure drop of refrigerant, kPa; D_i for inner diameter, m; G for mass flow in tube, kg/s.

At the same time, according to the research of Siaka Toure etc., the pressure drop of refrigerant is inversely proportional to the fourth power of heat exchanger tube diameter. This shows that a slight decrease in the diameter of the tube may lead to a drastic increase in the pressure drop of the heat exchanger. Excessive pressure drop is the main problem in the design of small-diameter heat exchangers. It is necessary to arrange the refrigerant side flow path reasonably. By increasing the number of parallel branches and reducing the length of each branch appropriately, the pressure drop of heat exchanger can be balanced.

4.2 Theoretical calculation

In order to better understand the effect of reducing the diameter of heat exchanger on the refrigeration performance of refrigerated display cabinet, this report verifies the feasibility of replacing the small diameter of heat exchanger of refrigerated display cabinet by a series of theoretical calculations. The theoretical calculation is as follows.

4.2.1 Analysis of 9.52mm tube-diameter heat exchanger prototype

According to the prototype of heat exchanger provided by Party A, the parameters and heat transfer performance of the prototype are analyzed. Existing condensers use copper tubes with a diameter of 9.52mm. The main view is shown in 4-1.

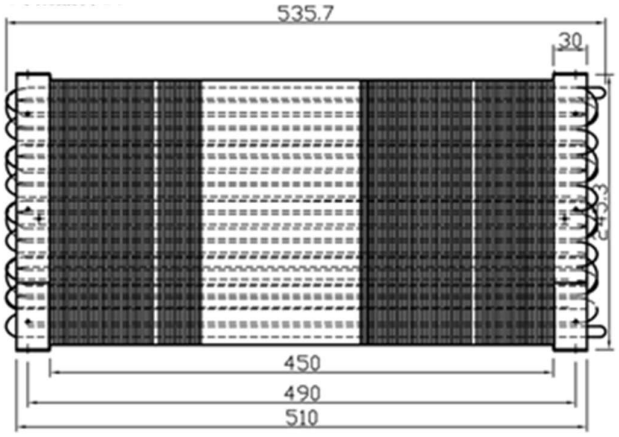


Figure 4-19.52mm tube-diameter heat exchanger prototype

The tubes are arranged in 3 rows and 9 rows. The effective length of heat exchanger tubes is 450 mm, and the spacing of aluminium fins is 2.7 mm.

Pipe row spacing is 21.65 mm and segment spacing is 25 mm. The heat transfer area is 4.79 m^2, the effective cross-sectional area is 1649.6 mm^2, the lateral area of the long fins per meter is 0.35 m^2, the area between the long fins per meter is 0.028 m^2, the total area outside the long tube per meter is 0.38 m^2, and the area inside the long tube per meter is 0.028 m^2.

4.2.2 Preliminary design

Under the premise of constant heat transfer, heat exchangers are designed to minimize pressure drop and improve heat transfer performance. So only assuming that the heat transfer capacity of heat exchanger is constant, 9.52 mm copper tube is replaced by 5 mm small diameter tube. The reference basis is as follows.

1) The heat transfer correlation refers to the correlation of heat exchange and pressure drop characteristics of R410A condensation in small diameter tubes by X. C. Huang et al.

2) Pipeline optimization refers to Ding Weiling and so on. The numerical simulation of small diameter air conditioning condenser is carried out and the flow design idea is given. It is considered that under the same number of heat exchanger tubes, the number of parallel branches should be increased and the length of each branch should be appropriately reduced. To balance the pressure drop.

3) The influence of pipe diameter on the energy efficiency of the whole system is analyzed by referring to Ren Tao. As far as the performance of the whole machine is concerned, the heat transfer efficiency of small diameter copper tube heat exchanger is better than that of large diameter copper tube heat exchanger, and its structure is more compact.

4) Many experts and scholars have studied the heat transfer, pressure drop and pipeline optimization of small diameter pipes.

4.2.3 Computational comparison

The preliminary design of 5 mm small diameter heat exchanger was compared with 9.52 mm tube diameter heat exchanger prototype. Under the same initial heat transfer rate, the performance parameters were calculated and compared. It is concluded that the heat transfer coefficient inside and outside the tube of small-diameter heat exchanger is increased by 30-50% and the total heat transfer coefficient of the heat exchanger is increased by 10-20%. Through preliminary pipeline arrangement, the number of branches is increased appropriately, the length of single tube is reduced, and the actual copper saving of small-diameter heat exchanger is 8-15%.

According to the calculation results, the reasons for the change of parameters are analyzed.

1、Heat transfer coefficient on the outside of the tube: The narrowest equivalent diameter of the element on the outside of the tube decreases, which increases the efficiency of the fin and the heat transfer area of the fin, which leads to the increase of the heat transfer coefficient on the outside of the tube.

2、Heat transfer coefficients inside and outside the tube: Because the diameter of the tube inside the tube decreases, and the mass flow rate remains unchanged, the mass flow rate increases, which affects the increase of the heat transfer coefficient inside the tube. The heat transfer coefficient in the tube increases with the increase of mass flow rate, and the smaller the diameter of the tube, the more obvious the trend is.

3、Heat transfer area: As the heat transfer coefficient inside and outside the tube increases, the total heat transfer coefficient of the heat exchanger increases, and the heat transfer area of the heat exchanger decreases while the refrigeration capacity remains unchanged.

4、Length of tube: The total heat transfer area of heat exchanger decreases, and the heat transfer area per unit length decreases. The decreasing trend of the heat transfer area per unit length of tube is larger than that of the total heat transfer area of heat exchanger, and the total length of tube increases.

5、Refrigerant charge: Reducing the diameter of the tube can greatly reduce the volume of heat exchanger, while saving copper, it can also reduce the refrigerant charge.

After a series of theoretical calculation and parameter comparison, 5 mm small diameter heat exchanger has certain advantages in heat transfer effect and cost consumption. It can be considered that the replacement of 5 mm small diameter heat exchanger in refrigerated display cabinet is feasible in theory.

Chapter V. tentative ideas for experimental research

It is not enough to design a small-diameter heat exchanger for refrigeration display cabinet only by calculation. In order to provide sufficient and reliable calculation basis for theoretical analysis and design of small-diameter heat exchanger, it is necessary to carry out corresponding experimental research. The experimental study on the performance of small-diameter heat exchangers is planned as follows.

5.1 Single tube experiment

5.1.1 The necessity of studying the relation of heat transfer with small diameter

After consulting a large number of literatures, it is found that there are many correlations between condensation heat transfer and pressure drop for R404A, but they are all based on 7 mm or 9.52 mm large diameter light tube or intensified tube, and there is no correlation between condensation heat transfer and pressure drop for R404A small diameter finned tube heat exchanger.

In this study, a number of correlations related to condensation heat transfer and pressure drop of R404A heat exchanger were screened out by means of control variable method and refrigerant priority method, combined with experimental research, and on this basis, a new correlation between heat transfer and pressure drop was proposed and verified by experiments. Applicability and deviation.

5.1.2 Single tube experiment content

The schematic diagram of the experimental device is shown in Fig. 5-1.

Fig. 5-1 schematic diagram of single-tube experimental device

The experimental device consists of two main cycles: one is refrigerant cycle system, including test section, condensation section and re-cooling section, and the other is refrigerant water cycle system for R404A condensation. The flow rate of refrigerant and refrigerant water is adjusted by changing the speed of the pump through the frequency converter and cooperating with the regulating valve. The refrigerant water loop includes the test section water loop, the condensation section water loop and the re-cooling section water loop.

Before refrigerant entering the test section, the inlet dryness of refrigerant is adjusted by electric heating. The refrigerant water loop in the test section is used to simulate the actual working conditions of the refrigeration display cabinet heat exchanger and control the heat

flux in the test section under different working conditions. At the same time, it provides conditions for studying the condensation heat transfer and pressure drop characteristics of R404A under different dryness and different mass flow rates. The heat transfer rate of refrigerant water is realized by adjusting the flow rate of refrigerant water or the temperature of refrigerant water. The temperature of refrigerant water is controlled by adjusting the electric heating in the refrigerant water circulating system reasonably through the PID controller, so as to keep the water temperature stable.

The range of test conditions is shown in Table 5-1.

Table 5-1 Experimental Conditions of R404A Condensation Heat Exchanger

Test parameters	Test scope
Condensation temperature/（℃）	40~50
Condensation pressure/（MPa）	1.82~2.28
External diameter/（mm）	5
Length/（mm）	1500
Heat flux/（kW/m^2）	0.7~1.0
Vapor quality	0.1~0.9

During the experiment, the experimental data were collected by a data acquisition instrument. The collected parameters were refrigerant temperature T, tube wall temperature T_{wo}, absolute pressure P_{in} and P_{out} at the entrance and exit of the test section, refrigerant pressure drop P, refrigerant mass flow q, refrigerant water mass flow q', and inlet and outlet temperature of refrigerant water. The pressure drop and heat transfer coefficient of R404A flow through the test section can be calculated directly or indirectly from these parameters.

5.2 Design and Simulation of small-diameter heat exchanger

5.2.1 The necessity of studying the flow path of small diameter heat exchanger

When the diameter of the tube decreases, the pressure drop of the heat exchanger rises sharply along the way. It is necessary to balance the adverse effects on the performance of the heat exchanger caused by the increase of the pressure drop through the rational design of the flow path. In addition to passively adjusting the flow path to keep the heat transfer performance unchanged, the active convection path should be improved and optimized to reduce the effective heat transfer area under the same heat load and consequently save copper consumption. In addition, reasonable flow path design can also make the refrigerant flow and heat transfer of each branch uniform, so that each part of the heat exchanger can achieve a

higher heat transfer coefficient, so that the heat transfer performance of the heat exchanger is better.

5.2.2 Influencing factors of flow path design

After consulting the literature, it is found that there is a lack of detailed research on flow design, and the existing research on flow structure is relatively limited, which is not practical in engineering. Or the conclusion is not perfect, and specific conditions of use need to be limited. The key point is that when the diameter of copper tube decreases, the flow path design cannot completely replicate the original method of large diameter heat exchanger, which needs to be adjusted.

There are many factors affecting the heat transfer performance of heat exchangers. In addition to the arrangement of refrigerant side flow path, the longitudinal and transverse tube spacing, the form and structure of fins outside the tube are all related to the performance of heat exchangers.

5.2.3 Design ideas

On the basis of reading a large number of Chinese and English literatures, using the method of logical verification, mutual verification of text and text, some inaccuracies and even errors are eliminated, and the principle of optimum flow path design for small-diameter heat exchangers is summarized. The optimum longitudinal and transverse tube spacing is calculated, and the form and structure of fins outside the tubes are integrated. The calculation experiment is assisted by Coil Designer or EVAP-COND numerical simulation. Several preliminary optimization design models were obtained, and then the performance of small-diameter heat exchangers was further verified by experiments.

5.3 Substitution performance testing of small diameter heat exchanger

5.3.1 Purpose of entity performance testing

A lot of work was done in the early stage to determine the heat transfer correlation. The design calculation of 5 mm small-diameter heat exchanger was carried out, mainly for the distribution of small-diameter flow path and the design of new small-diameter heat exchanger. In order to make the research more rigorous and convincing, the performance of the small-diameter heat exchanger was tested, that is, the performance of the heat exchanger was verified by experiments.

5.3.2 Method for testing the performance of small-diameter heat exchangers

The heat transfer performance of small-diameter heat exchanger was tested by enthalpy difference laboratory or heat balance laboratory.

Enthalpy difference laboratory or heat balance Laboratory for performance test of small-diameter heat exchanger is to provide a test standard environment for 5 mm small-diameter heat exchanger of refrigeration display cabinet, and provide - 10 C ambient temperature conditions to test the performance indicators of evaporator; provide 45 C ambient temperature conditions to test the performance indicators of condenser to meet the research and development of small-diameter heat exchanger products. Performance and reliability testing requirements.

When heat exchanger is tested, the air intake state is controlled by the temperature and humidity of the room; the refrigeration pipeline of the heat exchanger is connected to the refrigeration system of the device, and the test is completed by the enthalpy difference test device and the refrigeration device.

5.4 Testing of the whole machine

On the basis of the above work, according to the national standard "GB/T 21001.2-2015 refrigerated display cabinet Part 2 Classification, Requirements and Tests", the whole refrigerated display cabinet is tested, and the performance of the whole machine is verified by experiments.