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Green Solutions To Facilitate Heat Pump Technology Adoption For Tobacco Baking Application In China

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Abstract

In the motivation of energy conservation and emission reduction, several provinces in China are promoting and subsidizing heat pump (HP) technology adoption for tobacco baking rooms to replace conventional baking room with heat resources by coal burning and others. HP technology used in tobacco baking room illustrates significant benefits for better baked tobacco leaves quality, more automation by occupying less manpower and more environment friendly with less emissions. Total solution for this application is developed with dedicated designated ZW/ZWD compressor and customized system controller, in order to facilitate OEMs and contractors to better serve end users and quickly grasp the opportunity to enter the market. One field project explains processes of tobacco baking in baking room and how Emerson solutions secure good quality of finished tobacco.

Keywords: Tobacco baking; Heat pump; Total solution for baking; CO2 emission reduction

1. Introduction

China is the largest country in the world for its planting area of flue-cured tobacco, and also the largest tobacco consumer [1]. The annual planting area of flue-cured tobacco is about 2.5 million acres, and the annual output of flue-cured tobacco leaves is about 2 million tons, accounting for more than half of the world's total volume of cured tobacco [2]. Also, flue cured tobacco is an important agricultural product among China's crops, the main raw material for cigarette production, and one of the major agricultural products exported by China, making positive contributions to the national and local financial income increase and economic development [3].

At present, the tobacco curing technology in China is still relatively backward, and coal burning intensive curing houses are widely used to bake tobacco [4]. As the main way for baking, the total coal consumption of coal-fired baking is about 3.5 million tons per year. The coal consumption is large, and the cost of baking fuel is high. The flue gas emitted after the combustion of bulk coal carries a large amount of CO2, CO, SO2, NO, H2S and PM2.5 particles, and it is unable to conduct centralized desulfurization, and dust removal, causing serious environmental pollution, which has become a serious environmental problem in the tobacco baking regions [5]. According to statistics, the annual CO2 emissions of flue-cured tobacco leaves in China are close to 8 million tons, about 600 thousand tons of smoke and dust, and 30 to 50 thousand tons of toxic gases. The anthropogenic emission of air pollution particles and carbon dioxide has become a serious environmental problem [6-8]. With the increasing shortage of fossil energy and the continuous promotion of green ecological civilization construction, new and clean energy will become the new direction used in tobacco baking in China.

Since the year of the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China, China announced to take "green development" as one of the five development concepts, and clearly proposed that: to adhere to green development, we must adhere to the basic national policy of saving resources and protecting the environment, adhere to sustainable development, and form a harmonious development between

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human and nature. In recent years, President Xi has repeatedly emphasized that "green water and green mountains are golden and silver mountains", and he pointed out that "we should accelerate the formation of a green development mode, promote win-win economic development and environmental protection, and build a global society where economy and the environment advance together."

At the same time, on September 22, 2020, at the general debate of the 75th United Nations General Assembly, President Xi announced that China's carbon dioxide emissions would strive to reach the peak by 2030, and would get to be carbon neutral by 2060, including greenhouse gas emissions in the whole economy, from carbon dioxide to all greenhouse gases. This has brought huge challenges and market opportunities to China's refrigeration, air-conditioning and heat pump industry, including agricultural drying and baking.

It is said that by the end of 2017, China has built 1.2 million intensive curing rooms, including 1.19 million coal-fired curing ones, 3000 heat pump curing rooms and 6690 other energy types [5]. With the increasing awareness of environmental protection throughout China, the voice against the traditional flue-cured tobacco production mode is becoming stronger and stronger [9]. Coal fired flue-cured tobacco is no longer in line with the development in terms of heating mode and resource utilization efficiency [10]. It is an urgent problem to develop a clean and green tobacco curing room, which also brings huge business opportunities. The upgrading, reconstruction of the old intensive curing rooms and new constructions will add a market of 70 billion yuan. The following is a further description of the relevant policies in China and technical routes of new environment-friendly tobacco curing room combined with air source heat pump technology.

2. Application and promotion of modern baking room technology

This section describes the process and development related to the baking room and tobacco baking. In the past 100 years, the baking room equipment has changed from low to high level and simple to complex. Before the 1950s, China has been using the simple clay baking room, directly making a fire to heat in it. In the 1960s, the baking technology was improved with the popularization and application of dry and wet thermometer in tobacco baking, but the baking process was mainly empirical. Into the 1970s, the baking process adopted the “high temperature and fast baking” operation technology to pursue the goal of yellow, freshness and clean. From the mid-late 1980s to the early 1990s, the 5-stage, 7-stage and 6-stage of low temperature and humidity baking processes were proposed around the country successively based on the study of baking process, but it still stayed at the low level of inspecting tobacco by human experience and burning by personal feeling. In the 1990s, the baking technology and baking room equipment in China had obvious technical progress and innovation. And the 3-stage baking process was proposed, which achieved the similar level of the international general advanced baking [11].

Now, here introduces the 3-stage process in tobacco baking, which is divided as yellow discoloration, color fixing and stem drying stage, and each stage is divided into multiple temperature rising and holding stages, as shown in Figure 1.

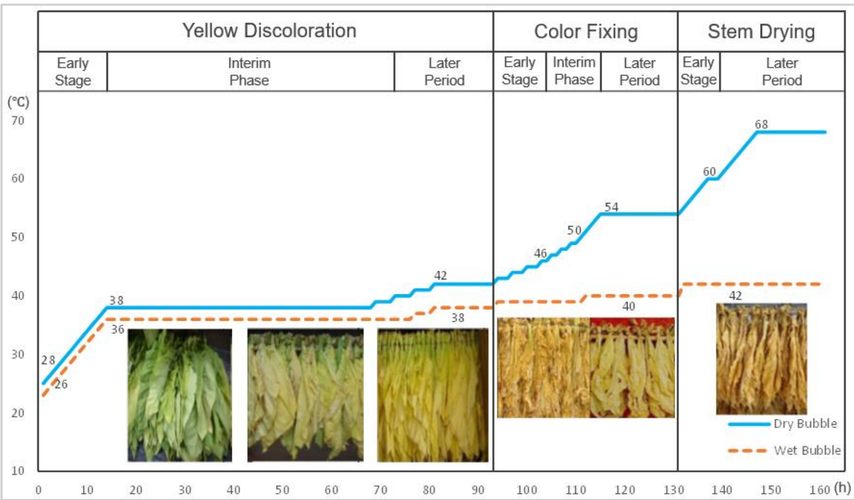

Fig.1. Tobacco Drying Process Curve

<u>Yellow discoloration stage</u>: The temperature and humidity in baking room should be gradually increased. And the temperature, humidity and baking time should be adjusted according to the actual situation of tobacco leaf change. The fresh tobacco leaves are tied reasonably and conveyed to the baking room, then start the heat pump unit. Gradually increase the temperature in the baking room to 38℃ and keep stable, with a difference of 2~3℃ between dry and wet bulb temperatures. When the tobacco leaves reach about 80% yellow, the

temperature in the baking room gradually rises to 42℃ and keeps stable. The difference between dry and wet bulb temperatures changes from 2℃ to 4℃. When the leaves become soft to fall on the shelf and yellow with little cyan, the yellow discoloration stage is completed.

Color fixing stage: The temperature in the baking room gradually rises to 54℃ with low to high heating rate. Before the temperature in the baking room reaches 50℃, the wet bulb temperature should be stabilized at 38~39℃. After the temperature in the baking room reaches 50℃, the wet bulb temperature should be stabilized at 39~40℃. The color fixing should be timely in this stage to improve the appearance grade quality and internal quality of tobacco leaves.

Stem drying stage: Temperature in the baking room gradually rises to 68℃, and the wet bulb temperature is rapidly adjusted to 41~42℃, to ensure that the whole tobacco leaves are dry and baked through, without wet stems and pieces, and swelled stems phenomenon.

With many years practice, air source heat pump system is proven that it's well controlled to stabilize the moisture content of tobacco and meet the temperature and humidity requirement of yellow discoloration, color fixing and Stem drying stage. Associated with modern control technology, heat pump system controller has multiple baking curves, which can modify the dry ball temperature, wet ball temperature and baking duration of each stage according to the local tobacco and climate status.

After seeing many and many successful projects from several provinces in China by introducing heat pump baking room technology, in order to further standardize the bidding and procurement behavior of baking room equipment, unify the construction standards and specifications of dense baking rooms, and promote the construction of new type baking rooms, the Office of the State Tobacco Monopoly Administration issued the "Management Measures for Bidding and Procurement of Baking Room Equipment" and "Revised Technical Specifications for Dense Baking Rooms (Trial)" in 2009. According to this policy, the baking room equipment to be bid must be designed and processed in strict accordance with the relevant requirements of the "Revised Technical Specifications for Dense Baking Rooms (Trial)", and suppliers are encouraged to actively carry out technological innovation and development of new equipment.

Meanwhile, Henan Tobacco Company released "Air Source Heat Pump Dense Baking Rooms" on December 15, 2020, which has been implemented on January 1, 2021. The standard specifies the basic structure, main equipment, and technical parameters of the air source heat pump dense baking rooms, and is also applicable to the new construction, reconstruction, and installation of heat pump baking room. The main components of the heat pump baking room are heating room, tobacco filling room, heat pump unit and controller. Figure 2 shows the standard requirements for the basic structure of the heat pump baking room (heating room, tobacco filling room), and Figure 3 shows the standard requirements for the display content of the main interface of the heat pump baking room controller.

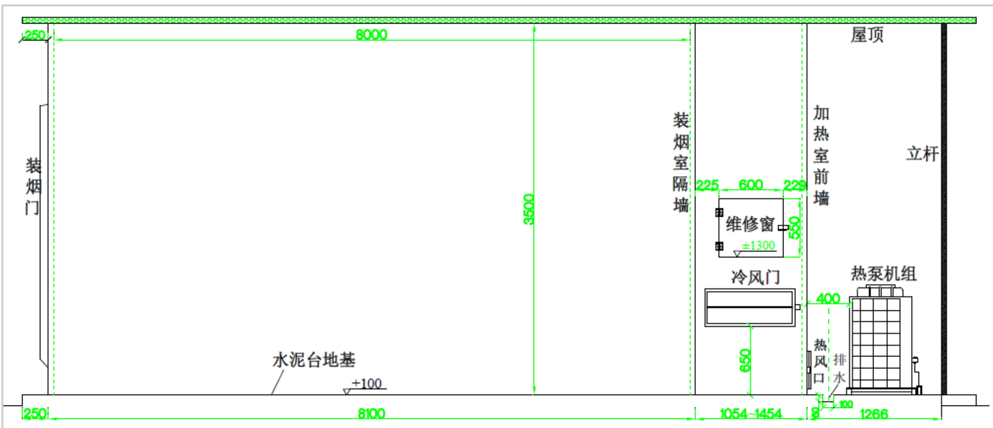

Fig.2. Defined Baking Room Size and Structure (For Reference)

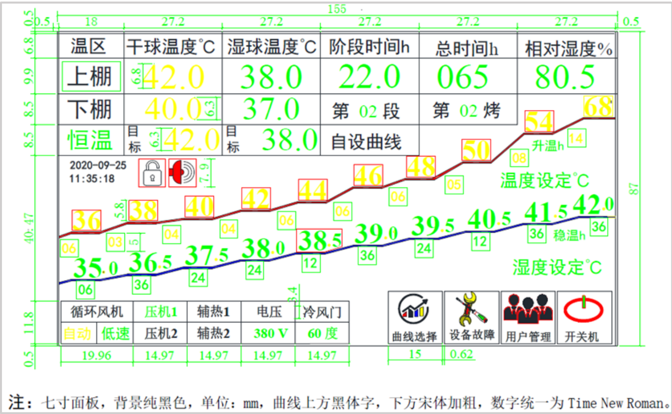

Fig.3. Defined Contents in HMI (For Reference)

3. Heat pump system design

The current application of heat pump system for tobacco baking can be roughly categorized as open loop system and closed loop system. Figure 4 shows the open loop system.

The low-temperature and low-pressure liquid refrigerant enters the evaporator to absorb the heat of the ambient air, and the refrigerant evaporates into medium-temperature and low-pressure vapor. The compressor consumes electric energy to make the pressure and temperature of gaseous refrigerant rise. Then the high-temperature and high-pressure gaseous refrigerant enters the condenser to release heat. The process of refrigerant heat release heats the return air on the other side of the condenser, so that the return air rises to a certain temperature. The refrigerant condensed into liquid is throttled by the throttle valve, and then becomes a low-temperature and low-pressure liquid, and then enters the evaporator to absorb heat. In this way, the thermal cycle process from the evaporator side to the condenser side is realized.

The performance of open loop system is greatly affected by ambient temperature. The starting and ending time of tobacco baking in different regions are not the same. When the weather is continuously rainy or the night temperature is lower than 10℃, the energy efficiency of the open loop heat pump is significantly reduced, COP is even less than 2.0, and the heat output may not meet the requirements of baking [12]. And in the late baking period, the moisture content of tobacco leaves is already low. The humidity of outdoor air can no longer meet the requirements of tobacco drying in the baking room, the only way is to reduce the relative humidity by rising the temperature of circulating air, but this will increase the load of the heat pump system. Meanwhile, the baking process requires that the temperature of the baking room should be maintained at 65~68℃ during the stem drying stage, which means the room for reducing the relative humidity by rising temperature is limited, so there are certain disadvantages and limitations for open loop system.

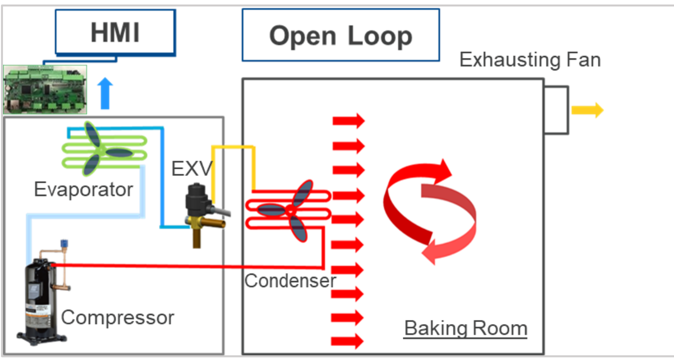

Fig.4. Open Loop Heat Pump System

Figure 5 shows a closed loop system, and the enthalpy-humidity chart of hot air cycle in the baking room is shown in Figure 6: Point R is the state of the hot air from the baking room, and it is divided into two parts. One first enters the sensible heat exchanger and is cooled from point R to point C without specific humidity change. Then enters the evaporator and is cooled and dehumidified from point C to point L. After coming out of the evaporator, it enters the sensible heat exchanger to pre-cool the high temperature air, and itself is heated from point L to point H without specific humidity change. Then it is mixed with another part of air along H-R to point M, and the mixed air enters the condenser and is heated to point S, and the air at point S is sent into the baking room along the heat-humidity ratio line to complete the hot air cycle.

Different from the open loop system, the cycle medium air of the closed loop system absorbs the moisture in the tobacco leaves in the baking room, and then dries tobacco leaves again after being dehumidified by the evaporator. The whole system basically does not introduce outdoor fresh air. Therefore, in the middle and late period of tobacco baking, the system can effectively reduce the humidity of cycle air to meet the requirements of drying process and reduce the heat load, but the dehumidification efficiency of evaporator will affect the drying efficiency of the whole tobacco baking process [12].

The closed loop system circulates the hot air in the baking room to form a closed loop heating for the baking room. So, the heat provided by it is the compressor power consumption. In the late period of tobacco baking, the heat load of the baking room decreases, but to ensure the dehumidification efficiency of the evaporator, compressor need to run continuously, causing the temperature in the baking room to continuously rise. At this time, part of the fresh air needs to be introduced to meet the requirement of baking process temperature in the baking room. The closed loop system is not affected by the ambient temperature and maximizes the retention of various fragrance substances in tobacco leaves. The heat load in the middle and late period of tobacco baking is lower than that of the open loop system because the closed loop system recycles the latent heat absorbed by the moisture in tobacco leaves when evaporating.

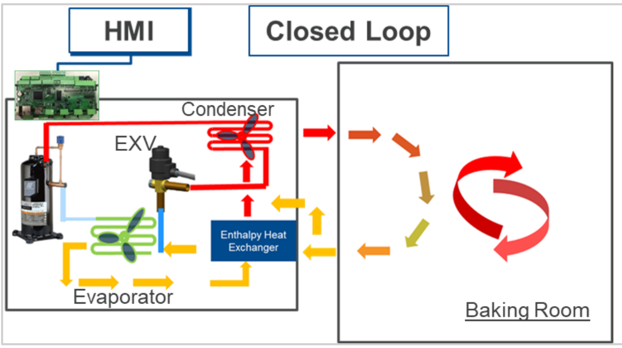

Fig.5. Closed Loop Heat Pump System

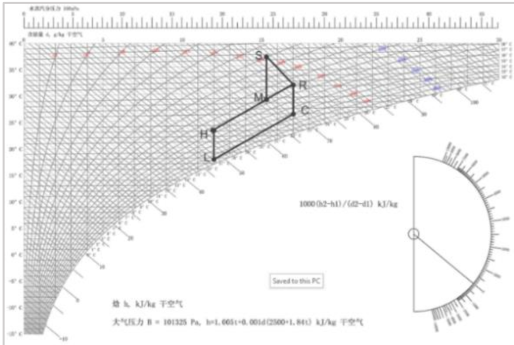

Fig.6. Enthalpy-humidity Chart Of Hot Air Cycle

After comparing the difference between open and closed loop heat pump system, these two types are commonly used in field, which reallly depend on HP OEM technical readiness and ambient temperature. In order to promote heat pump drying technology more efficiently, Emerson Asia provides an integrated and total soution for heat pump drying system from, which provide great convinent for customers to adopt with one-stop shopping. As shown in Figure 7, which offers all key compoents and then greatly simplifies the application of heat pump in drying system. This total solution includes digital and fixed compressors, programmable controller as system control, X-web monitoring, HMI (human and machine interface), temperature and pressure sensor, and electronic expansion valve for high temperature application.

Fig.7. Emerson Total Solution for Tobacco Baking

Digital and fixed compressors are designed for high evaporating and condensing temperature dyring and baking application and have superior reliability, proven in the field. Digital compressor, called ZWD, have capacity modulation with range adjustment from 10% to 100%, which could deliver precise temperature control to have better baking quality of specimen including tobacco leaves. Together with ZWD compressor, modulation controller, called XC35, is also provide to control capacity output for customer to easily adopt digital compressor with minor change to their existing HP system main controller. An optimized system control scheme is built into the system controller, called iPro Lite, to enhence system performance and reliability. It is also embedded the program for tobacco drying processes with lots of flexibilities. The electronic expansion valve (EXV), dedicated design for high temperature, is one body structure design for best sealing and qualified with high reliability. HMI is slim design and has a 7 inches LCD display with high resolution. X-web monitoring can be connected with system controller through RS485 to inspect the operating conditions and real status in baking room, and provides data for remote moniotring system.

ZWD digital scroll compressor features stepless energy regulation in the range of 10-100% to ensure accurate temperature control and reduce dry consumption of goods. To compare the temperature control curves of fixed speed compressor and digital compressor, we carried out the experiments of mushroom drying in fixed drying system and digital drying system respectively. Figure 8 shows the temperature and humidity curves in drying system's baking room with fixed speed compressor, and Figure. 9 shows that in drying system's baking room with digital scroll. It can be seen from the figures that the temperature and humidity curve in the digital drying system has a higher coincidence with the control target. In addition, compared with inverter technology, the structure of digital scroll compressor is less complex. A large number of practical applications also prove that digital scroll technology can provide higher reliability and energy efficiency thanks to mechanical modulation technology.

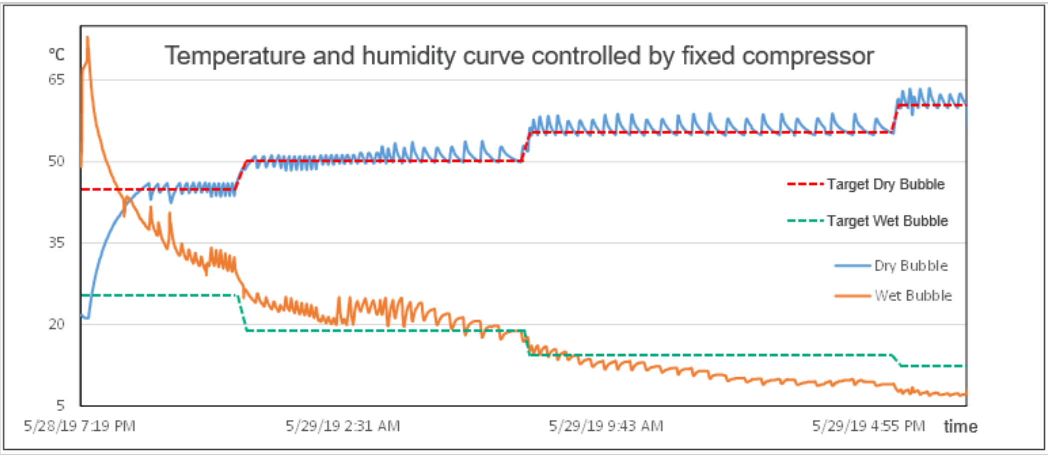

Fig.8. Temperature and Humidity Curve in Fixed Speed Drying System Baking Room

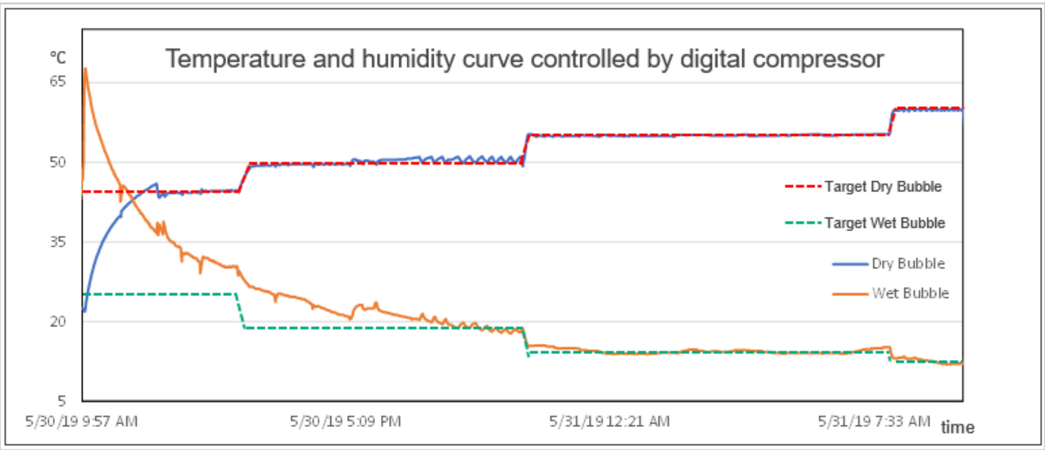

Fig.9. Temperature and Humidity Curve in Digital Drying System Baking Room

4. Field project summary

As mentioned above, when the traditional coal-burning drying is used, it is necessary to hire an experienced tobacco baking master to operate. In view of the pain points above, Emerson Asia has been doing in-depth researches and developing tobacco baking process, using iPro Lite programmable controller as the main control for air source heat pump system.

Taking the tobacco baking field test in Yuxi, Yunnan Province as an example, the system is an open loop heat pump system. The structure of the baking room is 8000mm×2900mm×4800mm, as shown in Figure 10, the wall material is double-sided color steel polyurethane plate. Its thermal conductivity is 0.023W/(m·K), indoor surface convection heat transfer coefficient is 8.7W/(m2·K), and outdoor surface convection heat transfer coefficient is 23.3W/(m2·K). Indoor temperature and humidity are given by tobacco baking process curve, as shown in Figure 1. The outdoor temperature is selected as the ambient temperature of 18~32℃ during the local baking period. Taking the tobacco leaves Yunyan 97 as an example, the weight of fresh tobacco leaves before baking was 3150kg, and the baking duration was determined to be 154h according to relevant literature and tobacco baking practice [13]. According to the existing references and relevant data, the law of water loss in tobacco baking can be obtained. The approximate water loss of tobacco leaves in the baking process is as follows: 27%-35% water loss in yellow discoloration stage, 50%-55% water loss in color fixing stage and 10%-23% water loss in stem drying stage[14]. The wet base moisture content of Yunyan 97 fresh tobacco is 88%, and about 6.5% at the end of baking[15], so the total water loss is 3150×(88%-6.5%)/(1-6.5%) = 2746kg. The water loss rate of each stage obtained from literature[15-16] is shown in Table 1.

Table.1. Water Loss Rate in Each Baking Stage

Baking Stage	Yellow Discoloration			Color Fixing		Stem Drying	
	30-36℃	36-38℃	38-42℃	42-48℃	48-54℃	54-60℃	60-68℃
Water Loss Rate %/℃	0.826	5.347	3.837	4.585	4.165	0.726	1.518

Fig.10. Baking Room Appearance

The sensible heat load of the baking room was the highest at the initial temperature rise, followed by the temperature rise of each stage, and the lowest at the temperature holding of each stage. In the early baking period, the moisture content of tobacco leaves is high, the water evaporation is more, the wet load is larger, but the duration is short. In the yellow discoloration temperature holding stage, the baking room needs to maintain a high humidity environment, the humidity load decreased. To the color fixing stage, the temperature of the baking room rises to 54℃, and the baking room needs to maintain a low humidity environment, and the humidity load increases to the maximum. The moisture content of tobacco leaves in stem drying stage decreased significantly, and the moisture evaporation was less, and the humidity load decreased to the lowest. The calculation result shows that the maximum heat load in the color fixing stage is 31.15kW. According to the calculated load of the baking room and the evaporating and condensing temperature of the heat pump operation, two ZW79KBC compressors are equipped for the baking room heat pump unit. Figure 11 shows the heat pump unit, control board and HMI.

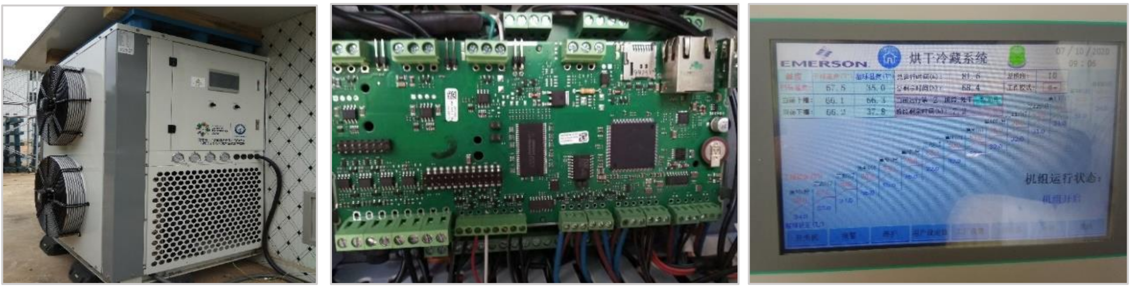

Fig.11. Heat Pump Unit, Control Board and HMI

Two exhaust fans are added to the baking room for strongly discharging humidity to enlarge the dedumudification capacity. Test data collection is shown in Figure 12 and comparison of tobacco leaves before and after baking is shown in Figure 13. The first stage is the low temperature yellow discoloration , compressor running rate is low as heat load is small. The second stage is color fixing, compressor runing rate is high, up to more than 90% as the heat and humidity load is large. The third stage is mesophyll drying, heat load is the main demand and humidity load need is affiliated. And compressor running rate is about 60%. Stage 4 is stem dryiny, basically heat load. And compressor running rate is consistent with stage 3. This tobacco baking test took 164 hours, and consumed 929.2kWh. The longer baking time is mainly due to the lengthening of yellow discoloration and stem drying. From the perspective of the whole drying process, the trend of the measured temperature and humidity curves in the baking room is highly consistent with the requirement of tobacco baking process shown in Figure 1. The air source heat pump drying technology has incomparable advantages in the accurate control of temperature and humidity.

In order to ensure the quality of tobacco baking, the baking room dry and wet bulb temperature control strategies are different at each stage. In the first stage, yellow discoloration of tobacco needs high humidity condition, so only dry bulb temperature needs to be controlled by adjusting the output of compressor. The exhaust fans are off and exhaust valaves are closed since there is no requirement for discharging humidity. In the second stage, baking room dry bulb temperature needs to rise gradually by increasing compressor output. At this time, the exhaust fans are on and the wet bulb temperature can be controlled by adjusting the opening of exhaust valves. For example, if baking room wet bulb temperature > setting value + offset, increase the exhaust valve opening. If baking room wet bulb temperature < setting value, decrease the exhaust valve opening. When baking room wet bulb temperature is between setting value and setting value + offset, keep the exhaust valve opening. When coming to the third stage, baking room dry and wet bulb temperature needs to be kept near the target value by controlling compressor output and exhaust valve opening. For the last stage, it is necessary to hit higher dry bulb temperature and keep wet bulb temperature close to the target in baking room by controlling compressor output and exhaust valve opening.

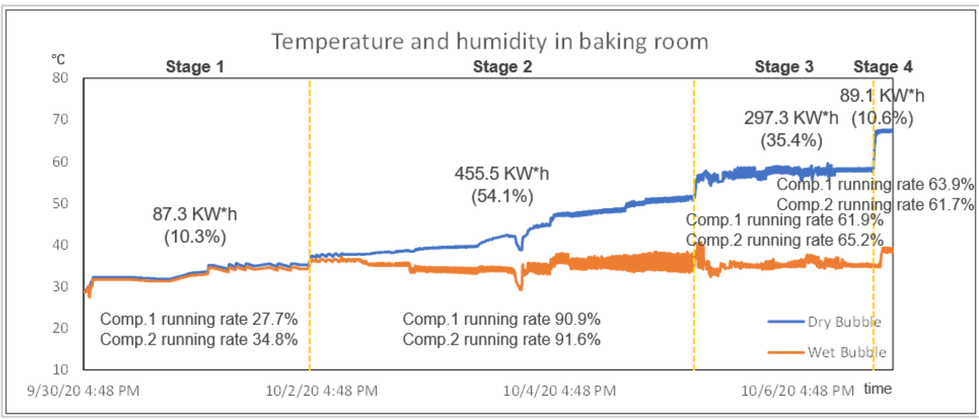

Fig.12. Tobacco Baking Test Data Curve for Heat Pump

Fig.13. Tobacco Leaves Before and After Baking

Compared to the coal-burning baking, the results are shown in Table 2. The power consumption of the heat pump baking room is 929.2kWh, and the labor cost of baking 1kg dry tobacco is 0.11 yuan. In coal-burning side, the electricity consumption of the coal-fired baking room is 181.8 kWh, the coal consumption is 808kg, and the labor cost of baking 1kg dry tobacco is 0.38 yuan. The electricity price is calculated as 0.53 yuan/kWh (the electricity price for agricultural production in the provincial power grid electricity price standard) and the coal price is calculated as 775 yuan/t. The total operating cost of 1kg dry tobacco in the heat pump baking room is 1.33 yuan, and that in the coal-fired baking room is 2.17 yuan. The baking cost of heat pump baking room is about 61% of that of coal-fired baking room, which saves 39% of the cost of tobacco baking. Moreover, the carbon emission of heat pump baking room is only 32% of that of coal-fired baking room, so the effect of cost saving and emission reduction is significant.

Table.2. Economic Comparison between Heat Pump and Coal-burning for Tobacco Baking

Item	Heat Pump Baking	Coal-burning Baking
Total weight of fresh tobacco leaves /kg	3150	3150
Total weight of dry tobacco after baking /kg	404	404
Power consumption /kWh	929.2	181.8
Coal consumption /kg	0	808
Electricity price per kWh /yuan	0.53	0.53
Coal price per t /yuan	775	775
Labor cost for 1kg dry tobacco /yuan	0.11	0.38
Baking cost for 1kg dry tobacco /yuan	1.33	2.17
Carbon emission /kg	473	1491

5. Summary and prospect

Traditional coal-fired tobacco baking not only has higher cost, but also has some uncertainty in baking quality, even brings serious environmental problems to tobacco regions. Under the influence of environmental policy, clean energy, especially air source heat pump technology has made great progress. Combing with the requirement of tobacco baking process, this paper expounds the important role of heat pump drying technology in energy conservation and environmental protection and improvement of tobacco baking quality and efficiency. Following summaries can be drawed:

(1) Even the initial equipment investment of heat pump drying technology is large, but its energy consumption and manual operation cost are quite low, and the long-term comprehensive benefit is attractive.

(2) Heat pump drying technology is highly electrified, and the temperature and humidity in the baking room can be accurately controlled, which greatly improves the proportion of top-grade tobacco.

(3) Heat pump drying technology can partically recover the waste heat from the baking room and realize a high degree of automation, significantly reduce the tobacco baking cost and improve the economic income of tobacco farmers.

In the future, with the continuous development of heat pump drying technology, the heat pump drying system and its control will be further optimized to make the temperature and humidity control of the whole baking process be more accurate, and the temperature fluctuation tends to be minimized. With more studies and practise on closed loop heat pump drying system, energy utilization efficiency could be further improved. In China, heat pump based tobacco baking room will has prospective future and it will contribute a lot to China national carbon emission targerts.

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