Application of Heat Pump Energy-Saving Flue-Cured Tobacco Technology

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Abstract. In view of many problems caused by the traditional "coal + electricity" flue-cured tobacco method, such as the environmental pollution, the high cost, the unguaranteed quality, and the demanding reliability of power supply, the researcher put forward the heat pump energy-saving flue-cured tobacco technology based on the field investigation. The technology equipment, including heat pump, condensing and draining roasting room and self-control system, uses smokeless hot air as medium to realize the drying of tobacco leaves, which solves the quality problem of residual sulfur in products. Moreover, the energy saving effect is remarkable, nearly 70% of the heat in the process of dehumidification is recycled. At the same time, the baking performance is stable, and the various indexes can be effectively and accurately realized to ensure the quality of the tobacco leaves. It only consumes 2kW·h of electricity to dry 1kg of tobacco leaves. Compared with traditional method, it’s conducive to environmental protection.

1. Introduction
The cultivation and production of flue-cured tobacco in China began in 1910-1915 [1]. In the past 100 years, the equipment of the baking room has been transformed, gradually forming a configuration that is compatible with the economic and technological conditions of rural China. After the 1970s, adopting the operation technology of “high temperature and fast roasting”, the baking process pursued the yellow, fresh and clean products. In the 1990s, the multi-segment "double low" baking processes were proposed successively in various places, but workers still stayed in a low level based on antique experience. The three-stage baking process of flue-cured tobacco has achieved the integration with the internationally advanced baking level [2].

According to the field research in a town, the researcher found many problems caused by the "coal + electricity" method. This backward method wastes labor, pollutes the environment, and cannot guarantees the quality of flue-cured tobacco. During the seven-day baking process, some people need to adjust the firepower and track the color of the tobacco leaves; otherwise, the quality of the roasted tobacco leaves will be inferior. In response to these problems, the researcher proposed a heat pump energy-saving flue-cured tobacco technology based on local conditions.
2. Heat pump energy-saving barn overview

The heat pump energy-saving barn is a device that uses a heat pump to transfer heat from the air to the baking room. The heat pump can transfer 5 to 6 times of the energy required by itself from low temperature to high temperature [3]. In experiments, the heat pump energy-saving barn only consumes 2kW·h of electricity to dry 1kg of tobacco leaves, which is greatly reduced compared with the previous method. At the same time, it can realize fully automatic digital control and reduce human resources. Take the baking base of 50~70 barn houses as an example, only one computer, two maintenance personnel and two baking technicians can complete the work, and most is done in the office. The working environment has been significantly improved [4].

2.1. Capacity of the barn

The capacity of the barn refers to the appropriate amount of smoke in the barn under normal conditions, often calculated as the number of soot [5]. Under standardized cultivation, when the tobacco leaves are mature and concentrated, 1 ha of tobacco fields can harvest 270-306 million pieces of tobacco, about 420-500 tons of tobacco. In combination with the town's fact, there are about 0.6 ha of tobacco fields, and the annual output of soot is about 360, so a medium-sized barn with a capacity of 300-350 rods is suitable.

2.2. Height of the barn

The height of the barn is determined by the number of hanging sheds and the length of the shed (including the distance between the shed, the spacing of the shed and the distance between the sheds). This design uses a naturally ventilated airflow riser, with three layers of airflow rise and drop barns. The bottom layer spacing is 900mm, and the spacing between the two layers is 800mm.

2.3. Structure of the barn

The outer box of the baking room adopts 50mm color steel polyurethane full-foam cold storage board as the heat preservation box body, and the heat preservation effect is good. The inside is equipped with a steel pipe bracket structure for placing flue-cured tobacco and supporting the box body. The baking room additionally includes a charging door, a maintenance door, a wet exhaust port, an observation window, and a fresh air outlet and so on.

2.4. Parameters of the barn

The main technical parameters of the medium-sized heat pump energy-saving barn are as follows:

| Project                          | Parameters               | Item         | Parameters               |
|----------------------------------|--------------------------|--------------|--------------------------|
| Hot air circulation method       | Airflow type             | Size         | 9500×2800×3500mm         |
| (smoke chamber)                  |                          |              |                          |
| Volume of smoke chamber          | 8000×2800×3500mm         | Shed height  | 1300mm                   |
| Standard pipe length             | 1400mm                   | Ceiling height | 3.35m                   |
| Loading weight                   | 2500-3500kg              | Wet window area | 0.5m²                  |
| Applicable area                  | 15-18 acres              | Heating chamber volume | 14.7m³              |

3. Dehumidification and heat recovery system

A large amount of hot and humid air is discharged during the drying of the tobacco. In order to maximize the recycling of heat energy, researchers use heat pump evaporator for heat recovery (see Fig.1). During dehumidification process, the hot and humid air is discharged from the dehumidification port of the system under the action of the exhausting fan, firstly contacting the evaporator of the heat pump for heat exchange, and then it is cooled and dehumidified through the evaporator system. After that, the air is discharged into the environment. The efficiency of heat recovery is around 70%.
4. Barn performance test
According to the above parameters of the barn, the researcher built a new type of medium-sized heat pump energy-saving barn for performance testing. The heating performance of the baking room was detected by sensors installed in the lower, middle and upper parts of the smoke chamber.

4.1. Heating performance test under no load
The empty furnace test is carried out before the baking of the tobacco leaves to compare the heating performance of the heat pump baking room and the ordinary baking room. Table 2 shows the time when the barn is raised from room temperature to 35°C, 38°C, 42°C, 47°C, 54°C, 60°C, and 68°C under no-load conditions.

| Object          | 35°C | 38°C | 42°C | 47°C | 54°C | 60°C | 68°C |
|-----------------|------|------|------|------|------|------|------|
| Heat pump barn  | 7    | 3    | 5    | 9    | 18   | 20   | 42   |
| Ordinary barn   | 13   | 7    | 13   | 20   | 30   | 31   | 50   |

Room temperature= 27.5°C.

It can be seen from Table 2 that the heating rate of the heat pump barn before 42°C is 1°C/min on average, and the temperature rise rate is slowed after 42°C. However, its heating performance is better than that of ordinary barns. It can be seen that the application of high-temperature heat pump barn heat pump significantly improves the thermal efficiency, and it also shows that the barn has good insulation performance.

4.2. Heating performance test under working state
The plane temperature difference and vertical temperature difference at the temperature of 38°C, 42°C, 47°C, 54°C, 60°C, and 68°C under high temperature heat pump barn load conditions are shown in Table 3.

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**Figure 1.** Condensate drains system.
Table 3. Plane temperature difference and vertical temperature difference under the operation of the barn load state.

| Temperature (°C) | Bottom layer | Middle layer | Upper layer | VTD (°C) |
|------------------|--------------|--------------|-------------|----------|
|                  | HPB          | OBN          | HPB         | OBN      | HPB     | OBN     | HPB     | OBN     |
| 38°C             | 0.1          | 0.2          | 0.9         | 0.8      | 0.1     | 0.2     | 0.9     | 0.8     |
| 42°C             | 0.1          | 0.1          | 0.6         | 0.5      | 0.1     | 0.1     | 0.6     | 0.5     |
| 47°C             | 0.2          | 0.5          | 0.6         | 0.4      | 0.2     | 0.5     | 0.6     | 0.4     |
| 54°C             | 0.5          | 0.7          | 1.1         | 0.6      | 0.5     | 0.7     | 1.1     | 0.6     |
| 60°C             | 0.3          | 0.2          | 0.7         | 0.4      | 0.3     | 0.2     | 0.7     | 0.4     |
| 68°C             | 0.9          | 1.2          | 1.6         | 0.7      | 68°C    | 0.9     | 1.2     | 1.6     |

Note: PTD = plane temperature difference; VTD = vertical temperature difference; HPB = high-temperature heat pump barn; OBN = ordinary barns.

It can be seen from Table 3 that the plane temperature difference is between 0.1°C and 1.6°C; the vertical temperature difference is between 0.4°C and 0.8°C, the plane temperature field is basically uniform, and the vertical temperature difference is further reduced. The room has good sealing performance and better insulation and moisturizing.

5. Ventilation and dehumidification performance

Table 4 shows the air inlet, drain port and leaf gap wind speed under heat pump barn load.

Table 4. Air inlet, drain and leaf clearance wind speed under heat pump barn load.

| Treatment | Yellowing stage AI | DP | BC | Fixing stage AI | DP | BC | Dry gluten stage AI | DP | BC |
|-----------|---------------------|----|----|-----------------|----|----|---------------------|----|----|
| HPB       | 3.1                 | 1.5| 0.24| 4.2             | 2.6| 0.27| 2.6                 | 1.1| 0.18 |

Note: HPB = high-temperature heat pump barn; AI = Air inlet; DP = Drainage port; BC = Blade clearance.

From the data analysis in Table 4, it can be seen that the test barn significantly improves the wind speed in the barn, and the moisture evaporated from the tobacco leaves during the baking and drying process can be removed and removed in time, so that the color of the tobacco leaves after roasting is more vivid.

6. Environmental impact analysis

This technology uses a heat pump to replace coal-fired flue-cured tobacco. The main equipment is heat pump and fan, so electricity accounts for the absolute position of energy consumption. No waste gas, solid waste or pollution sources are generated during the operation of the equipment. The annual reduction in pollutant emissions compared to the “burning coal and electricity” flue-cured tobacco is shown in the following table:

Table 5. Reduced pollutant emissions.

| Contaminants | CO₂ (tons/year) | CO | SO₂ | NOₓ | dust |
|--------------|-----------------|----|-----|-----|------|
| Quantity     | 13152           | 7891| 44.7| 39.4| 52.6 |

7. Conclusion

Based on the above analysis of the comparison between the heat pump energy-saving barn and the traditional "coal-powered" barn, the following conclusions are drawn:
1) The gas directly enters the barn and comes into contact with the tobacco leaves, causing sulfur in the finished tobacco leaves. The heat pump energy-saving barn uses the smokeless hot air as the medium to realize the drying of the tobacco leaves, solving the quality problem of the finished product.

2) Heat pump energy-saving barn heating performance is better than ordinary barn, with higher thermal efficiency. The temperature in the baking room is uniform, and the material conversion and yellowing and drying speed of the whole house tobacco are consistent. At the same time, the wind speed in the baking room is large, and the water evaporated from the tobacco leaves during the baking and drying process is eliminated in time. Because of these advantages, the leaves from heat pump energy-saving barn have good maturity, fresh color and uniformity of leaf back leaf after roasting.

3) It only consumes 2kW·h of electricity to dry 1kg of tobacco leaves in heat pump energy-saving barn. Compared with the previous “coal-powered” flue-cured tobacco method, energy consumption is greatly reduced.

4) The heat pump energy-saving barn can be automatically controlled, saving a lot of human resources. Most of the work is operated in the office, which optimizes the working environment.

5) Compared with the traditional “coal-powered” flue-cured tobacco method, the heat pump energy-saving barn has no waste residue and no pollution gas discharge during the working process, and has the advantages of green environmental protection.

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