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Application of Heat-Pump Drying Technology to Dry Longan Flesh with High Quality and Energy Efficiency

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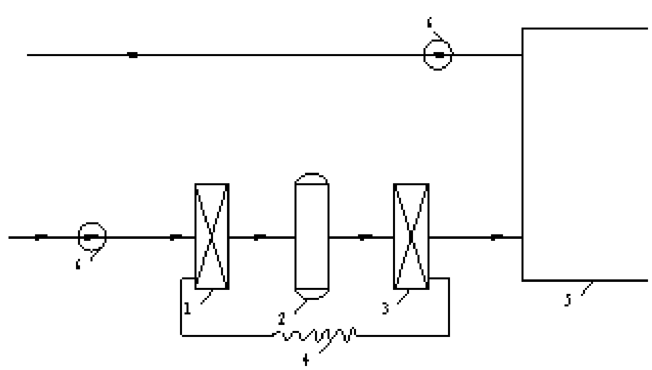
Abstract

The study has calculated and designed a drying system combined with the heat pump to dry longan for household scale. The study also has done experiments of drying and comparison with the drying mode without the heat pump, from which there are results to compare and evaluate the drying system and the drying process. Regarding the drying time, the drying mode with the heatpump has a faster drying time than without the heat pump about 40%. Regarding the energy consumption, it's about 45% to 50% energy savings when using the heat pump compared to without the heat pump.

Keywords: heat, pump, drying, technology, energy, efficiency

1. Introduction

Heat pump drying technology is commonly used in the world as well as in Vietnam. The simple heat pump drying system is composed of:



1: Evaporator
2: Compressor
3: Condenser
4: Throttle valve
5: Drying chamber
6: Fan

Figure 1: Principle diagram of the drying system with the heat pump
(the heat pump is composed of 1, 2, 3, 4)

Operation Principle:

Path of the drying agent: fresh air at ambient condition passes through the evaporator (1) will have a decrease in absolute humidity because a part of the moisture is separated from the air. Then, the air is lead through the condenser to increase the temperature up to about 50 ÷ 60 [oC], and now, the air has low relative humidity. Then, the air, now with high temperature and low relative humidity, is fed into the drying chamber (5) to take out water from the drying material.

Path of the refrigerant in the heat pump: in the heat pump, the refrigerant has a movement in a closed circulatory. The compressor (2) sucks the refrigerant from the evaporator (1), then performs an adiabatic compression process to change status of the refrigerant (it has also high temperature and high pressure), then pushs it into the condenser (3). In the condenser, the refrigerant exchanges heat with the air to reduce the temperature and pressure, then the refrigerant passes through the throttle vavle (4) to do throttle process, then circulate back to the evaporator (1) to complete the closed cycle and also start again the cycle.

The drying system using a heat pump has the following advantages over conventional drying systems as following:

- Provide the drying agent with low temperature and low relative humidity
- Using the condenser side and the evaporator side to server different purposes at the same time (the condenser side is used for drying purpose; the evaporator side is used for air conditioning).
- The energy cost to evaporate 1 kg of moisture is lower compared to other drying methods. In the climatic conditions in Vietnam, the heat pump coefficient reaches about 3 ÷ 4. Then the cost of energy using a heat pump for each 1000 [kcal] is only about 40 ÷ 50 [%] compared to using coal and firewood; 33 [%] compared to using electricity, 12 [%] compared to using gas, oil; 38 [%] compared to labor costs in natural drying (drying under the sun light).
- Simple structure, easy to operate, minimizes environmental pollution.
- Thanks to the mechanism that dries the product in an environment with low temperature, low humidity, and can operate independently in a closed environment, the heat pump drying technology is considered as a stable solution for quality (color, nutritional composition ...), especially for some agricultural products that are sensitive in temperature, color and nutritional ingredients are susceptible to change when using conventional drying methods.

Longan a famous agricultural product in Vietnam mainly concentrated in Hung Yen province of Vietnam with the average annual output of the whole province is about 53,000 tons / year *(refer to the annual report of the Agriculture Department of Hung Yen province).* Longan is harvested in the form of fresh longan. There are about 75% of production is sold in fresh longan and about 25% is used for producing the dried longan flesh. At present, the dried longan flesh is very developed and popular, but due to seasonal characteristics, production practices, currently, the drying technology used in most households is traditional manual drying method, which are not effective and the quality is not high. To improve the quality and value of products, improve working conditions for laborers, minimize environmental pollution... the heat pump drying technology is proposed to improve quality and energy efficiency.

2. METHOD

2.1. Design information

Based on the principle of convection drying in forced circulation and indirect drying, there can control the temperature, humidity, flow of the drying agent (the air mentioned above) easily. The drying system includes 02 heaters which can be use for operation in combination or independently:

- Heater 1: using a thermistor which can heat the drying agent to about 200 [^{0}C].
- Heater 2: using a heat pump which uses for moisture separation and heats the drying agent to about 45[^{0}C] and the relative humidity of about 15[%].
- Design productivity: 50 kg input material/batch
- Other economic - technical indicators:
    - Total power consumption: 8.35 [kW]. In which heat pump consumption is maximum of 1.6 [kW]; The thermistor consumption is maximum of 6 [kW]
    - Temperature adjustment Ranger of the drying agent: 30 ÷ 200 [^{0}C];
    - Humidity adjustment ranger of the drying agent: 10 ÷ 90 [%];
    - Flow adjustment ranger: up to 2500 [m^3 / h];
    - Power consumption rate: about 1.1 [kWh / kg moisture]

The calculation of equipment selection will be based on the required drying capacity and the drying time for each drying stage. With a productivity of 50 [kg / batch] of fresh longan (input material) at relative humidity of 78 [%], there can identify the amount of dry longan (without moisture) as following:

$$G_{khô} = (1 - 0{,}78) \times 50 = 11 \text{ [kg]} \quad (3)$$

Accordingly, the total amount of moisture needing to be separated in the considering stage of the drying:

$$\Delta Gn = (w1 - w2).\ Gkhô\ [kg] \quad (4)$$

The average amount of moisture needing to be separated for the whole considering stage of the drying:

$$\Delta \dot{G}_n = \frac{\Delta G_n}{\tau}\ [\frac{kg}{h}] \quad (5)$$

Mass flow rate of the required drying agent:

$$\dot{G}_k = \frac{\Delta \dot{G}_n}{d_2 - d_1}\quad [kg_k/h] \quad (6)$$

The volume flow rate of the required drying agent:

$$\dot{V}_1 = v_1 \dot{G}_k (1 + d_1) \quad [m3/h] \quad (7)$$

$$\dot{V}_2 = v_2 \dot{G}_k (1 + d_2) \quad [m3/h] \quad (8)$$

$$\dot{V}_3 = v_3 \dot{G}_k (1 + d_3) \quad [m3/h] \quad (9)$$

Power of heating equipment:

$$\dot{Q}_{3-1} = \dot{G}_k (I_1 - I_3)/3600 \quad [kW] \quad (10)$$

Determination of the parameters of the heat pump drying equipment will be conducted based on the required productivity and required drying time. Accordingly, the total amount of moisture needing to be separated in the considering drying stage is:

$$\Delta Gn = (w1 - w2).\ Gkhô \quad [kg] \quad (13)$$

The average amount of moisture needing to be separated for the whole considering stage of the drying:

$$\Delta \dot{G}_n = \frac{\Delta G_n}{\tau} \quad [kg/h] \quad (14)$$

Mass flow rate of the drying agent required for the drying stage:

$$\dot{G}_k = \frac{\Delta \dot{G}_n}{d_2 - d_1} \quad [kgk/h] \quad (15)$$

Volume flow rate of the drying agent required for the drying stage:

$$\dot{V}_1 = v_1 \dot{G}_k (1 + d_1) \quad [m3/h] \quad (16)$$

$$\dot{V}_2 = v_2 \dot{G}_k (1 + d_2) \quad [m3/h] \quad (17)$$

$$\dot{V}_3 = v_3 \dot{G}_k (1 + d_3) \quad [m3/h] \quad (18)$$

Power of heating equipment:

$$\dot{Q}_{3-1} = \dot{G}_k (I_1 - I_3)/3600 \quad [kW] \quad (19)$$

Total refrigeration capacity of the evaporator:

$$\dot{Q}_{2-3} = \dot{G}_k (I_2 - I_3)/3600 \quad [kW] \quad (20)$$

Dehumidification capacity of the evaporator:

$$\Delta \dot{W}_{2-3} = \dot{G}_k (d_2 - d_3)/1000 \quad [kg/h] \quad (21)$$

Latent heat capacity of the evaporator:

$$\dot{Q}_{l,(2-3)} = 2500\, \Delta \dot{W}_{2-3}/3600 \quad [kW] \quad (22)$$

Sensible heat capacity of the evaporator:

$$\dot{Q}_{s,(2-3)} = \dot{Q}_{2-3} - \dot{Q}_{l,(2-3)} \qquad [kW] \qquad (23)$$

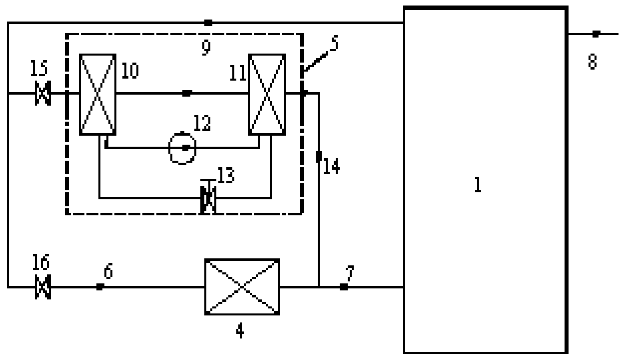


Figure 2: Operation priciple diagram of the drying system

When drying in the thermistor mode (without the heat pump): Only use the heat source by the thermistor (4) to produce the drying agent with temperature, humidity, which is suitable for the stage of the shaping drying and the stage of exhausting drying. At this time, the humidity outlet (8) opens, the valve (15) closes, the valve (16) opens. The drying agent (6) is heated to the required temperature T1 (100 ^{0}C for the shaping stage and 80 ^{0}C for the exhausting drying stage) thanks to the heat from the thermistor (4), then fed into the drying chamber (1) to do the heat exchange of self-convection and separate moisture from the material. Then, humid air (the drying agent after taking moisture from the material) was partially discharged through the moisture outlet (8), the rest circulate along the path (9 - 16 – 6) and repeat the drying process (addion of fresh air is at the position of thermistor (4).

In case of drying in the heat pump mode, the process is similar the thermistor mode, but the valve (16) is close, the valve (15) is open, the outlet (8) is close.

Figure 3: Photos of the manufacture of the drying system

2.2. Materials

Using the drying system to dry the material in two modes for 10 batches. In which, batches from 1 to 5, the drying system operates in the thermistor mode for all three drying stages (stage 1 – shaping drying, stage 2 – exhausting drying, stage 3 – tempering drying). For batches from batch 6 to batch 10, the drying system operates in the thermistor mode for the stage 1 and stage 2, and in the heat pump mode for the stage 3). From that there are the results to compare and evaluate the advantages of the use of heat pump in drying.

3. RESULTS AND DISCUSSION

3.1. Input data

The experiment of drying the longan flesh was done at the production facility of Huong Anh Company Limited (at Hong Nam Ward, Hung Yen City, Hung Yen province). Conducting the drying experiment for 10 batches. The dried longan products of the batches all met the requirement of quality and sensory: the humidity within the range of 12 to 18 [%], the colour was yellow and natural bright, the shape was evenly curled like lotus seeds. Summary of the test results shown as below:

Table 1. Input data

Batch No.	1	2	3	4	5	6	7	8	9	10
Input weight [kg]	50	50	50	50	50	50	50	50	50	50
Humidity of the input material [%]	80	80	80	80	80	80	80	80	80	80
Humidity of the input fresh air [%]	80	80	80	80	80	80	80	80	80	80

3.2. Results

To evaluate the efficiency of the drying mode using heat pump, the experiment did the comparison of the drying time and the energy consumption for each 1 kg of the finished product.

The comparison of the drying time shown on the chart as below:

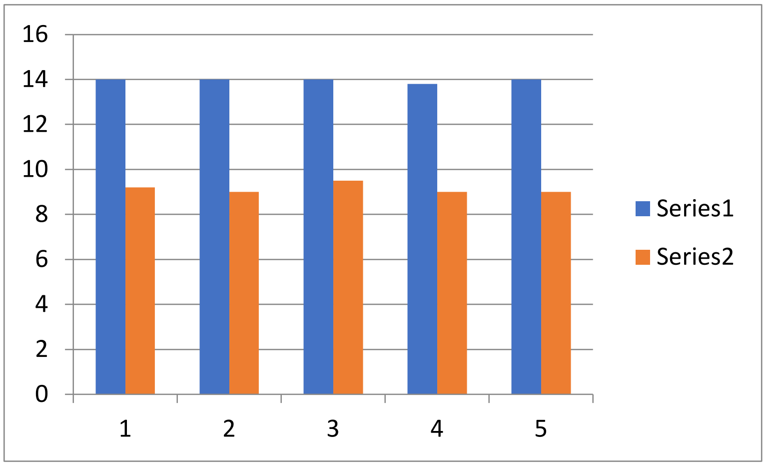


Figure 4: The comparison chart of the drying time between using the heat pump and not

By the chart, the first 5 batches without a heat pump, the drying time was 1.5 times longer than the drying mode using the heat pump.

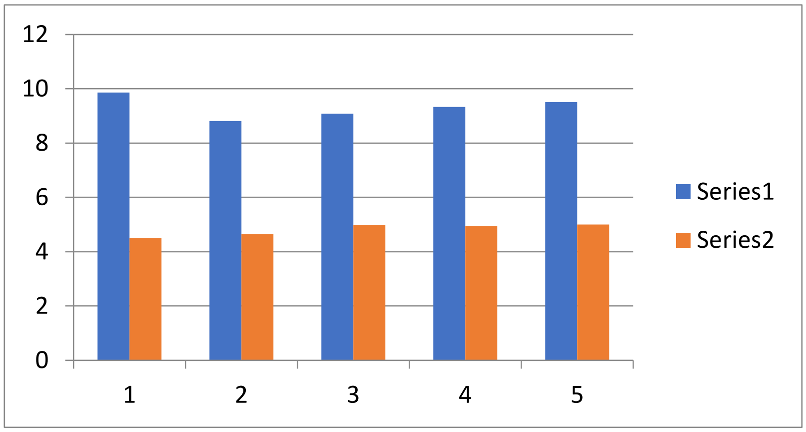


Figure 5: The comparison chart of power consumption between 2 drying modes

Using the drying system to dry the material in two modes for 10 batches. In which, batches from 1 to 5, the drying system operates in the thermistor mode for all three drying stages (stage 1 – shaping drying, stage 2 – exhausting drying, stage 3 – tempering drying). For batches from batch 6 to batch 10, the drying system operates in the thermistor mode for the stage 1 and stage 2, and in the heat pump mode for the stage 3). Test results showed that the batches 1 to 5 had the power consumption rate more than the batches 6 to 10. The cause was:

- ✓ The drying mode using in the batches 1 to 5 used the thermistor, which had the conversion efficiency from electric to thermal was lower than the use of the heat pump), to produce the drying agent for all 3 drying stages.
- ✓ The size of the moisture outlet (8) was small, so the moisture drainage was not good for stage 1 and stage 2 (the observation of the drying system while operation showed that it was stagnant water flowing out at the corners of the drying chamber) and the drying agent for stage 3 had high humidity (it was not good because this stage had the moisture of the material was relatively low, therefore, the moisture removal efficiency is not high). The product had 18% moisture was a little high although it stilled within the limit.

Thus, after the trial and adjustment of the drying process, the drying system using heat pump has operated well and met the technical requirements. The drying mode of batch 6 to batch 10 was selected to develop the optimum operating procedure for the drying system.

4. CONCLUSION

The drying system using heat pump is completely suitable for drying longan flesh for from household scale to the industrial scale in the technical and natural conditions of Vietnam.
The quality of the output product meets the food safety standards of Vietnam (Local standards - Special Longan, (HY-TCV 01-1999), 1999)
Investment for the system is at the acceptable cost and scalable, and special for the fruit growing areas, it helps drying the products for preservation.

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