Computer Assisted Design of Intelligent Electric Power Saving Dryer with Integrations of Steaming and Drying

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Abstract. The cost of existing relevant drying equipment is high and cannot meet the needs of steaming and drying of users. Aiming at the disadvantages of the electric driven hot air dryer with the highest market share, such as large heat loss and cannot meet the integration of steaming and drying, this scheme is based on solar heat collection and waste heat recovery to reduce the power consumption in the production process and realize the integration of steaming and drying. An innovative drying equipment equipped with waste heat recovery system and solar collector plate and optimized structure of carrier plate is designed. Rational use of plate fin heat exchanger to recover the heat in tail gas, heating with solar collector plate to reduce the power consumption in the heating process, and improving the structure of carrier plate to realize the two functions of steaming and drying at the same time will be the main breakthroughs. After calculation and measurement, a dryer with heat saving rate of 37.83% obtained.

Keywords: Dryer, Plate fin heat exchanger, Integration of steaming and drying, Solar collector

1. Introduction:
At present, the electric driven hot air dryer has a high market share, which can only meet the drying requirements. But the steaming process before drying is essential. The dryer cannot meet the need. Also, the waste heat in the tail gas is not recycled, resulting in the problems of high energy consumption and low drying efficiency of dryers in the market also make it impossible for them to use it for processing dry vegetables. So users have to adopt the traditional way of steaming and drying by solar energy. But this the two methods are greatly affected by the weather, leading to economic loss.

Having studied the vegetable dryer with the highest demand of users and market share, which has large power consumption and cannot meet the integration of steaming and drying. Through summarizing the large types of dryers on the market, a dryer with high economic benefits and meeting the integration of steaming and drying is determined. The addition of solar collector plate reduces the electric energy consumption for heating; The usage of plate fin heat exchanger fully recovers the waste heat in the tail gas and reduces the heat emission; The improvement of the carrier plate structure enables the integration of steaming and drying to be realized, which can meet the needs of users and reduce their economic burden at the same time.
2. **Materials and methods:**
Aiming at the widely existing electric driven hot air dryer in the market, the project proposes a new dryer in order to solve the problems existing in the current hot air dryer. The driving mode is improved to be driven by both electric energy and solar energy. The structure of the carrier plate is optimized to meet the functions of steaming and drying at the same time. At the same time, the plate fin heat exchanger is used to effectively recover the waste heat, reduce energy consumption and improve drying efficiency.

![Figure 1. Schematic diagram of the dryer model.](image1)

![Figure 2. Schematic diagram of internal structure of solar collector plate.](image2)

2.1. **Dual energy driving mode of electric energy and solar energy**
Different from the widely existing dryers in the market, which use electric energy as the only energy for drying, this product relies on the solar collector plate to gather heat for drying when the sun is sufficient.
In rainy days or at night, when the sun is insufficient, electric energy can be used as an auxiliary energy source for heating and drying. Two kinds of energy are used to assist each other in the whole process to maintain the normal operation of the dryer.

How to use solar energy efficiently and reasonably without increasing too much cost is a problem we need to consider. Considering the cost and the demand of dryer for heat collection efficiency, the plate solar heat collection mode is finally selected. Its specific structure is shown in figure 2. The structure comprises a glass cover plate, a heat absorbing coating, a heat absorbing plate, an air inlet, an air outlet and a diaphragm. The wavy design of the cross section of the heat absorption plate increases the heat absorption area to the greatest extent and improves the heat absorption efficiency. The heating method is: the cold air enters from the air inlet and travels along the path formed by the lower diaphragm of the heat absorption plate. At this time, the heat absorption plate transmits the absorbed heat to the cold air, and the cold air is heated by the solar collector plate and discharged from the air outlet.

Considering the heat loss in the drying process, an electric heating wire is added between the two load plates to realize multi-stage heating and keep the air flow in the dryer at a high temperature all the time. The air temperature is controlled by adjusting the power of the electric heating wire to ensure the quality of dried Day lily and improve the drying efficiency.

2.2. Usage of plate fin heat exchanger

At present, few drying equipment on the market for vegetable drying consider recycling the waste heat in the tail gas. For this, a new waste heat recovery system has been used, and its core structure is shown in figure (4). The structural material is brass. The hot tail gas mixed with water vapor passes through the wing shaped triangular channel on the right and exchanges heat with the cold air passing through the triangular channel on the left through the brass wall, so as to transfer part of the heat to the cold air and then discharge it into the air. This not only transfers most of the heat in the tail gas to the cold air because of the large contact area, but also effectively prevents the water vapor in the tail gas from entering the dryer again.

The principle of the fresh air system used in the building is similar to that of the plate fin heat exchanger of the dryer. It can transport fresh air and exchange heat efficiently to ensure that the temperature of fresh air transported from the outside to the room is less different from that of indoor air. The heat exchange efficiency of the heat exchange core of the fresh air system is generally 50% - 80%. The wide application of the fresh air system with heat exchange function in buildings also verifies the rationality of the waste heat recovery of our plate fin heat exchanger.

![Figure 3. The core structure of the plate fin heat exchanger.](image1)

![Figure 4. The plate fin heat exchanger.](image2)
2.3. Structural optimization design of loading plate
In order to realize the integration of cooking and drying process, this product starts with the structure of the carrier plate, and a water tank is added around the carrier plate. The design of the middle support column of the carrier plate makes the air in the closed space formed between the film and the carrier plate moderately controllable, as shown in figure (3). When cooking, cover the film to increase the air humidity and improve the cooking efficiency. After the temperature is reduced, the water vapor condenses into water droplets on the film and slides to the surrounding water tanks under the component force of gravity to collect them; when drying, a lot of water has been collected in the surrounding water tank. Take out the load plate, remove the covering film, pour out the water in the water tank, and then put the load plate back to its original place for drying.

2.4. Operation mode
The product has different operation modes under different environmental conditions. When the light is sufficient, the device is placed under strong light, the solar collector plate has the maximum power, and the electric heating wire power modulates the "energy-saving gear" (300W); When the light is insufficient, the power of the solar collector plate in the device is low, and the power of the electric heating wire is adjusted to the "heating gear" (900W).

During operation, the fan has been set to the optimal speed and is driven by electric energy in the whole process. Steaming process: wet vegetables are placed on the carrier plate and covered with a film to form a closed space. The hot air flows through each layer to heat the confined space, where the water vapor concentration is high and the temperature is high, and the vegetables are steamed. During steaming, a large amount of water vapor will condense on the surface of the film, and then slide down the film to the water tank around the carrier plate due to the gravity component to collect it. The two factors that have the greatest impact on the steaming effect are water vapor concentration and temperature, which not only ensures the high water vapor concentration in the confined space where the vegetables are located, but also condenses the water evaporated from the vegetables into water droplets and collects them in the water tank. It not only ensures the steaming effect, but also prepares for drying.

Drying process: after the steaming process is completed, just take out the load plate along the slide,
remove the film and drain the water in the sink. Then put the load plate back and continue heating and
drying.

Air flow direction: Cold air enters the heat exchanger through the duct and exchanges heat with the
hot tail gas. The preheated air flow enters the solar collector plate through the duct and flows in a curved
way below the heat absorbing plate of the solar collector plate. Meanwhile, the heat absorbing plate
transmits the absorbed solar energy to the air flow for heating, and then the hot air flow is blown into
the dryer by the fan through the duct to dry the vegetables. In order to ensure the temperature of the air
flow, an electric heating wire is arranged between the two load plates for secondary heating. Then, the
hot tail gas enters the duct through the tail air hole and is led to the fresh air system for circulation. As
shown in figure 6.

3. Theoretical calculation

3.1. Theoretical calculation of thermal efficiency of plate fin heat exchanger
The following theoretical calculations are carried out under the following assumptions:
(a) The flow rate of tail gas is equal to that of cold air.
(b) The influence of geometric factors of heat exchange surface on heat exchange efficiency is
ignored.
(c) The influence of the physical properties of air on the heat transfer coefficient is ignored.

Heat exchange per unit area q = \( h \Delta t \).

\[
h = \frac{1}{A} \int A h_x \, dA.
\]

\( A \) is the whole convective heat transfer area. \( h_x \) is the local surface heat transfer
coefficient. \( h \) is the heat transfer coefficient of the heat exchanger made of brass in this product, \( h=80W \)
\( / (M^2 \times k) \). In this plate fin heat exchanger, the side length of each equilateral triangular channel is
3cm. The tail gas temperature is \( t_0 \), the cold air temperature is \( T_1 \), and the heat exchange efficiency is \( \eta \).
The specific heat capacity of air is \( C_p \).

\[
\eta = \frac{q}{C_p \rho V (T_1 - t_0)} \times 100\% \\
= \frac{C_p \rho V (T_0 - T_1)}{h (t_0 - t_1)} \times 100\% \\
= 74.31\%
\]

3.2. Theoretical calculation of thermal efficiency
The theoretical calculation in this part is based on the following conditions:
(a) There is no heat exchange between the hot air flow process and the outside world.
(b) Ignore the heat lost during the switching between cooking and drying.
(c) Ignore the influence of air temperature change in the dryer on its specific heat capacity.
(d) Ignore the effect of water vapor concentration on air density.

| Table 1. Some parameters of the dryer. |
|-------------------------------------|
| parameter                     | numerical value |
|---------------------------------|-----------------|
|                                 | Traditional dryer | This dryer |
| hot air temperature(℃)         | 88              | 76        |
| exhaust temperature(℃)         | 46              | 36        |
| air volume(m³/h)               | 4000            | 2350      |
| drying time(h)                 | 6               | 10        |
| Specific heat capacity of air(kJ*kg⁻¹*℃⁻¹) | 1.005         |          |
The heat required for making 250kg dried day lily by traditional dryer is
\[ Q_1 = C_{pa} \cdot \rho \cdot V \cdot \Delta T \]
\[ = 1,879,695.72 \text{kJ} \]

The heat required for making 250kg dried day lily by this dryer is
\[ Q_2 = C_{pa} \cdot \rho \cdot V \cdot \Delta T \]
\[ = 1,168,593.9 \text{kJ} \]

The heat saving rate is
\[ \varphi = \frac{Q_1 - Q_2}{Q_1} \times 100\% \]
\[ = 37.83\% . \]

4. Conclusions
In order to meet the needs of the integration of cooking and drying and reduce the cost of electric energy, we adopt the dual energy driving mode of solar energy and electric energy, adopt the plate fin heat exchanger, and propose a new energy-saving dryer. Through performance calculation and analysis, the following conclusions can be drawn:

Make full use of energy, energy conservation and emission reduction. The waste heat can be recycled through the plate fin heat exchanger. The solar collector plate is reasonably added to make full use of solar energy and reduce the consumption of electric energy. The design supported by the film of the carrier plate and the inclined water tank can quickly reduce the water content and improve the drying efficiency after steaming. This product can operate normally regardless of weather conditions. The high heat recovery efficiency is considerable, up to 37.83%.

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