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The infrared radiation and vacuum assisted drying kinetics of flue-cured tobacco leaf and its drying quality analysis

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Abstract

Dehydration is widely involved in tobacco processing such as tobacco leaf curing, tobacco trip redrying and cut tobacco drying, which plays a key role due to its effect on the physical and chemical quality of tobacco. The current drying methods in tobacco processing mainly use heat conduction, heat convection or their combination to dehydrate tobacco materials. However, radiation heat transfer as one of basic heat transferways has not been investigated in the tobacco drying. In the present work, infrared radiation dryer was designed to explore the tobacco infrared radiation drying characteristics. The effect of radiation heat transfer conditions and vacuum on the drying kinetics and temperature of tobacco leaves was investigated. Diffusion coefficient of middle tobacco leaves C2F is between 0.848×10^{-10} *~* 1.597×10^{-10} m^2/s*. At the same time, the pore structure andpetroleum ether tobacco extracts in dried tobacco were also analyzed in order to explore the different effects of infrared radiation drying and traditional drying technology on tobacco quality.*

Keywords: *Flue-cured tobacco; Infrared radiation; Vacuum; Dryingkinetics; Tobacco quality*

1. Introduction

In tobacco primary processing, drying plays a key role due to its effect on the physical and chemical quality of tobacco[1]. Therefore, to explore new drying method is always the focus of tobacco processing technology. In terms of heat transfer ways, the current drying methods in tobacco processing mainly use heat conduction, heat convection or their combination to dehydrate tobacco materials. However, radiation heat transfer as one of basic heat transfer ways has not been investigated in the literatures involving tobacco drying. The infrared-vacuum drying, infrared-hot air drying and infrared-heat pump drying, have been investigated and applied in the argo-processing such as seeds, vegetables and fruits [2-8]. Many results have showed that the infrared radiation drying could improve the drying efficiency, reduce the shrinkage of dried materials and maintain the nutrient and functional components when compared to the traditional hot-air drying method. Whereas, there is little work on the infrared radiation heat transfer in the current tobacco industry, especially in the tobacco primary processing. Considering this, in the present work, two kinds of infrared radiation dryer were designed to explore the tobacco infrared radiation drying characteristics, including the fixed bed dryer and cylinder dryer. The effect of radiation heat transfer conditions and vacuum on the drying kinetics and temperature of tobacco leaves was investigated.

2. Materials and Methods

2.1 Materials

The flue cured tobacco C2F from Luoyang of China were chosen as experimental materials. Tobacco leaves were pretreated into cut tobacco by a cutter. The raw material is pretreated as follows: by adding a calculated amount of distilled water to cut tobacco, and moisture content of cut tobacco was adjusted to the desired level of moisture content. In this work, moisture content of the testing cut tobacco was set as 30% (on the wet basis). After adjusting the moisture content, cut tobacco was bagged and put into isothermal and equal humidity equipment to balance moisture for 48h.

2.2 Experimental apparatus

The structure of infrared-vacuum drying apparatus was shown in Fig.1. The drying chamber size is 45*45*45 cm. 4 pieces of ceramic radiant panel with the size of 12*12 cm were arranged in the rectangular on the top of drying chamber. A temperature sensor is installed on ceramic radiant panel and connected to the temperature controller unit, which could control the radiation temperature with the precision of ±1 ℃. A vacuum pump with the swept volume of 4 L/s (S.T.P.) is connected to the drying chamber through exhaust line. The pressure of drying chamber is adjusted and controlled by the flow meter and vacuum meter in exhaust line. A weighing sensor with the precision of 0.1g is set at the bottom of drying chamber. During the drying experiments, the radiation heat transfer conditions and vacuum degree can be flexibly adjusted according to requirements.

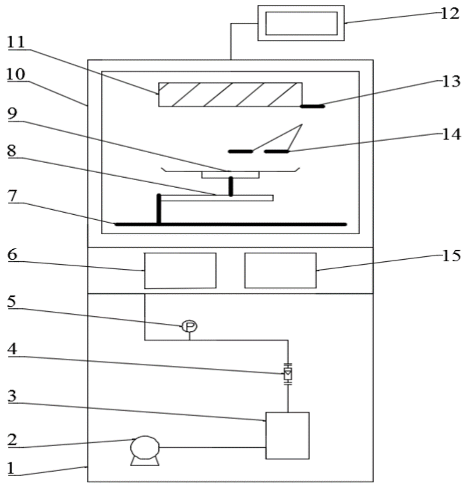


Fig.1 Infrared-vacuum drying apparatus. 1 The bottom of cabinet; 2 Vacuum pump; 3 Buffer vessel; 4 gas flow meter; 5 Vacuum meter; 6 Temperature display panel; 7 Bracket; 8 weighing sensor; 9 Material plate; 10 the upper of cabinet; 11radiant panel; 12 weight display panel; 13 radiation temperature sensor; 14 material temperature sensor; 15 temperature controller

2.3 Experiment methods

Before drying, the radiation temperature and distance are set as the desired levels. Then the apparatus is preheated for 30 min until the stable radiation temperature is reached. The sample of 35g cut tobacco is put into a thin layer on the material plate and then placed on the bracket of weighing sensor. The vacuum pump is started and pressure of drying chamber is adjusted to the desired level. During drying of cut tobacco, the mass and temperature data of sample are collected at the frequency of 30s until the constant weight of sample is reached. Four levels of radiation temperature are investigated, and they are 353 K, 368 K, 383 K and 398 K. The pressure of drying chamber is investigated at the levels of 30 kPa, 45 kPa, 60 kPa and 75 kPa (absolute pressure).

3. Results and discussion

3.1 Infrared-vacuum drying curves of cut tobacco

The moisture and temperature evolution of cut tobacco were investigated at different levels of radiation temperatures, as shown in Fig.2. It can be seen that, when radiation temperature changed from 353 K to 398 K, the drying times of samples were reduced by 50% (when cut tobacco was dehydrated to the moisture content of 12%). The temperature of cut tobacco during drying also has an increasing trend at higher radiation temperature, and the final temperature of sample has a slight increasing.

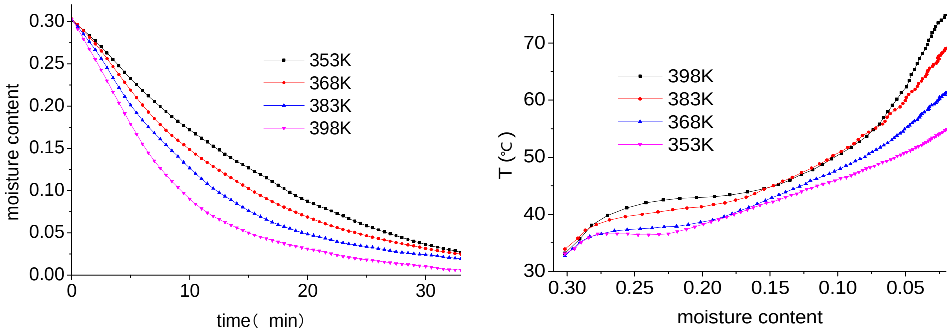


Fig. 2 Effect of radiant temperature on cut tobacco moisture content and temperature

The moisture and temperature evolution of cut tobacco were investigated at different levels of vacuum degrees, as were shown in Fig.3. As can be seen, the vacuum degree has opposite influence on the drying rate and temperature of cut tobacco. Low pressure, namely high vacuum degree, resulted in the increasing of drying rate and the decreasing of final sample temperature. The effect of vacuum degree was associated with its impact on the following two aspects. On the one hand, high vacuum degree could increase the difference of vapor partial pressure between the internal and external of wet materials. At the same time, high vacuum degree also leads to the low boiling point of water, which reduces the evaporation temperature of water during drying. The synthetic effect of the above two aspects caused that drying rate increased and final sample temperature decreased when vacuum degree is increased.

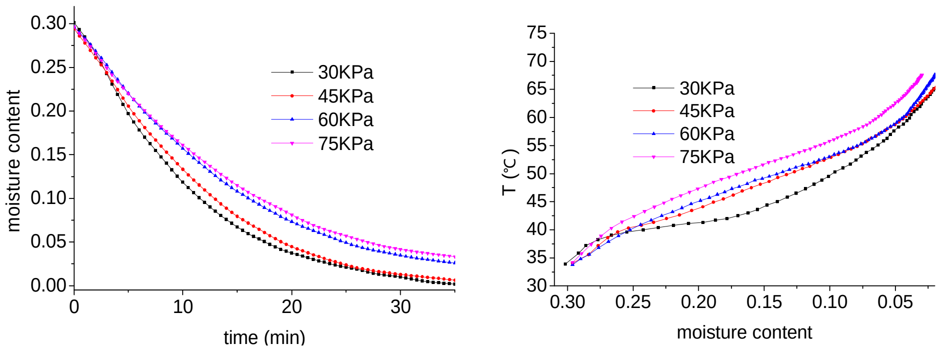


Fig. 3 Effect of vacuum level on cut tobacco moisture content and temperature

3.2 Moisture diffusion coefficient of cut tobacco

According to the Fick's second law[9], the following diffusion equation was used to describe the variation of cut tobacco moisture.

$$\frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left[-\frac{(2n+1)^2\pi^2 D_e t}{4L^2}\right] \quad (1)$$

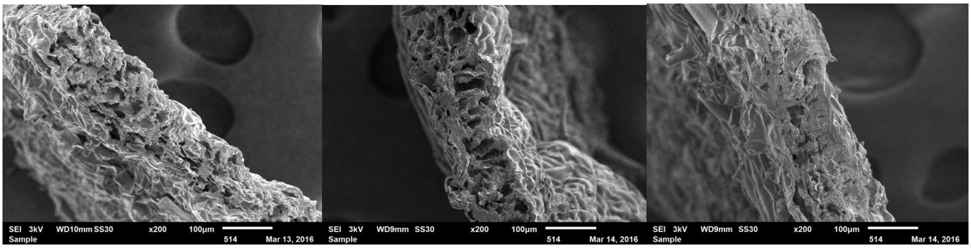
Where, M_0, M and M_e are the moisture content of cut tobacco at t=0, t=t and t=∞, respectively. The D_e is the effective diffusion coefficient of cut tobacco. The t is drying time. L is half of cut tobacco width. In the above equation, the M_e, as equilibrium moisture content of cut tobacco at the drying condition, could be neglected. The L is 0.5mm. The first three terms were taken into account to calculate the effective diffusion coefficient[10]. The calculated values of D_e for two kinds of tobacco were shown in Table 1. It can be seen that the diffusion coefficient of tobacco during infrared-vacuum drying increased with the increasing of radiation temperature and vacuum degree. The radiation temperature has more significant influence on diffusion coefficient than vacuum degree. The diffusion coefficient of middle tobacco leaves C2F is between 0.848×10^{-10} ~ 1.597×10^{-10} m^2/s.

Table 1. The D_e experimental values of cut tobacco

Radiation temperature / K	**Vacuum degree / kPa**	**D_e ($\times10^{-10}$) / $m^2\cdot s^{-1}$**
353	30	0.8409
368	30	1.0317
383	30	1.2657
398	30	1.5529
383	45	1.1049
383	60	0.9645
383	75	0.8419

3.3 Pore structure in dried cut tobacco by different drying methods

The microstructure of dired cut tobacco was analyzed by SEM. Different drying methods were compared, including infrared-vacuum drying, infrared drying and triditional hot air drying at 55ºC. The results were shown in the Fig.4. It can be seen that both the infrared-vacuum drying and infrared drying resulted in the porous microstruture in the cross section of cut tobacco. This indicated that the infrared radiation heat transfer decreased the pore drying shrinkage of pore structure compared to the triditional hot air drying, as could be related to the penetrating heating characteristics of infrared radiation.



(a) ***(b)*** ***(c)***

Fig. 4 Pore structure of cut tobacco C2F by different drying methods: （a） dried by infrared radiation and vacuum, （b） dried by infrared radiation, （c） dried by hot air

3.4 Petroleum ether tobacco extracts in dried tobacco

The petroleum ether tobacco extraction mainly consists of volatile oil, resins, fatty acids, waxes, lipids, sterols, and pigments. Its content is often considered as an important index in estimating the quality of tobacco aroma. The petroleum ether tobacco extraction in dried cut tobacco by different drying methods was analyzed, as shown in the Table 2. It can been seen that the infrared radiation heat transfer improved the content of petroleum ether tobacco extraction compared to the triditional hot air drying. The tobacco aroma change during drying mainly could be realted to two factors. The one is the Maillard reaction in tobacco during drying, which leaded to the increase of aroma components. The other one is the evaporative loss of volatile flavor components. The infrared radiation heat transfer may be more beneficial to the Maillard reaction than the hot air drying. However, the the vaccum would cause the increasing loss of volatile flavor components. The effect of two aspects resulted in that the petroleum ether tobacco extraction content for infrared-vacuum drying is higher than that of hot air drying, while lower than that of infrared drying.

Table 2. The petroleum ether extract content

Drying methods	petroleum ether extract content / %
Before drying	3.95
Hot air drying	4.01
Infrared-vacuum drying	4.23
Infrared drying	4.67

4. Conclusions

The infrared-vacuum drying characteristics of flue-cured tobacco leaf were investigated. Drying quality of tobacco was analyzed by comparing to the traditional hot air drying. The results showed that the average drying rate and final temperature of cut tobacco increased with the increasing of radiation temperature. The vacuum degree has opposite influence on the drying rate and temperature of cut tobacco. Low pressure, namely high vacuum degree, resulted in the increasing of drying rate and the decreasing of final sample temperature. Diffusion coefficient of middle tobacco leaves C2F is between 0.848×10^{-10} ~ 1.597×10^{-10} m^2/s. The infrared radiation heat transfer decreased the pore drying shrinkage of pore structure compared to the triditional hot air drying. The infrared drying resulted in the higher petroleum ether tobacco extraction content than infrared-vacuum drying and hot air drying.

5. References

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