Research and Design of Rice Wine Aging Device Based on Fluent

Hongjun Ni¹, Kaixuan Wang¹ ², Shuaishuai Lv¹, Xingxing Wang¹, Fubao Zhang¹ *, Peng Liu¹

¹School of Mechanical Engineering, Nantong University, Nantong, Jiangsu, 226019, China
²Graduate School of Advanced Technology and Science, University of Tokushima, Tokushima, 770-8506, Japan

* Corresponding author’s e-mail: zhang.fb@ntu.edu.cn

Abstract. Rice wine has a spicy and poor taste, which becomes soft and long aftertaste after natural aging for more than one year. According to the problems of long time, large area and low efficiency in natural aging process, rice wine aging device was designed in this paper. Firstly, the requirements of rice wine aging device were analyzed to establish its three-dimensional model. Then, heat transfer performance of this device was analyzed with Fluent software and the effect of temperature field distribution on the aging process of flower dew was studied, which determines the best aging temperature. Finally, a prototype of rice wine aging device was made, and the samples of rice wine were aged in it. The results show that the aging device can keep 55 ℃ for 12 days, which can achieve the effect of natural aging for one year, and the aging effect is significant, which is of great significance for the realization of mechanized production in wine industry.

1. Introduction
Rice wine is a kind of high nutrition, low alcohol drinking wine [1], which is mainly made of water, rice and wheat and brewed through many processes. However, the new rice wine is often spicy and has a strong delayed effect, affecting the drinking experience. Therefore, the new rice wine is stored for a period of time to eliminate the taste and increasing the sense of aging wine. This stored process is called aging, which can make the rice wine soft with a long aftertaste [2-3]. With the increase of rice wine demand, artificial aging method has been developed rapidly.

Aging device is an important equipment in the artificial aging process, which can reduce the harmful components such as fusel oils in the wine, promote the esterification reaction between alcohol and acid, and make the wine fragrant, smooth and soft [4-5]. The research of rice wine aging device promotes the development of wine industry mechanization, and is a very important part of realizing the mechanization and automation production [6]. At present, due to the complex aging reaction and poor aging effect, the design of aging device needs further research.
2. Materials and Methods

2.1. Design of pretreatment device
In the pretreatment part, the heat preservation and mechanical stirring are used to pretreat rice wine to improve the activation energy of each molecule, accelerate the rate of chemical reaction, and promote the oxidation and esterification reaction. The pretreatment part is mainly composed of frame, reactor, transmission device, motor and heating device. As shown in Figure 1, the frame part mainly includes the shell and handle. The shell adopts the thin-wall design of the rotary body, and the handle is the hollow thin-wall design, which can support and fix the whole aging device. The heating device adopts a three-dimensional heating mode, where the heat transfer carrier is heated by the heating element and transferred to the water bath. Finally, the rice wine is heated by the water bath and heated evenly by stirring device.

![Figure 1. Model of frame part](image1)

As shown in Figure 2, the transmission device mainly includes drive shaft, fan, turbulence net, mixing head and other auxiliary parts, which are made of food grade stainless steel 304. The transmission shaft is connected with the motor as a whole, and the fan and turbulence net are connected by bolts. HC6330 single-phase series excitation motor is used to drive the mixing head, which has the advantages of high speed, large starting torque, small volume, light weight and wide range of applicable voltage. The speed can be adjusted by voltage regulation, which is simple and easy to realize. The output power is 90W, the rated speed is 11000 r/min, the rated voltage is 220 V ~ 50 Hz, the working system is S3 with open for 1 min/stop for 5 min, the shaft length is 8 cm, the shaft thickness is 0.71 cm, the width at both ends of the wire head is 6.1 cm, and the distance between the screw holes is 1.0 × 2.3.

![Figure 2. Model of transmission](image2)

2.2. Design of aging device
In the aging treatment part, the rice wine is aged by heat preservation, magnetic stirring and oxidation, where the heating temperature, holding time and the amount of oxidant can be changed. The aging treatment part mainly includes reaction kettle and constant temperature water bath with magnetic stirring. The rotary design is adopted in the reaction kettle that is made of food grade stainless steel 304, and the bottom diameter is 110mm, the top diameter is 120 mm, the height is 160mm, and the wall thickness is 1mm. HCJ-4D double row four hole type is selected for constant temperature water bath with magnetic stirring, which can be accurate to 0.1 ℃ and improve the experimental efficiency.

2.3. Heat transfer analysis of aging device

2.3.1. Establishment of heat transfer model
In the aging process of rice wine, the reaction kettle is heated by constant temperature water bath, and the heat is transferred to the rice wine in the reaction kettle to heat the wine. In the actual heating process, the mechanism and process of heat transfer in the reactor are relatively complex, so it is necessary to simplify in the simulation analysis, where a physical model suitable for calculation is established, and each boundary of the model are named [7]. In the aging process, only the bottom part of the reaction
kettle is immersed in the constant temperature water bath that the heat source is constant temperature, and the upper part is in the air. Therefore, according to the actual situation, the boundary definition of the reaction kettle is shown in Figure 3.

![Figure 3. Definition of reactor boundary](image)

After established, the model is meshed according to the actual situation, and the Mesh module in workbench is used to mesh the fluid part and the solid part respectively. Due to the simple structure and regular shape of the reactor, combined with the characteristics of various grid structures, tetrahedron is used for mesh generation.

### 2.3.2. Parameter setting

The physical properties of rice wine are shown in Table 1, and the properties of reaction kettle materials are shown in Table 2. The aging part is set as solid domain, and the wine sample is set as the fluid domain. The iterative algorithm and relaxation factor remained the default settings.

| Temperature (℃) | Density (kg/m³) | Specific heat (J/kg·K) | Thermal conductivity (W/m·K) | Viscosity (mPa·s) |
|-----------------|-----------------|------------------------|-----------------------------|------------------|
| 40              | 964.76          | 4.125                  | 0.5010                      | 1.060            |
| 45              | 961.06          | 4.123                  | 0.5199                      | 1.015            |
| 50              | 958.30          | 4.121                  | 0.5306                      | 0.907            |
| 55              | 955.39          | 4.119                  | 0.5357                      | 0.814            |

| Material        | Density (kg/m³) | Specific heat (J/kg·K) | Thermal expansion coefficient | Thermal conductivity (W/m·K) |
|-----------------|-----------------|------------------------|-------------------------------|-----------------------------|
| Stainless steel 304 | 7930            | 500                    | 1.72×10⁻⁷                    | 16.3                         |

2.3.3. Simulation analysis

Maillard reaction is an important reaction in the aging process of rice wine [8]. When the temperature exceeds 60 ℃, the Maillard reaction will be intensified, resulting in nutrient loss, making the wine color dark brown and creating products that are not easy to be digested [9]. Therefore, the temperature range is selected as 40 ℃ ~ 55 ℃ in the simulation analysis. In Figure 4, the temperature distribution can be obtained by setting the temperature of the constant temperature water bath pot at 40 ℃, 45 ℃, 50 ℃ and 55 ℃ respectively, and aging for 20 min.
It can be seen from the figure that the temperature of the rice wine sample center is the lowest, and the inner wall of the reaction kettle is the highest which gradually increases form the center of the rice wine sample to the inner wall of the reaction kettle. With the passage of time, the temperature of the wine sample gradually rises to the temperature set by the constant temperature water bath. In the process of water bath heating, heat conduction plays a major role. According to the order of heat conduction, the reaction kettle and rice wine sample are heated in turn. Therefore, the temperature from the inner wall of the reaction kettle to the center of the wine sample decreases in turn.

According to the simulation results of different temperature and different time, it shows that under the same temperature, the temperature of wine sample is more and more close to the temperature set by the constant temperature water bath pot with the passage of time; at different temperatures (less than 60 ℃) and same processing time, the higher the temperature set in the constant temperature water bath, the faster the heat transfer speed. Therefore, the best aging temperature of rice wine is 55 ℃, and the temperature of constant temperature water bath is 55 ℃ in the follow experiments.

3. Results & Discussion
Based on the design and simulation analysis results, a prototype of the rice wine aging device was made, including pretreatment part and aging treatment part. The physical objects of each part and the whole are shown in Figure 5.
Firstly, set the stirring speed to 6000-8000r/min and stir the rice wine sample for 10 minutes to increase the activation energy of the molecules and accelerate the rate of the aging reaction, so as to prepare for the next aging treatment. Then, comprehensive heating, heat preservation, magnetic stirring and oxidation methods were used to aging the rice wine samples to improve the molecular activation energy and promote the oxidation and esterification reaction. The aging process of rice wine samples was recorded after aging at 55 °C for 12 days. The experimental process is shown in Figure 6.

As shown in Figure 7, the color of the rice wine samples were recorded after aging on the 3rd, 6th, 9th and 12th days. It can be seen that after 3 days, the color of rice wine sample is slightly deepened, the pungency is reduced less and slightly sweet. After 6 days, the color of rice wine sample is obviously deepened, the pungency is reduced, and the sweetness is slightly. On the 9th day, the color of rice wine sample deepened even more, the pungency disappears, and the sweetness is obvious. On the 12th day, the taste is sweeter than that after 9 days of aging. It can be found that with the gradual increase of the aging time, the color of the wine samples gradually darkened from slightly yellow to brown, the pungent taste gradually disappeared, and the taste gradually became sweet. By comparing with natural aged rice wine, we can see that the aging device is maintained at 55°C for 12 days, which can achieve the effect of natural aging for 1 year and realized the aging treatment of the rice wine.
4. Conclusions
According to the aging environment and process of rice wine, a set of rice wine aging device was designed, including pretreatment device and aging treatment device, and the three-dimensional model of aging device was established. Based on the knowledge of heat transfer, the heat transfer performance was analyzed by Fluent software. On this basis, the prototype of rice wine aging device was made, and the aging experiment of rice wine samples was carried out with the designed prototype. The color and taste of new rice wine samples after aging treatment were recorded. The results show that the aging effect is related to the distribution of temperature field, treatment time, aging time and other factors. The increased temperature can promote oxidation, esterification and other reactions in the aging process of rice wine, but when the temperature is too high, it will damage the taste of rice wine. Through the heat transfer analysis of the aging device, the optimal aging temperature is 55 ℃. By using the designed aging device to maintain 55 ℃ for 12 days, the effect of natural aging for one year can be achieved.

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