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# EFFECT OF INNER AND OUTER COILS ON HEATING PERFORMANCE OF ANAEROBIC FERMENTATION TANK

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**ABSTRACT**

In order to further study the effect of internal and external coils on the heating performance of fermenters, this paper studied the advantages and disadvantages of internal and external coil heating fermenters under different TS value materials and different ambient temperature conditions, and passed the total heat transfer coefficient. The heating rate, temperature uniformity and temperature control economy of the fermentation system compare the difference between the inner and outer coils. The results show that the ambient temperature has a great influence on the external coil; as the TS value increases, the inner coil heating rate is higher than the outer coil, but the tank temperature uniformity is lower than the outer coil.

**Keywords:** coil heating; high concentration anaerobic fermentation; heat transfer coefficient; heating rate; temperature field unevenness;

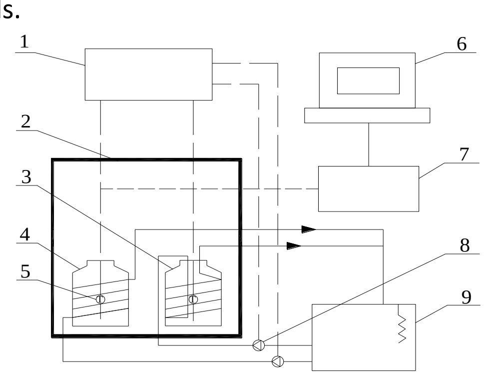
## 1. INTRODUCTION

In the biogas project, the spiral coil is widely used in the anaerobic fermentation system because of its simple structure, convenient production and large heat transfer coefficient. The use of the spiral coil is mainly the inner coil and the outer coil. The two coils have their own advantages and disadvantages due to different installation positions, and also cause differences in heat transfer process, which in turn affects the heat transfer coefficient and heating effect[1~3]. At present, the main research object of heating coils at home and abroad is the wet anaerobic fermentation with low TS value of water and fermentation raw materials. The inner coil heating system mainly studies the arrangement of coils, the simulation of temperature field and the flow in coils[4~6]. In terms of characteristics, the research on external coil heating anaerobic fermentation system is relatively rare, and most of them are research and design calculation of overall heat transfer performance, and there are few studies on high-concentration raw material fermentation, especially the heating process of dry fermentation system[7].

## 2. EXPERIMENTAL AND THEORETICAL ANALYSIS

### *2.1 Introduction*

As shown in Figure 1, the fermenter tank has a height H of 500 mm, a diameter D of 400 mm, and a volume of V of 50 L. The outer side of the fermenter is wrapped with 25 mm thick rubber-plastic insulation cotton. The inner and outer coils are made of PE pipe with a length of 12 m and a size of DN16. The length of the inlet and outlet pipes of the constant temperature water tank to each fermenter is 4 m. The coil is 50 mm from the bottom of the fermenter and the total coil height is 320 mm. In order to determine the temperature distribution in the fermenter, three temperature sensors are arranged at the center line of the tank, which are located at 100 mm, 200 mm, and 300 mm from the bottom, and the data collector records the temperature change in the tank every 2 seconds.




1. Temperature Controller 2. Constant temperature cold room 3. Inner coil fermenter 4. Outer coil fermenter

5. Temperature Sensor 6. Computer 7. Data acquisition instrument8. Hot water circulation pump 9. Constant temperature water tank

Fig.1. Schematic diagram of controllable heating test device

### *2.2 Analysis formula*

The heating rate is the ratio of the elevated temperature of the raw material in the fermenter to the time required for the temperature rise, and reflects the change of the temperature of the raw material in the fermenter with time. The formula is as follows:

$$v_s = \frac{t_{\text{aver}} - t_0}{\tau_{\text{aver}} - \tau_0} \qquad (2.1)$$

The temperature field non-uniformity is the degree of dispersion of the temperature at each point in the fermenter space at any time. It is an indicator of the temperature distribution of the heating material in the tank with space. In this paper, the standard deviation algorithm is used to calculate the unevenness of the temperature field of the tank liquid. The formula is as follows:

$$\Delta t_0 = \sqrt{\frac{1}{3}\left[\left(t_{zhong} - t_{aver}\right)^2 + \left(t_{shang} - t_{aver}\right)^2 + \left(t_{xia} - t_{aver}\right)^2\right]} \qquad (2.2)$$

### *2.3 Results and Discussion*

**Heating rate**

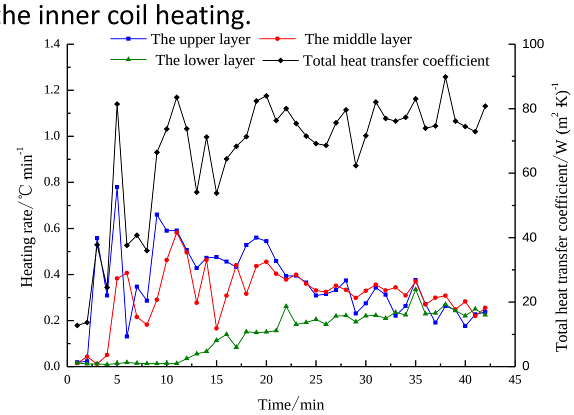
(1) Different TS values

It can be seen from Fig. 2(a), (c), (e), (g) that in the initial stage of heating, the temperature change in the inner coil fermenter of TS8% is obvious, and the total heat transfer coefficient of the coil is also rapidly increased. The temperature of the upper layer and the middle layer rises rapidly, then decreases continuously, and finally the temperature rise rate of the lower layer is close to that of the lower layer, while the temperature rise rate of the lower layer temperature changes lazily. After a period of heating, it begins to gradually increase, and then tends to be stable. . Compared with the TS8% inner coil fermenter, the temperature rise rate of the three temperature layers in the inner coil fermenter is delayed after TS20%. The heating process starts after a certain time, and the total heat transfer coefficient can also be seen. In the initial stage of heating, the total heat transfer coefficient increases slowly, then rapidly reaches the peak value, and then gradually decreases. The upper layer has a larger fluctuation rate of the heating rate, and the temperature rise rate of the middle and lower layers is smaller, and the temperature rise rate of the three temperature layers is finally obtained. They are gradually approaching. It can be seen from Figures 2(b), (d), (f), (h) that the temperature rise rate fluctuations of the three temperature layers in the fermenter heated by the outer coil are small, with respect to the upper and middle layers, the lower layer The heating rate fluctuates less, is basically below 0.05 °C/min, and its total heat transfer coefficient does not change much, and remains basically unchanged throughout the heating process.

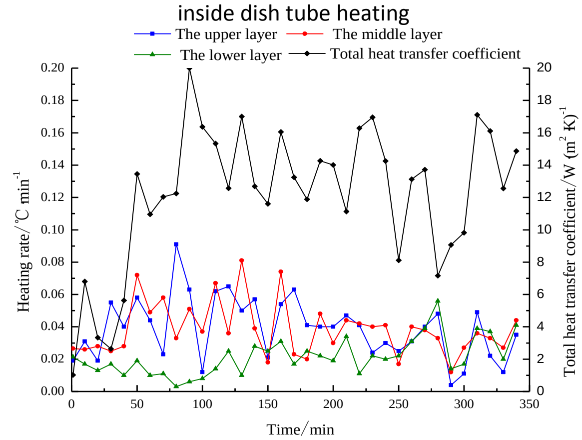
(2) Different ambient temperatures

It can be seen from Fig. 2that the change of the ambient temperature has little effect on the inner coil heating fermenter, and the heating process of comparing the two different TS value raw materials is also basically similar. Compared with the inner coil, the outer coil heating fermenter reacts more to the change of ambient temperature, and the heating time at low ambient temperature is significantly higher than the heating time at high ambient temperature.

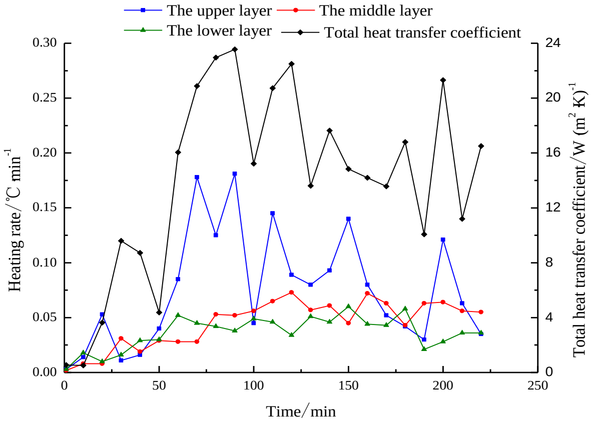
In summary, as the TS value increases, the heating time of the inner and outer coils increases greatly, the total heat transfer coefficient of the coil is greatly reduced, and the ambient temperature has little effect on the inner coil heating.



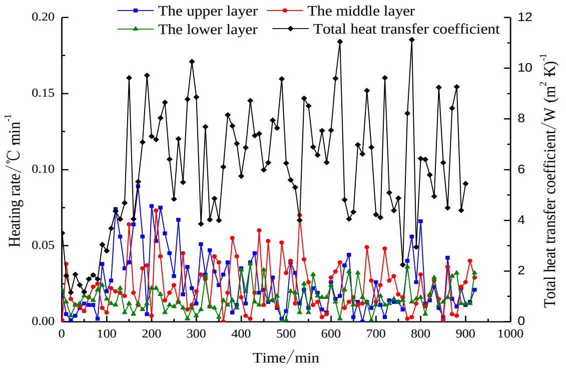

（a）The environment temperature 10℃TS8 % inside dish tube heating



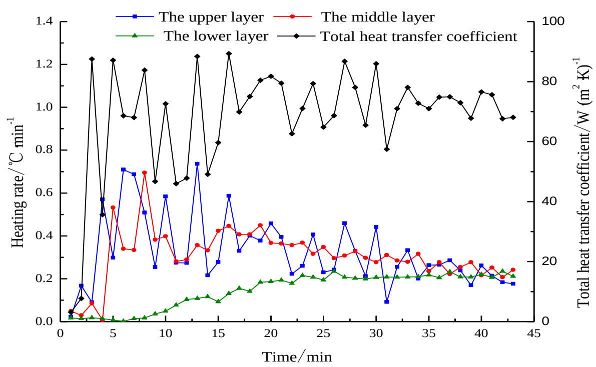

（b）The environment temperature 10℃TS8 % outside dish tube heating



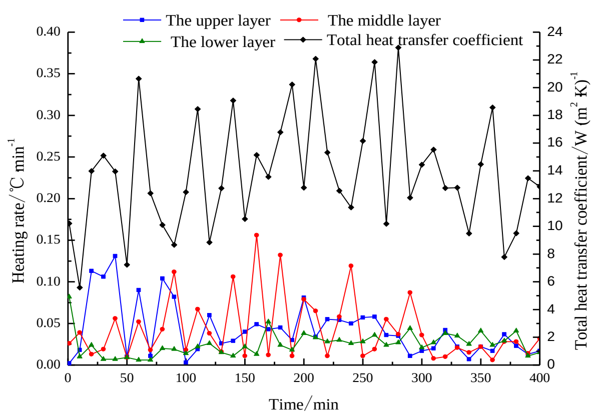

（c）The environment temperature 10℃TS20% inside dish tube heating



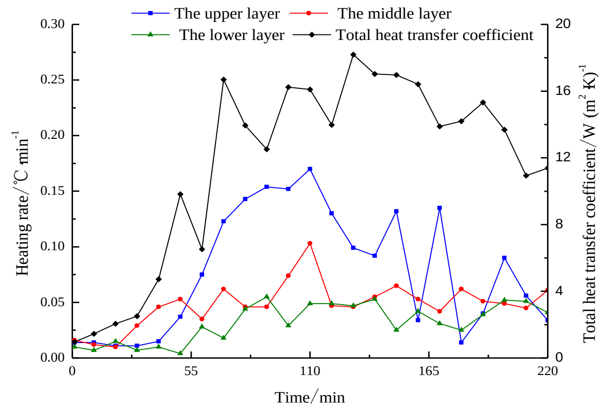

（d）The environment temperature 10℃TS20 % outside dish tube heating



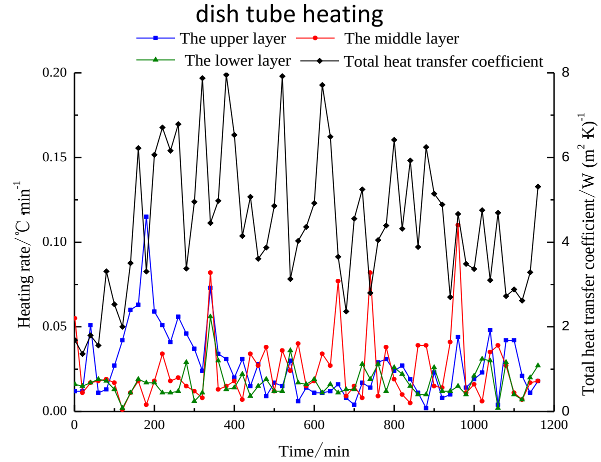

（e）The environment temperature -10℃TS8 % inside dish tube heating




（f）The environment temperature -10℃TS8 % outside dish tube heating




（g）The environment temperature -10℃TS20% inside dish tube heating




（h）The environment temperature -10℃TS20 % outside dish tube heating

Fig. 2Heating rates of internal and external coils at different ambient temperatures and TS concentrations

**Temperature field unevenness**

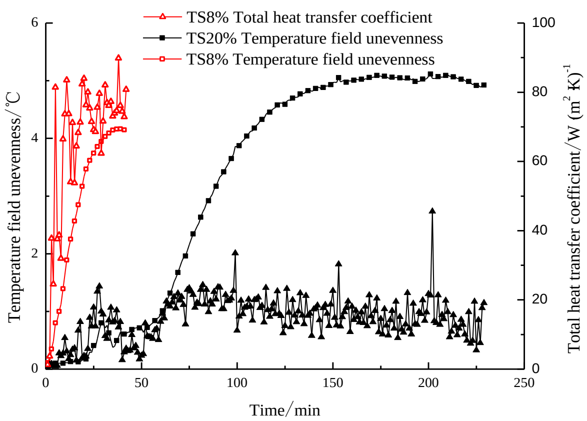
(1) Different TS values

As shown in Figure 3, the same ambient temperature and heat supply, the temperature of the internal and external coil heating fermenter unevenness under different TS values. It can be seen from the figure that as the TS value increases, the heat transfer coefficient of the coil gradually decreases, and the degree of unevenness of the final temperature field in the fermenter increases. The temperature field in the fermenter heated by the outer coil is less uneven than the temperature field in the fermenter heated by the inner coil.

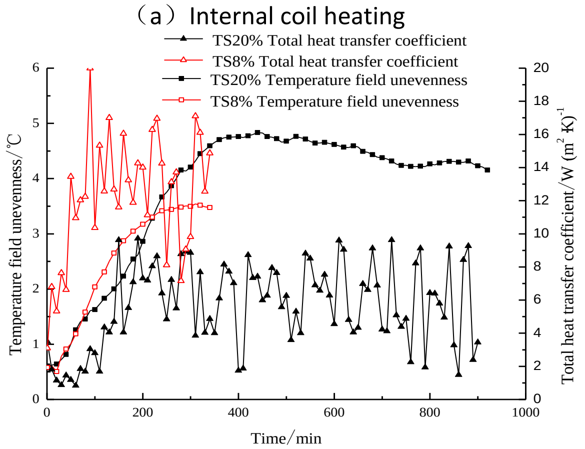
(2) Different ambient temperatures

As can be seen from Fig. 4, when the TS value is 20%, the temperature field unevenness in the fermenter at ambient temperature of 10 °C is always greater than the temperature field in the fermenter at -10 °C, because the TS value is 8%. The physicochemical properties such as specific heat and viscosity of the liquid are lower than those of the TS value of 20%, so the change in the heat dissipation of the fermenter caused by the change of the ambient temperature is more obvious. As the ambient temperature decreases, the degree of non-uniformity of the temperature field in the fermenter also decreases, and the temperature field inhomogeneity in the fermenter decreases more when the TS value is 20%. Comparing the heating of the inner and outer coils, it can be seen that the temperature field unevenness in the fermenter heated by the inner coil tends to be stable after reaching the highest, and the temperature field unevenness of the outer coil heating in the fermenter will continue to decrease after reaching the highest level. The distribution of the temperature field inside the tank will gradually become uniform.

In summary, as the TS value increases, the degree of unevenness of the final temperature field in the fermenter also increases, compared with the temperature field in the fermenter heated by the inner coil, the outer coil is heated in the fermenter. The temperature field is less uneven. As the ambient temperature decreases, the degree of non-uniformity in the temperature field within the fermentor also decreases. Therefore, the temperature uniformity of the outer coil is better than that of the inner coil.

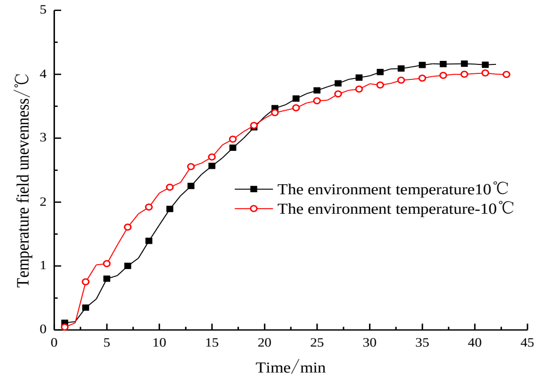



（a） Internal coil heating

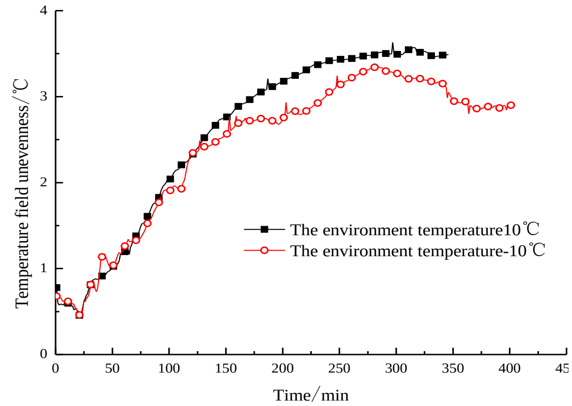



（b） External coil heating

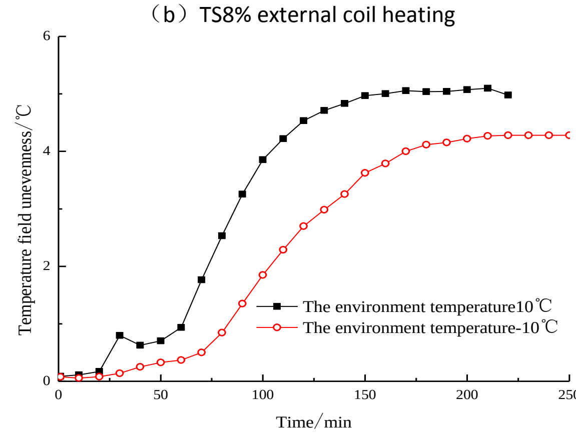
Fig. 3 Temperature field unevenness extent of the internal and external coils at different TS concentrations



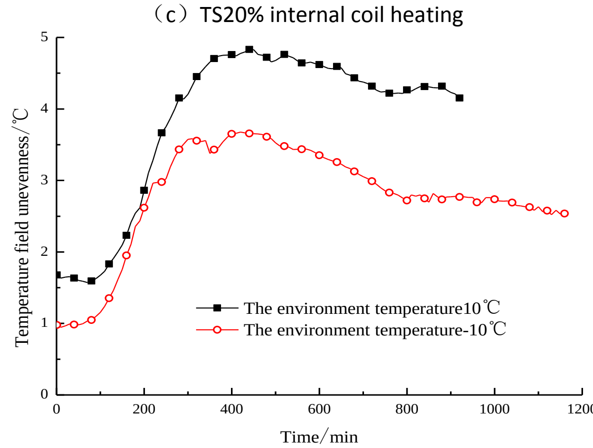

（a） TS8% internal coil heating




（b） TS8% external coil heating




（c） TS20% internal coil heating




（d） TS20% external coil heating

Fig. 4 Temperature field unevenness extent of the internal and external coils at different ambient temperatures

**Field synergy analysis**

As can be seen from Fig. 5, as the Dean number De increases, the field synergy Fc in the coil also increases. Under the same Dean number De, with the increase of TS value, the internal coordination number of the inner coil tube gradually decreases, the synergy between the velocity field and the temperature field in the tube gradually deteriorates, and the convective heat transfer coefficient in the tube gradually decreases, while the outer disk The number of internal coordination of the pipe is gradually increased, the synergy between the velocity field and the temperature field in the pipe is gradually improved, and the convective heat transfer coefficient in the pipe is gradually increased.

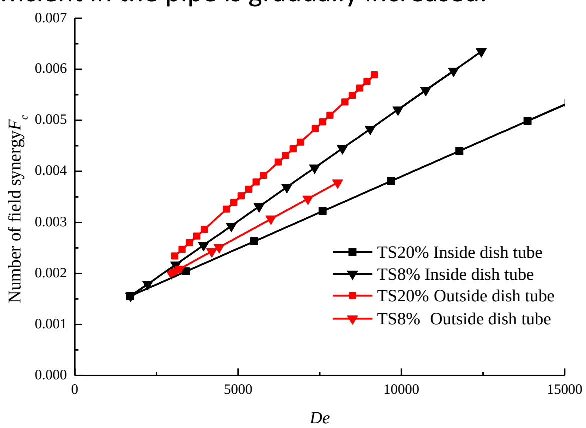



Fig. 5 The field synergy of internal and external coils varies with De at different TS concentrations

*2.4 Conclusions*

（1）When the cow dung with different TS values is used as the heating raw material, the value of the heating raw material TS is the main factor affecting the heat transfer coefficient of the inner and outer coils, the heating rate and the temperature field unevenness in the tank. As the TS value of the raw material increases from 8% to 20%, the heating time of the inner and outer coils and the temperature field inhomogeneity increase are 4.2, 1.7, 0.25, and 0.14, respectively, and the heat transfer coefficient and heating rate are reduced to the original ones. 23%, 54% and 7%, 40%. Compared with the TS value of the raw material, the ambient temperature has the least influence on the heating process of the inner and outer coils, but the degree of unevenness of the temperature field in the tank is reduced, and the temperature field unevenness of the outer coil heating is always lower than that of the inner coil. It can be obtained that the temperature uniformity of the outer coil heating tank is better than that of the inner coil.

（2）As the Dean number De increases in the coil, the synergy between the temperature field and the velocity field in the coil becomes better, and the convective heat transfer coefficient in the tube also increases, and because the curvature of the outer coil is smaller than the inner coil, When the heating raw material is water, the field synergy of the outer coil is always greater than the field synergy of the inner coil, and the convective heat transfer coefficient in the outer coil is always greater than the inner coil. Under the same Dean number De, with the increase of TS value, the internal coordination number of the inner coil tube gradually decreases, the convective heat transfer coefficient in the tube gradually decreases, and the internal field synergy of the outer coil tube gradually increases, and the convection heat transfer in the tube The coefficient gradually increases.

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