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Design and Test of Tunnel-Type Naan Baking Stove

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Abstract. In view of the problems such as high labor intensity, low processing efficiency and great potential danger during the baking process of Xinjiang Naan, an electric tunnel-type Naan baking stove was designed. By the COMSOL software, the thermal simulation of tunnel-type Naan baking stove drawn by SolidWorks was made, so as to find out the heat distribution, heat source loss position and the Naan sizes suitable for processing in Naan baking stoves. In the workshop, a baking experiment was made on the prototype in order to realize the baking of Naan. The simulation results show that the heat dissipation at the inlet and outlet of the baking oven is serious, and the large distance between the heating rods is not suitable for heating Naan. The test results show that the baking stove has good baking effect and stable baking performance under the test conditions of determining the transmission speed of 6m/s and the heating tube temperature of 260 °C by adjusting various horizontal factors and parameters, which can achieve the expected design objectives and has certain value for popularization and application.

Keywords. tunnel-type; naan baking; stove; designed

1. Introduction

Naan has a long history and can be stored for one month in northwest China when it is ventilated. In ancient times, it was called "Hu cake" and "oven cake" [1]. With golden skin and crisp and delicious, naan is the traditional staple food of Uygur, Tajik, Kazak and other ethnic minorities, and is popular in various regions of Xinjiang [2]. At present, the processing of Xinjiang Naan bread is mainly manual, high labor intensity, low efficiency, not suitable for mass processing, in the process of baking naan bread is easy to be polluted.

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The commonly used naan equipment is naan pit, electric naan box, gas naan box, etc. Naan pit is a use of clay and wool mixed into mud, and then handmade masonry stove, belly big mouth small, generally burning wood or anthracite. The advantage of naan pit is the strong traditional cultural flavor [3], easy to eat the taste of Xinjiang, the disadvantage is that fuel is easy to cause environmental pollution, some of the produced naan look bad. Electric and air naan boxes are characterized by static baking, which is a waste of time.

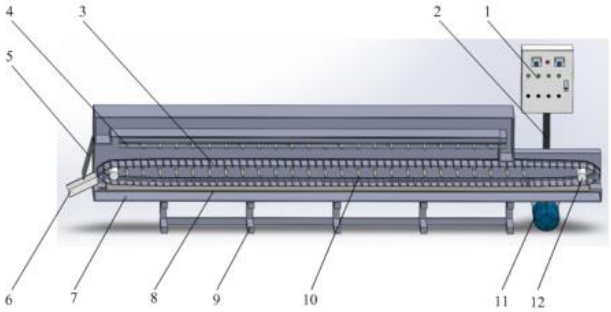
In 2009, the infrared Naan pit designed by Patiguri Abdureyimu installed the main body of Naan pit on the top surface of the control base, installed the infrared heating device on the bottom surface of Naan pit, installed the high temperature resistant microcrystalline glass plate, and finally installed the Naan pit cover at the top opening of the main body [4]. In 2014, the drawer type ceramic naan oven invented by Abdel Thermal-man Toheti arranged environmental ceramic firing layer around the inside of the naan oven, and several heating pipes were installed on both sides of the drawer. The heat from the heating pipes was used to process naan bread, providing a new way for processing naan bread [5]. In 2017, Bayraj Pasha invented the electric intelligent naan pit, which uses the electric bar at the bottom and the electric heating wire on the side wall of the naan pit body to heat the naan pit, which will not produce black smoke, energy saving and environmental protection [6]. Li Chuanfeng of Tarim University invented the drum type naan toaster. The inner wall of the drum is equipped with a number of naan tanks, and the drum is located in the baking room. The design idea is advanced, the efficiency is high, the structure principle is simple, and the operation is convenient [7]. In 2017, Shi Yong from Xinjiang Agricultural University designed a gas-heated rotary naan toasting device, which has compact structure, simple operation, low pollution and can realize mechanized continuous baking of naan [8]. It can be seen that relevant researchers have carried out various modifications on the naan device and achieved some results, but if the naan is processed in an assembly line, there is no corresponding device support.

In view of the problems encountered in the current research situation of Xinjiang Naan pit, the author designed the tunnel type naan oven, and carried out thermal simulation of the tunnel type naan oven, and carried out assembly and laboratory test on the naan oven device.

2. Overall Structure and Working Principle of Naan Oven

2.1. Structural composition

The tunnel type naan oven is mainly composed of four parts: the frame, the power and transmission mechanism, the electrical system, and the heating component, as shown in Figure 1. The tunnel type naan oven is 4m long, 0.85m wide, 0.95m high and 0.65m high. The main parameters are shown in Table 1. The frame part includes the body support frame, naan shell, outlet guide plate, heating tube support frame, import and export high temperature resistant baffle cloth, baking slag collection box; Power and transmission mechanism mainly includes distribution box, motor, master-slave gear, transmission shaft, transmission plate, gear shaft, etc; The electrical system mainly includes the main power switch, power indicator light, long open linkage button, AC contactor, temperature controller, voltage regulating transformer, etc. The heating part includes heating tube, power lead and circuit protector.



1. Distribution box 2. Power lead 3. Conveying plate 4. Heating tube support frame 5. Outlet high temperature baffle 6. Outlet guide plate 7. Naan oven housing 8. Baking slag collection box 9. Body support frame 10. Heating tube 11. Motor 12. Gear shaft

Figure 1. Section view of structure of tunnel-type Naan baking stove

Table 1. Main technical parameter

Parameter	Unit	Numerical value
Grilling furnace form		Tunnel type
Outer box size (length× width× height)	mm	4000×850×950 (650)
Supporting power	kW	20
Heating pipe power	kW	17.5
Maximum heating temperature	℃	450
Width of conveying plate	mm	490

2.2. Working Principle

Tunnel type Naan oven is suitable for large, medium and small naan bread baking. Working principle: Firstly, the oven is energized, and the temperature of the heating tube is set on the control panel. The heat source in the furnace is generated by the heating tube through electric heating. When the upper heating tube and the lower heating tube of the conveying plate are in open mode, the heating tube radiates heat into the oven through radiation heat transfer and convective heat transfer to raise the temperature. Adjust the frequency modulation mechanism, control the motor rotation speed to control the conveying plate speed, adjust to the appropriate speed, run for a period of time, under the dual action of convective heat exchange and radiation heat exchange of the heating tube, so that the temperature of the conveying plate and air temperature of the box body reach a state of thermal balance [9], the raw naan bread is placed on the conveying plate at the entrance of the naan oven, after the naan bread has passed through the oven, Through the convection radiation between air and naan bread and the heat transfer between the conveying plate and the surface of naan bread, the heating and baking of naan bread are realized. Finally, the naan bread is collected from the outlet guide plate.

3. Design Key Components

3.1. Shell design of Naan oven

A heating tube, a transmission mechanism, a support frame and an outlet guide plate are

installed in the naan shell. The whole shell is placed on the frame, and a three-phase asynchronous motor is hung below it. The shell is a sandwich design, hollow inside, to prevent heat dissipation, stuffed with 10CM thick glass fiber insulation cotton. In Figure 1, the right side is the entrance of the naan oven and the left side is the exit. The length, width and height of the outer shell are 4000×850×665mm. The surface of the shell is welded by steel plate with a thickness of 3mm.

3.2 Transmission part

The output power of Naan oven is a three-phase asynchronous 380V, 2.5KW motor, after a level of bevel gear and frequency converter for deceleration, driving the transmission plate around the main and slave shaft rotation, mechanical transmission mode for sprocket chain transmission, transmission plate installed between the sprocket chain, through the chain drive and transmission plate rotation at the same time, The unheated naan bread is transported from the entrance of the naan oven to the interior of the naan oven. After baking by the heating tube, it is discharged by the outlet guide plate.

3.3 Electrical part design

The power supply of naan oven adopts the municipal three-phase and five-wire AC power supply mode. The working power supply voltage of the heating tube is 380V AC, and the voltage of the control loop is 220V. And the TEL72-9001 temperature controller is used to realize real-time temperature measurement and monitoring of the heating temperature of Naan oven and control the furnace temperature of naan oven, as shown in Figure 2.

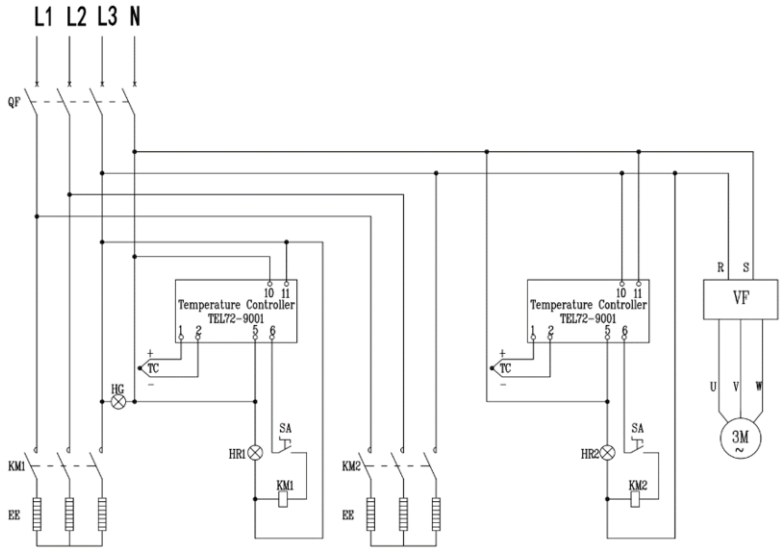


Figure 2. Electrical schematic diagram of tunnel-type Naan baking stove

When the main power switch QF is switched on, the power indicator HR1 and HR2 are on, press the long open linkage button SA, the AC contactor KM1 and KM2 are energized [10], the main contact of KM1 and KM2 is switched on the 380V power supply,

the working power indicator HG is on, and the heating tube EE works. When the heating temperature reaches the set temperature, the temperature controller starts to work. Control the working time of the heating tube EE, so as to control the temperature of the naan oven. The voltage regulating transformer VF adjusts the AC 220V voltage to the adjustable AC 380V, and drives the motor 3M to operate.

Press the long close linkage button SA1, AC contactor KM1 and KM2 power off, main contact of KM1 and KM2 disconnect the working power of 380V power supply, indicator light HG goes out, heating tube EE stops working.

3.4 Heating tube selection

The metal heating tube is a metal tubular electric heater element for heating naan bread, which is put into the electric heating element in the metal tube. This device uses tubular air dry burning 220V electric heating tube, the metal heating tube is a metal tubular electric heater element for heating naan bread, this device uses tubular air dry burning 220V electric heating tube, Calculate the power required for heating from the initial temperature to the set temperature within a specified time and the power sufficient to maintain the constant temperature of the medium under working conditions [11]. According to the two calculation results, the type and number of heaters are selected, and the total power is the maximum of the above two kinds of power [12]. Since the air in the chamber of this naan oven flows with the outside, and the conveying plate is also in the displacement transmission state, the safety preload coefficient is considered as k=1.5, and the calculation process is as follows:

1) The power required for initial heating

$$KW_1=\{(C_1M_1\triangle T+C_2M_2\triangle T)\div 864/H+P/2\}\times k \quad (1)$$

Where C_1——is the specific heat of the container (Kcal/Kg℃)

C_2——The specific heat of the medium (Kcal/Kg℃)

M_1——Mass of container (Kg)

M_2——Mass of medium (Kg)

$\triangle T$——The difference between the desired temperature and the initial temperature (℃)

H——The difference between the desired temperature and the initial temperature (h)

P——The heat dissipation of the container at the final temperature (Kw)

2) The power required to maintain constant medium temperature

$$KW_2= (C_2M_3\triangle T/864+P)\times 2 \quad (2)$$

Where: M_3——The mass of the medium increased per hour (Kg/h)

Combined with the overall structure of the test bed and the corresponding parameters, take C_1=0.46KJ/Kg.℃, C_2=1KJ/Kg.℃, M_1=293Kg , M_2=0.91Kg $\triangle T$=275℃, H=15min, P=0.85, M_3=20Kg.

Is obtained from equations (1) and (2) KW_1 =33.3KW, KW_2 =10.815Kw.

The single heating pipe used in this device has a power of 0.8KW, which is arranged on the upper and lower sides of the naan chamber respectively. A total of 47 pipes, with a total power of 37.6Kw, are adjusted by the temperature controller to meet the requirements of the equipment.

4. Thermal Simulation of TUNNEL NAAN OVEN and Parameter Setting

4.1 Modeling process

The steady-state temperature field of tunnel-type Naan oven was simulated by COMSOL. ① A tunnel-type Naan oven model was established. ② Define the material parameters of each component of tunnel naan oven; ③ Set the boundary parameters of tunnel naan oven; (4) Suitable meshing of naan oven; ⑤ Steady state simulation of Naan oven model; ⑥ Analyze the simulation results [13].

4.2 Establishment of 3D model

The three-dimensional modeling software SolidWorks was used to draw and assemble each component of the tunnel-type naan oven. The assembled models were imported into COMSOL software. The left and right sides of the naan oven were symmetrical, so half of the models were selected for simulation.

4.3 Define material parameters of simulation model

The material parameters of some parts of the Naan oven are set. The material of the inner wall of the oven and the conveying plate is 304 stainless steel, the material of the heating tube is 310S stainless steel, and the internal fluid area is air domain. Therefore, the material property parameters of the tunnel Naan oven are shown in Table 2.

Because the outer side of the Naan oven wall is wrapped with thermal insulation material, after reaching a stable state, the heat loss of the naan oven wall heated by the heating tube is limited, which can be simplified as the Naan oven wall does not carry out surface heat exchange with the outside world.

Table 2. Material parameter of Naan baking stove

Parameter type	density/($kg \cdot m^{-3}$)	specific heat capacity/($J \cdot kg^{-1} \cdot K^{-1}$)	Thermal conductivity/ ($W \cdot m^{-2} \cdot K^{-1}$)
Air domain	1.413	1003	0.023
304 stainless steel	7850	0.50	16
310S stainless steel	7980	0.50	18.7

4.4 Set physical field boundary parameters and heat flux equation of simulation model

The air temperature at the entrance of naan oven was set at 25°C, the air flow rate was set at 0.05m/h, and the heat transfer coefficient was set at 5W/ (m2·k) and the heat conduction coefficient was set at 76.2W/(m·k) in the case of natural convection heat transfer. In order to better obtain the simulation effect, the temperature of the upper and lower rows of heating tubes was set at 400°C under steady state.

4.5 Cell grid division of simulation model

The mesh is divided by tetrahedron, triangle, circle and other structures. In this simulation, adaptive mesh cells are divided, with a total of 1.01 million cells. The maximum cell is 0.02m, the minimum cell is 0.007m, and the average unit size is 0.01m. The mesh model of naan baking stove as shown in Figure 3.

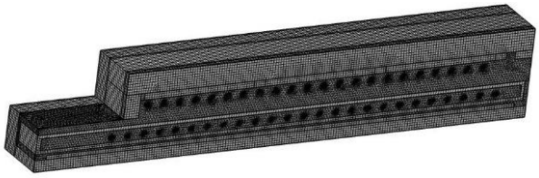
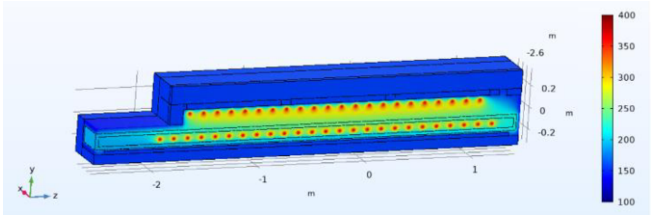


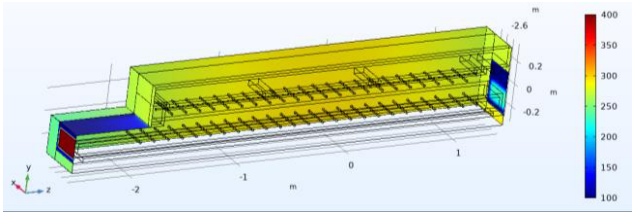
Figure 3. Mesh model of Naan baking stove

4.6 Simulation results and analysis

After the grid is established, steady-state temperature simulation analysis is carried out on the Naan oven model, and the temperature field distribution in the Naan oven is simulated, as shown in Figure 4. As can be seen from Figure 4-a, the upper and lower heating temperatures of naan can be more uniform if the height of naan can be increased appropriately or the distance between the upper and lower heating rods can be reduced. As shown in Figure 4-b, heat loss is more serious at the leftmost inlet and outlet of the naan oven, and insulation measures should be strengthened. In order to improve the heating efficiency, the distance between the upper and lower two layers of the heating tube is adjusted from 350mm to 225mm. In order to prevent serious heat loss, the device is equipped with fiberlike heat insulation refractory material and high temperature resistant cloth made of refractory fiber at the entrance and exit of the naan oven.



(a) Surface temperature distribution



(b) Normal total heat flux

Figure 4. Temperature distribution and normal heat flux diagram of tunnel-type Naan baking stove

5. Laboratory Experiment and Results

5.1 Experimental design

In order to verify the function of the tunnel type naan oven, so that the baked degree of naan bread meets the qualification rate, the test was carried out in Xinjiang Naan Keng Wang Equipment Manufacturing Co., LTD., Aksu Prefecture, Xinjiang Uygur Autonomous Region, on May 2, 2023, the temperature was 20°C and the wind speed was

less than 1 meter. The tunnel type naan oven was selected as the baking object to carry out the baking experiment,as shown in Figure 5. Before baking, the thickness of naan bread is 10~15 mm, the mass is 280~300 grams, the front surface area is about 0.2 ~ 0.28 square meters, the ratio of surface water is 2:1, the number of naan bread is 100. The equipment factors affecting naan quality include heating tube temperature and conveying plate speed. In the experiment, the test bench can realize the adjustment of two horizontal factors: the speed of the naan conveying plate and the temperature of the heating tube. The speed of the naan conveying plate can be adjusted from 0.01m/s to 1.00m/s by setting the speed of the speed-regulating hydraulic motor. Through the coordination of the heating tube, knob temperature controller, temperature measuring element, relay and other elements, the temperature can be adjusted from 0 to 280°C.

Figure 5. Field test

5.2 Experimental analysis determination of edible quality

Sensory evaluation is mainly based on the color, shape, internal structure, taste, and flavor of naan bread. During the evaluation, 6 judges with experience in evaluation conduct appearance evaluation and taste test [14]. Before evaluation, the sample should be coded in advance. In order to improve the reliability of evaluation, the same sample is generally scored three times at three different times in different sequences to take the average value of the C results [15]. The sensory evaluation standards of naan edible quality are shown in Table 3.

Table 3. Sensory assessment standard for the eating quality of Naan

Index	Grading standards	Proportion	Good	Middle	Be poor
Colour and lustre	Golden yellow and uniform color.	20	20~16	16~12	12~8
form	Full, no cracks	20	20~16	16~12	12~8
Inner structure	Soft and tender inside	20	20~16	16~12	12~8
Taste	Strong fragrance, tender inside and scorching outside.	20	20~16	16~12	12~8
Smell, taste	Has rich flavor and unique flavor of Nan pancake.	20	20~16	16~12	12~8
Aggregate score		100	100~80	80~60	60~40

5.3 Experimental analysis influence of conveying plate speed experimental analysis

The temperature of the heating tube is designed to be 260°C, and the speed of the conveying plate ranges from 4m/H to 8m/H. Data is collected at an interval of 2m/H, as shown in Table 4.

Table 4. Sensory evaluation of the eating quality at different transmission speeds

Conveying plate speed	Sensory score	Nan cake size
4m/H	60	28.0cm
6m/H	98	28.1cm
8m/H	67	28.2cm

It can be seen from Table 4 that when the conveying plate speed is 6m/H, the sensory score is the highest. This is because in the process of baking, when the conveying plate speed is too slow, baking time is too long, resulting in excessive water loss of naan bread, making the surface color black, dry and hard to eat; When the speed of the conveying plate is too fast, the baking time is too short, and the heat in the conveying plate and the naan oven is too little, resulting in the skin of the naan bread, and the heart is not cooked.

5.4 Experimental analysis influence of heating tube temperature

The speed of the conveying plate is designed to be 6m/H, and the temperature range of the heating tube is 230~290℃. Data are collected at an interval of 10℃, as shown in Table 5.

Table 5. Sensory evaluation of the eating quality at different heating tube temperatures

Heating pipe temperature	Sensory score	Nan cake size
230℃	71	28.3
240℃	79	28.2
250℃	86	28.2
260℃	95	28.1
270℃	89	28.0
280℃	78	27.9
290℃	64	27.8

As can be seen from Table 5, as the temperature of the heating tube increases, the sensory score increases first and then decreases. When the temperature of the heating tube is 260℃, the sensory score is the highest. This is because the temperature of the heating tube is low, ripening is slow, and the surface is difficult to paint, resulting in low maturity of naan bread and low taste, as shown in Figure 6 (b); When the temperature of the heating tube is too high, the baking time remains the same, resulting in excessive water loss of naan bread, reduced size, black surface color, dry and hard to eat, as shown in Figure 6 (a).

(a) burn the naan bread (b) half-cooked naan bread (c) ripe naan bread

Figure 6. Baked object of Naan

Therefore, the best maturation process of naan bread for conveying plate speed 6m/H, heating tube temperature 260℃.

6. Conclusion

1) An electric tunnel type naan oven was designed based on the theory of heating tube power. According to the simulation results, the heating efficiency can be effectively improved by adjusting the distance between the upper and lower layers of the heating tube from 350mm to 225mm.

2) The field test results showed that when the distance between the upper and lower layers of the heating tube was 225mm, the tunnel type naan oven was used, the conveying plate speed was 6m/H, and the temperature of the heating tube was 260°C, the sensory evaluation effect of naan eating quality was the best.

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