Research on development and prospect of ceramic furnace

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Abstract. As the current greenhouse effect continues to intensify, the pollution caused by the combustion of fossil fuel will continue to deteriorate, and a new type of combustion is urgently needed. This paper mainly studies the low pollutant emission characteristics of natural gas catalytic combustion furnace kiln flue gas, confirming the feasibility of heating glazed tile. Combined with the comparison of existing furnaces in kiln shapes, structural materials, fuel, burners, emissions and other aspects, we will explore the future direction of furnace development. It is pointed out that the furnace kiln technological innovation will be developed in the following aspects: small temperature difference kiln structure, light weight, low heat loss kiln wall, kiln low nitrogen burner, clean fuel.

1. Introduction

China is the hometown of ceramics. It has a long history and glorious achievements in the production of ceramics. Chinese ancestors invented and developed ceramic craftsmanship and technology, which have a profound influence on world culture [1]. It can be said that the history of the ceramic industry is as long as the furnace develop history. In 2011, the output of ceramics in China reached 5 billion pieces of production, and the value exceeding 30 billion yuan. The ceramic industry has made significant contributions to China's economic construction, but also brought serious air pollution problems. In face of the increasingly severe environmental protection situation, the Ministry of Environmental Protection formulated for the first time. The "Ceramic Industry Pollutant Emission Standard" (GB 25464-2010) was promulgated and implemented, and strict limits were imposed on dust, SO₂, and NOₓ emissions. For the treatment of ceramic furnace kiln flue gas, a single pollutant control combination technology was used abroad; although China has mature dust removal and desulphurization technologies, it lacks effective pollutant control technologies such as NOₓ and heavy metals [2]. The realization of energy saving and emission reduction of ceramic furnace kilns cannot be delayed. Ceramic furnace kilns are indispensable and very important in the production of ceramic processes. The capability and environmental protection property of furnace is closely related to its kiln shape, kiln wall material, burners [3,4].

The low-carbon catalytic combustion of natural gas is a new combustion method. The traditional single-phase combustion process always generates a certain amount of nitrogen oxides (NO and NO₂) and harmful gases of CO, and contains unburned fuel, and heterogeneous catalytic combustion. However, the extremely lean hydrocarbon/air mixture can be burned below the minimum limit of conventional combustion and its pollutants can reach near zero with an efficiency of nearly 100% [5]. The application of catalytic combustion to industrial furnaces can improve the environmental pollution of traditional industrial furnace kiln flame combustion, and can more effectively use natural gas,
saving energy [5]. This article analyzes the characteristics of catalytic combustion furnaces from the perspective of furnace pollutants, and combines the shape of ancient and modern kiln, kiln wall structure, fuel type and burner evolution. It explores the future direction of the furnace from the above aspects.

2. Perimental process and device

Figure 1 shows the catalytic combustion kiln system. The kiln is connected to the burner in the system. The inverter controller is utilized to control the fan speed; the natural gas flow rate is manually adjusted; the flow of air and natural gas is measured by a mass flow meter. The steady-state power supplies energy to the flowmeter; the air and natural gas are premixed in a certain proportion and then release heat through the catalytic burner in the furnace. The glazed ceramics are placed on a tray that rotates on a variable frequency motor; the furnace is evenly heated; the kiln passes the digital thermometer measures the temperature directly above the glazed pottery. In order to prevent the burner from excessively high temperature during the combustion process, the burner is cooled by the circulating cooling water; the flue gas from the kiln outlet is passed into the flue gas analyzer through a thin pipe to determine the composition changes of the flue gas.

![Figure 1. The system diagram of catalytic combustion furnace.](image)

The instruments used in the experiment include air volume flowmeter (CMG400A080100000), vortex air pump, frequency conversion controller (SIEMENS, MICROMASTER420), flue gas analyzer, thermocouple digital thermometer, gas volume flowmeter (CMS0050BSR200000), and dual-path stabilizing current power supply (DH1715A-5 type). The catalytic burner used in the experiment is composed of two square monoliths placed side by side. The monolith used is cordierite honeycomb ceramic (5SiO$_2$•3Al$_2$O$_3$•2MgO), and the surface is coated with an oxidizing carrier Al$_2$O$_3$ loaded with ZrO$_2$, BaO and other catalytic aid. The inner surface is plated with the active catalyst Pd-Rh (active ingredient ratio 11:1). Each monolithic side has a length of 150 mm and a thickness of 20 mm. The monolithic channel has a size of 1 mm x 1 mm and a wall thickness of 0.18 mm. In order to rectify the gas mixture, two blank monoliths were used behind the two monoliths [6].

During the experimental process of natural gas catalytic combustion kiln burning glazed tile, the temperature increase rate can be strictly controlled by controlling the furnace door opening and the input power of the furnace, so that it can increase according to the trend of heating curve, which can meet the required temperature of firing glazed tiles. Catalytic combustion of natural gas occurs outside the conventional meteorological flammability limit [6], so combustion is more stable. The natural gas catalytic combustion furnace is a low-emission, low-pollution furnace.

3. Furnace development status and energy consumption comparison

3.1. Evolution of kiln shape
The traditional Shantou kiln, the horseshoe kiln is a semi-falling kiln, the flame first rises from the combustion chamber to the top of the kiln, then falls back to the bottom of the kiln and passes through the smoking mouth below the back wall, smoke is discharged through the chimney. The class kiln, developed from the Long Yao, it was built on the slopes of the mountains. It is better to use waste heat. Former combustion exhaust gas passes through the "broke foot" under the partition wall. Then the latter products can be warmed up. Jingdezhen kiln was established in Jingdezhen. The kiln body is like half an egg shape. It gets the advantages of light and strong structure, large volume, and a big burning capacity. The top of the chimney is pointed and inclined towards the kiln. To prevent the fluctuation of the pumping force or reverse irrigation when the wind direction changes. Now that it is possible to abandon the limitations of previous environmental technologies, most of the furnaces are shuttle kiln and roller kiln. Roller kiln is a kind of tunnel kiln without kiln car. The outstanding feature is that instead of the kiln car as a vehicle for firing the blank, a roller table consisting of a number of rotating rollers arranged in parallel are used. The blank can be placed directly on the roller table or on a hot plate. The drive system rotates the roller and the fired blank moves forward along the channel. After the pre-tropical and firing zone, it is cooled out of the cooling zone and exits the kiln. The shuttle kiln is a modern intermittent kiln with natural gas. Its structure is similar to the burning section of the tunnel kiln. It consists of two parts: the kiln room and the kiln car. The blank code is placed on the kiln car frame and the kiln is fired indoors. After firing and cooling, the kiln car and products are pulled out of the kiln. It is suitable for small batch and multi-variety production [7].

3.2. The evolution of furnace, kiln structural material burners and fuel
Traditional materials for furnace construction are mostly brickwork, but lightweight, high-efficiency ceramic fiber insulation materials are now used. It gathers the characteristics of energy-saving-heat, lightweight and easy assembling. Burners from traditional agricultural fire to combustion nozzles, nozzles are tools for converting energy into heat. The nozzles used by European countries were first invented by the British scientist Venturi, so they were called by Venturi nozzles. Its working principle is that the nozzle sprays natural gas (or gas) to burn, which is supported by the automatic air intake. Now this kind of nozzle has gradually been eliminated in European and Japanese ceramic companies, The combustion air in the nozzle does not need to be sucked from the atmosphere by the air ring, but it is supplied by the machinery, so that when the kiln burns into a positive pressure at this time, the flames will not be taken from inside and outside of the kiln, which not only reduces the thermal radiation loss of the flame, but also prevents the nozzle parts from being damaged by high temperature erosion. In terms of fuel, at present, the fuels in ceramic kilns are not only coal gas, light diesel oil and heavy diesel oil, but also cleaner natural gas, almost eliminating raw coal.

From the comparison of the energy consumption of the three types of kiln units shown in table 1, it can be seen that the energy consumption of the shuttle kiln is the highest and the roller kiln is the lowest. This has a lot to do with the improvement of the kiln shape and materials. Since the roller kiln does not have the heat absorption of the kiln car, the roller kiln is more energy-efficient than the tunnel kiln. The whole-fiber tunnel kiln uses lightweight, high-efficiency ceramic fibers as the kiln lining. Therefore, the maintenance of heat and the use of residual heat are very good, so it is more energy efficient.

| Kiln model         | Unit energy consumption (kJ/kg) |
|--------------------|---------------------------------|
| Mingyan Tunnel Kiln| 6700—9200                      |
| Full fiber tunnel kiln | 4200—6700                  |
| Roller kiln        | 3100—4200                      |
| Shuttle kiln       | 9200—10500                      |

4. Test results and discussion
Figure 2 shows the finished product of the glazed tile ridge animal in the natural gas catalytic combustion furnace kiln. This is the lion shape. The lion is the king of beasts. In ancient times, it was a mighty guardian of the law, representing brave and majestic. From the appearance, the carcass is intact without deformation. Because the catalytic The burner is exothermic to the surroundings in the way of high temperature radiation, the glazed pottery is evenly heated, the color is relatively uniform, the texture is smooth and has a certain brightness, and the glaze is tightly attached on the tire, the color is soft, the surface is smooth, the overall appearance is exquisite, simple and ancient, the color is gorgeous, exquisite, delicate and has a very good decorative effect and high artistic value. In summary, the natural gas catalytic combustion furnace can control the temperature change of the furnace and grasp the firing time, so that high-quality glazed tiles can be fired, which can be compared with the glazed tiles fired by traditional industrial furnaces.

**Figure 2.** Glazing tile roof animals fired in a catalytic burner.

**Figure 3.** Concentrations of CO and NO\textsubscript{x} in the flue gases of a catalytic combustion kiln.

From the perspective of pollutant emissions: figure 3 shows the change of CO and NO concentration in the flue gas of gas catalytic combustion furnace. It can be seen that the CO concentration in the first 15 minutes is in a downward trend, dropping from 27 ppm to 1ppm, because the first 15 minutes of the experiment is the preheat burner stage, where the combustion is ordinary flame combustion, so the CO concentration is higher; After entering the catalytic combustion state, the contaminants are smaller. When the furnace door is closed, the CO concentration rose to its peak of 12 ppm, which is far less than the CO allowable emission limit of 200 mg/m\textsuperscript{3} as stipulated by the Beijing Municipal Industrial Kiln Discharge Standard [8]. The pollutants were almost zero-contaminated at 120 minutes. The concentration of NO was not very high overall because the lower activation energy of the catalytic combustion reaction allowed the reaction to occur at a lean hydrocarbon concentration, so the temperature of the adiabatic reaction below the limit of NO\textsubscript{x} formation, and complete oxidation, no formation of CO and incompletely combusted hydrocarbons, combustion occurs outside the normal gas phase flammability limits, so combustion is more stable. It shows that the flue gas emitted during the natural gas catalytic combustion furnace kiln firing process is clean, the pollution for the atmosphere is almost zero, and it can be directly discharged into the environment. However, at present, the research and application of NO\textsubscript{x} treatment technology in ceramic flue gas is still in a blank stage. Although there are corresponding technologies for coal-fired flue gas treatment, due to the different structure and function of ceramic kiln and coal-fired boiler, the existing boiler denitification and heavy metal removal technologies are not suitable for ceramic flue gas treatment, and dry adsorption is used abroad. Although the effect is good, the adsorption and purification of NO\textsubscript{x} is not suitable for China's national conditions due to the cost of treatment is too high. Catalytic combustion
fundamentally reduces the production of nitrogen oxides from combustion, thereby saving the cost of secondary treatment of flue gas.

From the perspective of the kiln, the kiln shape of the roller kiln tends to widen and lengthen. As the width increases, the heat loss of the unit product and the heat dissipation of the kiln wall decrease. The reason is that as the width of the kiln increases, although the heat radiation area of the kiln body also increases, the output of the product per unit time also increases. Therefore, the heat quantity is reduced relative to the past, and the heat removed by the flue gas is basically the same, so the heat loss per unit product decreases as the kiln width increases. The temperature difference between the product and the kiln wall decreases as the kiln width increases. Therefore, from the perspective of energy conservation, in a certain range, the larger the kiln width is, the better it is. So now there is a kiln width over 3 m. On the other hand, as the length of the kiln increases, the heat taken away by the kiln head decreases, and the quality of the product is further improved. The temperature of the pre-tropical zone, the firing zone, and the cooling zone is often kept in a certain range, and it is easy to grasp the firing law, so the quality is also good, and the damage rate is also small. Therefore, the length of the kiln is generally nearly 100 meters, and many roller kilns have exceeded 100 meters, reaching about 150 meters. However, the increase in kiln length is limited by the site, and the increase in kiln length increases the resistance to gas flow in the kiln. Therefore, the suitable kiln length and wide section are the development direction of the roller kiln. But for small batch production, higher components, shuttle kilns are more suitable. Therefore, the selection of the kiln shape depends on the circumstances, and the most suitable kiln is selected.

From the fuel point of view, the fuel must be more and more clean and pollution-free. Compared with light diesel oil, liquefied petroleum gas is easier to burn, does not require high-pressure device. Gas burners have a low incidence of failure and are easier to operate. The calorific value reached 46.09 MJ/kg, which is very clean in storage and use. It can be fully burned, and it is smokeless, ashless, odorless, nontoxic, and free of residue after burning. This is important for baking products. It can be avoided during the combustion process. The heat contained in the natural gas was also high at approximately 37.86 MJ/M³, as long as the transformer was used to apply natural gas to the kiln. And there is no quality loss caused by the content, no fuel storage equipment and tank safety measures. According to research, there are still more than 200 tunnel kilns burning heavy oil in our country. The total annual fuel consumption is 500,000 tons, equivalent to 780,000 tons of standard coal. If it is changed to burn coal gas, it can save 30% to 40% of fuel annually. It is about 21.3 to 28.3 ten thousand tons of coal [9]. It can be seen that the use of clean liquids and gaseous fuel not only ensures the high quality of ceramics, but also greatly saves energy. In 2016, the proportion of China's energy end-use consumption (according to the electric thermal equivalent method) is 44% of China's terminal energy consumption. Power generation is still dominated by thermal power generation [10]. In view of the different energy structure in China, although the electric furnace kiln is clean, but it is still not the first choice, so the renovation of ceramic furnaces cannot copy foreign experience.

From the burner's point of view, it is more apt to low-nitrogen combustion and reduces the emission of pollutants fundamentally. Low-nitrogen burners are used more in boilers, but they are rarely found in ceramic furnaces. The burners of natural gas catalytic combustion furnaces just provide ideas. The combustion method should also use the premix method. Not only can a fully-closed nozzle be used better, but theoretical analysis shows that the gas-fired premixed combustion method itself has many advantages for low NOx emissions [11].

The traditional brickwork structure of kiln structural materials is not only complex in structure but also very energy intensive. For example, the thickness of the kiln wall in early tunnel kiln is more than 1-2 m. Due to the heavy refractories used in the kiln wall structure, the heat loss is very high. The use of lightweight high-efficiency ceramic fibers as a kiln liner can reduce fuel consumption by 30% to 40% and shorten the firing time by 40% to 50%.

5. Conclusion

- Fuel from coal to oil to gas and then to electricity is gradually getting cleaner. Fuel cleaning is
very important for fire products. It can avoid the production of defects due to pollution. However, taking into account China’s national conditions, China is a country with lean oil, less gas and more carbon. China is still dominated by thermal power. Basically, electricity consumption is still not the best environmental protection method, and it has caused a waste of high-grade energy.

- Pursuit of low heat loss. The heat preservation adopts full fiber or fiber plus light brick, which meets the requirements of modern high-efficiency energy-saving kiln materials. Due to the high-efficiency heat insulation effect of ceramic fiber, the energy consumption of firing is greatly reduced.
- The choice of kiln shape is firstly based on product characteristics; and the second point is the appropriate length and width of the kiln which will be more energy saving.
- More efficient and energy-saving burners. The development of low-nitrogen burners can make up for vacancies in ceramic kiln, natural gas catalytic combustion technology. Not only it prevents the generation of pollutants from the source, but also achieves the purpose of energy saving by the full use of smoke. However, there are also disadvantages, for example, the catalytic burner is expensive and the catalyst is easily deactivated for a long time. It is necessary to explore the cheaper and durable catalyst.
- The cleanliness of pollutant emissions should start with three aspects on clean fuels, the development of cost-effective flue gas treatment equipment and the use of highly efficient and pollution-free burners.

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