Study on the design of high thermal efficiency gas stove based on waste heat recovery

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A new design of high thermal efficiency gas stove which can effectively utilize waste heat of the stove has been proposed by directing at the low thermal efficiency problem of existing open combustion-type gas stoves. Based on practical product investigation, technical methods including introduction of closed furnace body design, adding of waste-heat utilization heat exchanger and design of gas premixing device are applied by aiming at heat loss of imperfect gas combustion caused by open combustion, heat loss taken away by high-temperature flue gas, and heat loss produced by flame radiation and convection in the open space, so as to effectively improve the thermal efficiency of gas stove. The thermal efficiency experiment of model machine has verified the effectiveness of this design.

Keywords: Waste Heat Recovery, Gas Stove, Thermal Efficiency, Innovative Design.

Introduction

More and more countries have treated energy saving and environmental protection as main duties of social development. Compared with electric furnace and coal-fired furnace, gas stove is cheaper, easy to use and environmental. Therefore, it has become the preferred cooking utensil of many developing countries. Throughout the world, gas stove applied the most extensively is open combustion-type gas stove. Moreover, in order to satisfy the function of “sharp fire and stir fry” in Chinese-style catering, blowing-type gas supply is dominant. Such blowing-type and open combustion and heating method has the following three problems:

(1) In the process of open combustion, gas flame will directly contact the surrounding air. The temperature produced by combustion can generate

high-temperature flue gas above 200 degree Celsius. If it is directly discharged into the surrounding environment, heat loss will be caused and meanwhile the environment of kitchen operating space might be worsened. This is the biggest part for heat loss of gas stove at present.

(2) When there is no wind-protection structure, the flame of gas stove will be influenced by surrounding airflow and scattered form can be generated. In this way, the heating efficiency of pan bottom will be reduced. Meanwhile, scattered flames will also spread the thermal energy carried by them to the surrounding environment. Thus heat loss will be caused and the kitchen environment might be worsened.

(3) The high-pressure airflow in blowing-type burning stove will carry fuel gas to flow rapidly. Some fuel gas will be carried away by airflow before it is completely burnt. In this way, thermal energy that should have been produced and utilized will be lost.

By directing at the existing problems of gas stove, many research institutions and manufacturers at home and abroad have conducted special researches. The overseas research direction mainly focuses on structural modification of furnace shape and utilization of good thermal insulation materials. The domestic researches mainly concentrate upon pre-mixer energy-saving technology [1], fire-protection energy-saving ring technology of shielding flame [2,3], energy-saving technology of changing convective heat transfer into radiant heat transfer [4], and flue gas waste heat recovery technology [3,4]. However, most of the above researches focus on the single research node like heat recovery, and heat transfer efficiency. There are few research achievements about overall design of efficient gas stove.

Therefore, this paper plans to apply technical methods including introduction of closed furnace body design, adding of waste-heat utilization heat exchanger and design of gas premixing device, to effectively improve the thermal efficiency of gas stove.

Design Scheme for Thermal Efficiency Improvement of Gas Stove

Based on analysis of main heat loss possibilities of pressurized blowing-type and open combustion gas stove, the design scheme proposed by this paper includes the following points.

(1) Open combustion is changed into closed combustion. In another word, a totally-enclosed combustion chamber is designed, so as to complete main processes including gas combustion, heat transfer and exhaust gas recovery in

this closed space, and to solve direct flue gas discharge and flame dissipation problems.

(2) Premixed combustion technology is adopted and a pre-mixer is designed. Thus fuel gas and air can be fully mixed before combustion, and the fuel gas can be thoroughly burnt in the combustion chamber. In this way, the problem of insufficient fuel gas combustion can be solved.

(3) Waste heat recovery device. Heat transfer device is added to conduct heat transfer for high-temperature flue gas produced by combustion. In this way, the heat directly discharged into the air in the past can be reutilized through heat transfer device. Meanwhile, the influence of high-temperature flue gas on kitchen environment is reduced. The key to design of this part lies in heat transfer form and structure design of heat exchanger.

(4) Application of thermal insulation materials. In the closed combustion environment, heat produced by flue gas combustion will circulate in the entire stove. Heat transfer loss of thermal radiation form can be caused easily after heat passes combustor and hearth. Therefore, insulation structure is designed in key parts, so as to prevent heat loss via thermal insulation materials.

Gas stove Design Practice Based on Waste Heat Recovery

Combustion chamber design

Combustion chamber design is the key part of this study, and it covers three key points. Firstly, the form of combustion chamber should guarantee that the fuel gas of combustion and high-temperature flue gas produced after combustion can conduct sufficient heat exchange with pot and other cooking utensils. Secondly, combustion chamber design should be beneficial to collection and discharge of flue gas produced after combustion. Finally, the combustion flame should be able to heat the bottom of cooking utensil in a concentrated way through the outer flame with the highest heat.

In design practice, open and deep-well combustion chamber design is adopted, as shown in Fig.1. In which, 1 – Thermal insulation of pan circle, 2 – Thermal insulation of furnace wall; 3 – Thermal insulation of furnace bottom; 4 – Combustor, 5 – Flue gas recovery cavity, 6 – Flue gas recovery pipeline, 7 – Air-intake pipeline, 8 – Gas pipeline.

Fig. 1. Schematic diagram for combustion chamber design

1) Deep-well design can be utilized to guarantee sufficient combustion space and flue gas recovery space. In addition, in order to make the airflow flow sufficiently, the combustor is designed as a circular table form.

2) The cavity between combustor and furnace wall is designed as heat-carrying flue gas recovery cavity. According to the rule that high-temperature gas will flow upward, heat-carrying flue gas outlet is designed at the upper end of flue gas recovery cavity. The size and layout of flue gas outlet are designed according to the cavity size of combustor. Meanwhile, insufficient fuel gas combustion caused by excessively fast flue gas flow velocity and fuel gas tempering phenomenon triggered by excessively slow flue gas flow velocity should be avoided.

3) Thermal insulation materials are used. Materials like vermiculite and fire-proof sponge are used to make an insulating layer by directing at parts that can radiate heat to the outside easily, as shown in the part indicated by red arrow in Fig. 1. Insulation treatment is conducted for furnace circle, furnace wall and furnace bottom.

Premixed combustion design

By directing at the requirements of closed combustion, this paper adopts premixed combustion design. In another word, after fuel gas and air are fully mixed according to the predetermined proportion, the mixture will jet through the ingeniously designed combustion hole. It will be sufficiently burnt in the combustor, thus the effective utilization ratio of fuel gas can be improved. Fig. 2 is the schematic diagram for premixed combustion. In which, 1 – Pedestal, 2 – Combustion bowl, 3 – Fuel gas inlet, 4 – air inlet, 5 – Pre-mixer, 6 – Wind-protection tray, 7 – Nozzle.

Fig. 2. Schematic diagram for premixed combustion design

In order to guarantee intensive mixing of fuel gas and air in the pre-mixer, and realize complete combustion, this paper sets up a wind-protection tray device below the pre-mixer. By establishing a slant round hole, it can make air form a rotational flow of a certain degree after entering the pre-mixer. In this way, rapid and uniform mixing with fuel gas can be promoted.

Application design of heat exchanger

In order to reutilize the heat of heat-carrying flue gas, this paper introduces heat exchanger technology. The whole waste heat recovery and utilization process is shown in Fig. 3. Heat-carrying flue gas after combustion will flow through the heat exchanger, and be discharged as cold flue gas after transferring the heat to pressurized cold air through heat exchange. Pressurized cold air after heating will be burnt after it is mixed with fuel gas as premixed air. On the one hand, this design has effectively utilized the waste heat of flue gas; on the other hand, premixed air after heating will contribute to fast combustion. In which, 1 – Heat-carrying flue gas, 2 – Cold flue gas, 3 – Pressurized cold air, 4 – Warmed cold air, 5 – Tubular heat exchanger.

Fig. 3. Schematic diagram for heat exchange of heat transfer device

Experimental Researches on the Improvement of Thermal Efficiency Via Waste Heat Recovery

Experimental design

Experimental goal: By taking the situation of heating cold water under 15 degree Celsius to 100 degree Celsius as an example, whether waste heat recovery mode is beneficial to thermal efficiency increase of gas stove is verified through the experiment of comparing combustion thermal efficiency of different stoves.

Laboratory appliance: Natural gas is used as fuel; the rated heat flux of stovetop burner is 4.6kW; the test cookware is the semi-spherical wok with the tip diameter of 380mm and thickness of 1.6mm.

Experimental conditions: It is conducted in the laboratory of room temperature. During the test period, the room temperature of laboratory is maintained at the constant temperature of 15 degree Celsius. The supply pressure of natural gas is 2200Pa; the quantity of fresh water used for the experiment is 3.75kg; cookware and stove are cooled to the room temperature before the experiment, to guarantee that various original states are the same. The cookware is uncapped in the heating process. The data collection standard is to increase the water temperature from initial temperature to boiling state till the glass thermometer reads 100 degree Celsius. The flame is blue in the test process and the combustion is stable and normal.

Major parameters of heat exchanger used for the experiment: The material of tubular exchanger used for the experiment is aluminum and the heat exchange

area is 6m². Cold air passes inside the pipeline and high-temperature flue gas passes outside the pipeline.

Experimental results and data analysis

Table 1 gives the thermal efficiency values of gas stoves with and without heat transfer device under different parameters. In the table, H means the distance from pan bottom to furnace end (unit: minute), s means the area of hot waste gas port (unit: square meter), v means the cavity volume (unit: Liter), T means the heating time (unit: minute), V means the consumption of fuel gas (unit: cubic meter), η means the thermal efficiency (unit: %).

Table 1 List for experimental values of thermal efficiency under different stove design parameters

Heat transfer	H	s	v	T	V	η
No	0.09	2.5×10^{-3}	7.9	4.3	0.039	27
No	0.09	2.5×10^{-3}	10.3	4.3	0.042	24
No	0.1	2.5×10^{-3}	7.9	4.2	0.042	24
No	0.09	5.3×10^{-3}	7.9	4.2	0.044	23
Yes	0.09	2.5×10^{-3}	7.9	2.8	0.028	56.6

According to the experimental results, after heat exchanger is added, thermal efficiency value of the whole gas stove can be increased substantially. Meanwhile, structural design of combustion chamber has a huge influence on thermal efficiency. Combustion cavity volume, distance from furnace end to pan bottom, and area of hot waste gas port are all important factors of influencing thermal efficiency.

Conclusions

Based on the analysis of reasons for heat loss of the existing open combustion gas stoves, this paper designs a new gas stove by introducing closed combustion, adding waste-heat utilization device, and adopting premixing design. According to the experimental results about thermal efficiency of different gas stoves in the situation of heating water, thermal efficiency of gas stove is increased substantially after waste-heat utilization device is added. However, data of this paper are obtained through experimental researches on several gas stoves with different design parameters. The optimization for heat exchanger parameter design and combustion chamber structure design is not completed. In the future, more elaborate experimental data should be collected, and parameter optimization design needs to be conducted on such basis.

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