Household gas stove based on multi jet tangential circle and TVC vortex structure

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Abstract. In view of the heat loss after combustion and the single-stage direct combustion after contacting with the air caused by the simple structure of the traditional boiler frame, the project adopts the advanced TVC standing vortex technology and multi jet tangential premixed technology. TVC standing vortex technology uses its unique vortex structure to increase the combustion efficiency. As the structure of the project is a semi closed cavity structure, it has great significance for the heat after combustion. It has a high interception effect. In order to improve the combustion efficiency, the multi jet tangential premixed technology is used to achieve the appropriate air coefficient in the burner. This project is of innovative significance to improve the combustion efficiency of the current gas stove.

1. Introduction
It is understood that China's natural gas consumption in 2018 has exceeded 280 billion cubic meters, becoming the third largest total natural gas consumer in the world. However, the use of gas stove still has the disadvantages of low thermal efficiency, high pollutant emission and backward combustion technology.

As shown in Figure 1, for the existing domestic burner, the yellow fire generated by gas stove is the incomplete combustion caused by air hole blockage, and the blue flame is at the more complete
combustion. In view of the heat loss after combustion and the single-stage direct combustion after contacting with the air caused by the simple structure of the traditional boiler frame, the project adopts the advanced TVC standing vortex technology and multi jet tangential premixed technology. TVC standing vortex technology uses its unique vortex structure to increase the combustion efficiency. As the structure of the project is a semi closed cavity structure, it has great significance for the heat after combustion It has a high interception effect. In order to improve the combustion efficiency, the multi jet tangential premixed technology is used to achieve the appropriate air coefficient in the burner. This project is of innovative significance to improve the combustion efficiency of the current gas stove.

2. Innovation of the project
This project mainly includes the following innovations:
(1)The structure of the Laval nozzle can obtain stable air flow without external power source through the suction;
(2)The proper air coefficient is formed in the combustor by using multi jet tangential technique;
(3)Using TVC standing vortex technology to increase combustion efficiency;
(4)A double bluff body with guide vanes is designed in the trapped vortex combustor, which makes the gas have better combustion stability.

3. Design scheme
The device is mainly composed of Laval nozzle which plays the role of air entrainment at the bottom, multi jet tangential full premixed equipment at the bottom, catalytic combustion equipment at the middle and upper heating zone. Through full premixed and catalytic combustion, the combustion efficiency of gas is improved, the emission reduction of harmful gas and the maximum utilization of heat are realized.

Figure 2. Device design drawing.
1- Ejector;2- Multi jet tangential premixer;3- Combustion chamber;4- Top fire cover

3.1. Laval nozzle
The bottom of the work adopts the Laval nozzle design, which is in the form of flaring at both ends and closing in the middle, using Bernoulli equation:
It can be concluded that: When the methane gas flows from the flaring inlet to the middle closing part, the velocity of the gas flow increases and the pressure of the flow area decreases, thus entraining the external air into the pipe, and then into the multi jet tangential premixer of the next part.

The jet pipe based on Laval nozzle structure consists of the expansion inlet, middle throat, outlet and suction chamber. The natural gas enters the jet pipe at a speed of 3m/s to form turbulent jet. In the process of natural gas flowing forward, the speed is accelerated, and a certain negative pressure is formed through the inlet area, which makes the external air continuously inhaled into the jet pipe, and then enters the multi jet tangential premixer of the next part after mixing with the natural gas.

\[ P + \frac{1}{2} \rho v^2 = \text{constant} \]  

(1)

3.2. Design of multi jet tangential premixer

In order to achieve full premixed combustion, this work designs a multi-channel air injection and tangential mixing structure. Based on the idea of tangential combustion of pulverized coal in large coal-fired boiler, three Venturi tubes are set up and the position of Venturi tube is arranged reasonably to form tangential mixing flow field.
Figure 5. Design model of multi jet tangential premixer.

After repeatedly adjusting the $y$-axis rotation angle $\beta$ and $z$-axis rotation angle (warping) $\gamma$ of venturi, the project team found that the rotation angle $\beta$ gradually increased until the combustion coefficient of methane to air was expected to reach $\alpha = 1.2$ between $16^\circ$ and $18^\circ$ and the air coefficient gradually decreased and the average velocity of injected air decreased beyond this angle; when the warping angle $\gamma$ was between $6.5^\circ$ and $7^\circ$ the average velocity of injected air decreased The average velocity of air reaches the maximum. Therefore, the best condition $\beta = 17^\circ$ and $\gamma = 7^\circ$ is used to simulate the combustion of multi jet tangential premixer.

Figure 6. Relationship between rotation angle $\beta$ and air coefficient $\alpha$. 
3.3. **TVC standing vortex structure for household gas stove**
In order to overcome the problems of low combustion efficiency and high pollutant emission caused by the heat loss after combustion and single-stage direct combustion after contacting with air due to the simple structure of the existing boiler frame, the invention provides a new type of domestic gas stove boiler frame based on TVC vortex structure, which makes full use of the heat energy after natural gas combustion, and realizes the increase of combustion efficiency and the reduction of pollutant emission.

The technical scheme adopted by the invention to solve the technical problem is: to design a domestic gas stove pot frame which uses TVC vortex technology to realize the increase of thermal efficiency and the reduction of combustion pollutants, including a shell, a bracket, a primary air inlet, a secondary air inlet, a guide ring, a support column, a vortex chamber, a bluff body and a connecting frame, and the upper and lower parts of the shell are evenly distributed with 24 primary air inlets A total of 72 secondary air inlets and 4 supports are evenly distributed on the inner part of the shell. A support column is fixed on the inner side of the shell, a guide ring is fixed on the support column, a connecting frame is connected on the inner side of the guide ring, and the bluff body is fixed on the inner side of the guide ring through the connecting frame.

![Figure 8. General drawing of the device.](image)

3.4. **Double bluff body structure with deflector**
Trapped vortex combustor, TVC is a new combustion chamber with compact structure, wide stable working range and less emission of combustion pollutants. TVC adopts the combustion organization
mode of classified division, which is mainly divided into the vortex zone and the main combustion zone. In order to realize the ideal double vortex structure in the vortex zone, the proper matching of the intake velocity ratio of the front and rear walls is needed. The different combustion chamber structures have different corresponding velocity ratios, which increases the difficulty in design and regulation, and brings inconvenience in application.

![Figure 9. Cross section of combustion chamber model.](image)

Based on ANSYS simulation, the distribution of cold flow field in a dual bluff body TVC with guide vanes is studied under different bluff body shapes and arrangement distances.

4. Research basis and feasibility analysis of the project

4.1. Analysis of bluff body technology in trapped vortex combustor

4.1.1. Calculation model and method. In order to compare the effects of bluff body shape and bluff body spacing on the cold flow field performance, the turbulent flow of four bluff bodies with rectangular, slotted, triangular and arc cross-section and four kinds of bluff body spacing in a standing vortex combustor were simulated. Figure 10 shows the cross section of the geometric model with guide vane and triangular bluff body. The first bluff body is near the guide vane, and the second bluff body is near the back wall of the cavity.

![Figure 10. Screenshot of combustion chamber model.](image)

According to the experimental results of the first generation of the vortex combustor, the total length of the combustor is LC=250mm and the inlet width L1=50mm is determined. The front wall of the
cavity is 50mm away from the inlet, the length of the cavity L=36mm, and the length of the front and rear wall surface Hf = Ha = 30mm. The length and width of blunt body are 12.5mm and 3.6mm respectively, and the thickness of guide plate is 1mm.

The incompressible N-S equation is used in numerical calculation. The turbulence model is real k-ε model, the near wall surface adopts the standard wall function method, the pressure velocity coupling adopts simple method, the convection term adopts the second-order upwind difference scheme, the diffusion term adopts the second-order central difference format, the inlet boundary condition of the combustion chamber is the velocity inlet, and the outlet boundary condition is the pressure outlet. The inlet velocity vm = 30m / s, methane to air equivalence ratio 0.6, initial temperature 400k, outlet pressure 101.325kpa.

4.1.2. Cold numerical simulation. Figure 11 and show the cold flow field distribution of rectangular, circular arc, slotted and triangular bluff bodies with spacing of 10 mm and 20 cm respectively. When the air flows through the first and second bluff bodies, the distribution of air flow is almond shaped.

![Image of flow field distributions](image)

Figure 11. Spacing 10 mm.

There are vortices behind the rectangular, arc-shaped and triangular first-order bluff body and second-order bluff body, which hinder the development and expansion of vortices behind the first-order bluff body due to the limitation of bluff body spacing; the velocity of gas flowing through the slotted bluff body is greater than that passing through the front and rear walls of the bluff body, and the gas flow through the slotted first-order bluff body is squeezed with the trapped gas, which hinders the development of the bluff body Therefore, there is no vortex behind the slotted bluff body.

The results show that there are vortices at the rear corner of rectangular bluff body, circular bluff body and triangular bluff body, but the development is different due to the shape of bluff body. For slotted bluff body, there is no vortex at the rear corner.

4.2. Benefit analysis

According to the design parameters of the open pipe: the flow rate of CH4 in the natural gas pipeline is 2m / s, the flow rate of air entrained by Laval nozzle is 2.5m/s, the methane inlet pipe is a cylindrical pipe with a diameter of 10 mm, and the air inlet pipe is an annular pipe with an outer diameter of 26 mm and an inner diameter of 10 mm. Through the flow calculation formula:
\[ Q = \frac{\pi D^2}{4} \cdot v \]  

(2)

It can be seen that the flow rate of CH4 and air is respectively:

\[ Q_{\text{air}} = \pi \times [(0.13)^2 - (0.05)^2] \times 2.5 = 0.1m^3/s \]  

(3)

\[ Q_{\text{CH}_4} = \pi \times (0.05)^2 \cdot 2 = \frac{0.0157m^3}{s} \]  

(4)

According to the calculation formula of mixed gas concentration, it can be seen that:

\[ n_{\text{air}} = \frac{1L}{22.4L} = \frac{0.047mol}{s} \]  

(5)

\[ n_{\text{CH}_4} = \frac{0.0157L}{22.4L} = \frac{0.0007mol}{s} \]  

(6)

\[ M_{\text{CH}_4} = 0.0007mol \times 16 = 0.0112g \]  

(7)

Therefore, in the mixed gas, the volume fraction of CH4 is 15.7%, which is beyond the upper limit of methane explosion concentration and can burn stably:

\[ X_j = \frac{Q_j}{\sum_{j=1}^{N} Q_j} \]  

\[ Z_j(t,p) \]  

(8)

Among: XJ is the mole fraction of natural gas component J; Q is the volume fraction of natural gas component J; Z is the compressibility factor of natural gas component j, where \( z = 0.9981 \);

The mixed gas is regarded as the ideal gas

\[ H_m^0(t_1) = \sum_{j=1}^{N} \left( X_j \cdot \frac{M_j}{M} \right) \cdot H_j^0(t_1) \]  

(9)

Among: \( H_m^0(t_1) \) is the ideal mass calorific value of the mixture; \( H_j^0(t_1) \) is the ideal mass calorific value of natural gas component J; Xj is the mole fraction of natural gas component J; Mj is the molar mass of natural gas component J; M is the molar mass of the mixture;

Finally, the results are as follows:

\[ H = 58.87 \times 0.0112 = 0.6593KJ \]  

(10)

The calculation formula of wall heat loss QL is as follows:

\[ Q_L = h_0 \cdot \sum A(T - T_0) + \varepsilon \sigma \sum A(T - T_0) \]  

(11)
Among: $\sigma$ is the Stephan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8} \text{W/(m}^2 \cdot \text{K}^4)$; 
$A$ is the heat exchange area of the wall outside the combustion chamber, $A=0.019 \text{m}^2$; 
$T$ is the average outer wall temperature of micro combustor; 
$T_0$ is the ambient temperature, $T_0=25^\circ\text{C}$; 
$h_0$ is the natural convection heat transfer coefficient, $h_0=10 \text{W/(m}^2 \cdot \text{K})$; 
$\varepsilon$ is the wall emissivity, $\varepsilon=0.7$; 
According to the results of finite element analysis, the temperature in the middle of the gas stove is about 994.1k, the final calculation is as follows:

$$Q_L = 10 \times 0.019 \times 694.1 + 5.67 \times 0.7 \times 694.1 \times 10^{-8} = 131.86J \tag{12}$$

Heat loss after conversion is $Q_L=131.86J$.

It can be seen from this, Thermal efficiency of the gas stove is:

$$\eta = \frac{H - Q_L}{H} = 86.7\% \tag{13}$$

The efficiency of the existing advanced burners in the market is generally between 55% and 60%, and the combustion efficiency of this product reaches 86.7%, which is far higher than that of the existing products, and has higher energy saving and emission reduction benefits.

5. Conclusions

This project adopts advanced TVC standing vortex technology and multi jet tangential premixed technology. TVC standing vortex technology uses its unique vortex structure to realize the increase of combustion efficiency. As the structure of this project is a semi closed cavity structure, it has a high interception effect on the heat after combustion. In order to improve the combustion efficiency, the multi jet tangential premixed technology is used to achieve the appropriate air coefficient in the burner. The efficiency of the existing advanced burners in the market is generally between 55% and 60%, and the combustion efficiency of this product reaches 86.7%, which is far higher than that of the existing products, and has higher energy saving and emission reduction benefits.

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