

# Research Status and Development Trend of Household Gas Stoves

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**Abstract:** With the increasing global demand for pollution-free cooking energy, the development of efficient and clean domestic gas stoves has been promoted. This article first provides a comprehensive overview of the thermal performance and pollutant emissions of household gas stoves through stove protocols, and organizes relevant design and development literature to gain a deeper understanding of their current development status; Secondly, the impact of natural gas, thermal performance, emission performance, and control systems on energy conservation and emission reduction of household gas stoves was analyzed one by one; Finally, the trend of intelligent development of domestic gas stoves in China was discussed. In summary, this study can provide useful references for the design and theoretical research of domestic gas stoves in China.

**Keywords:** Cooking energy; Household gas stoves; Control system; Thermal performance; Emission performance; Intelligence.

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## 1. Introduction

Cooking is an essential household activity that requires energy supply. The energy for cooking is obtained by directly burning fuel in the stove. In 2021, over 39% of households worldwide, or 2.6 billion people, use polluted and unhealthy solid fuels for cooking[1]. They usually use traditional stoves or three stone structure stoves to burn traditional biomass, which is very inefficient because the potential energy of biomass fuel is only 5-10% used in the cooking process, and usually emits high levels of pollutants [2,3]. These pollutants may lead to lung dysfunction, asthma, arterial dilation, heart disease, etc. [4,5]. The resulting household air pollution causes 3.2 million premature deaths annually[6].

Clean fuels and efficient stoves are crucial for addressing energy needs and ensuring safe cooking for billions of people worldwide. Among the 17 Sustainable Development Goals of the United Nations, providing clean cooking solutions is the primary task of Sustainable Development Goal 7[7]. As an industrialized country, China relies on widespread access to natural gas for clean cooking[8]. The use of natural gas has improved cooking efficiency [9], reduced the fuel collection burden on women and children, and also strengthened the prevention and treatment of related diseases [10]. It is predicted that the demand for natural gas in China will reach  $3700 \times 10^8$  to  $7000 \times 10^8 \text{m}^3$  by 2050 [11,12]. Faced with such a large-scale demand for natural gas, China's gas industry is developing rapidly, and the sales of household gas stoves (hereinafter referred to as gas stoves) are steadily increasing. However, currently, the thermal efficiency of most gas stoves on the market has just reached the standard of 55%. For such large-scale use, even small improvements in the thermal efficiency of gas stoves can significantly save energy. Therefore, studying household gas stoves is of great significance for improving energy efficiency, reducing pollutant emissions, improving indoor air environment, and promoting environmental protection and energy conservation [13].

The calorific value of natural gas varies greatly depending on its different components [14]. Some researchers have

added hydrogen to natural gas to increase its combustion value and reduce pollutant emissions [15]. Of course, more literature has improved the structural design of gas stoves through numerical and experimental research [16] to achieve optimal combustion and heat transfer efficiency. With the development of sensors and the Internet of Things, gas stove control systems are moving towards intelligence, making them safer, more efficient, and more convenient [17,18]. Researchers have been studying the impact of technological advancements in natural gas composition, stove design, and control systems on energy conservation and emission reduction in gas stoves. In order to further improve the efficiency and technological progress of gas stoves, and create a better future, it is necessary to compile existing data on the design and performance parameters of gas stoves both domestically and internationally. However, there is currently no comprehensive literature review on it in China. This article summarizes the technical work of gas stoves both domestically and internationally, in order to identify the areas of past work and further determine the areas that can be focused on in the future.

## 2. Global Agreement

How should stove performance testing be conducted? This is a frequently asked question. Even for the same fuel, the efficiency of different furnaces varies greatly. In 1982, the Volunteer Organization for Technical Assistance (VITA) made its first contribution to promoting the development of testing protocols for stoves. The purpose of VITA testing is to assess the comparability of stove design and to assist the testing stove team in analyzing and interpreting the results [19]. VITA has developed three protocols for evaluating stove performance: water boiling test (WBT), kitchen performance test (KPT), and controlled cooking test (CCT); WBT is designed as a simple laboratory test for quickly comparing the performance of different stoves. According to literature research up to 2020, 73% [20] of the experiments followed the standard WBT protocol. The characteristics of the three protocols are compared as shown in Table 1.

**Table 1.** Comparison of WBT, KPT, and CCT protocols

Numble	protocol	Usage scenarios	Repeatability	Type	comment
1	WBT	Laboratory	Repeatable	Testing of energy transfer	Used for quickly comparing the performance of different stoves
2	KPT	On site	Non repeatable	Task oriented testing	On site evaluation of fuel efficiency for household stoves reflects the actual situation of users
3	CCT	On site	Repeatable	Task oriented testing	Comparing the same cooking methods on different stoves or comparing different cooking methods on the same stove

These three protocols cannot directly relate to the results of stove testing, let alone provide a meaningful evaluation of the overall performance of the stove. The overall efficiency of KPT has been severely distorted by WBT testing; People have demonstrated through more complex testing methods that WBT in open flame stoves underestimates 77% [21] of incomplete combustion products and 370% [22] of particulate matter emissions. Similarly, the fuel consumption estimation for task oriented testing has also been proven to be misleading, as the fuel consumption in KPT is not represented by WBT or CCT [23,24].

### 3. Gas

Natural gas stoves can significantly reduce the production of carbon dioxide annually [25]. Fossil energy emissions are an important source of carbon dioxide emissions in China. To achieve the goal of carbon neutrality, the growth space of fossil fuels will undoubtedly be limited. Natural gas is one of the fossil fuels with the lowest carbon emission intensity. Table 2 summarizes the CO<sub>2</sub> emission coefficients of fossil fuels. It can be seen that natural gas, as the cleanest fossil energy, is currently the best choice to meet the needs of human ecological environment.

**Table 2.** Comparison of Fuel Emission Factors

Numble	Fuel	Fuel emission coefficient (tCO <sub>2</sub> /TJ)	Literature sources
1	wood	121.0	[26]
2	coal	96	[27]
3	kerosene	71.5	[27]
4	Liquefied petroleum gas (LPG)	63.0	[27]
5	natural gas	56.9	[25]

Normally, natural gas is supplied to households through pipelines, known as PNG. Natural gas is a multi-component mixture that varies greatly due to different gas sources, and the heat released during combustion also varies greatly. Ko et al. [14] proposed a series of different components in natural gas, whose calorific value varies greatly; The maximum and minimum calorific values of natural gas are 41.7 and 36.2 MJ/m<sup>3</sup>, respectively, with a 15% variation within this range. Chen et al. [28] introduced the composition and performance changes of 11 different test gases under environmental conditions. The higher calorific value in these groups varies between 43.7 and 37.0 MJ/m<sup>3</sup>.

### 4. Thermal Performance

The equivalence ratio of gas to the first air mixture will affect the formation of pollutants and the stability of the flame during combustion. Therefore, the first air mixing equivalence ratio plays a crucial role in the performance of household gas stove burners. Namkhat et al. [29] studied the air entrainment characteristics in self priming gas burners through thermal and cold tests. They concluded that air entrainment depends on factors such as the momentum rate of the gas, the type of gas, and the geometry of the mixing tube and burner ports. Yang et al. [30] compared the entrainment rate of nozzle outlet geometries for five different nozzle structures, namely conical, elliptical, square, rectangular, and cross shaped, using digital simulation. They found that the cross shaped nozzle produced the highest entrainment rate.

Ko et al. [14] used a single gas burner to study the effect of gas composition changes on burner performance, and found that as the calorific value of natural gas increases, the amount of first entrained air required to prevent incomplete combustion increases, leading to more oxygen supply for chemical reactions, more complete flame combustion, and correspondingly improved thermal efficiency.

Changing the equivalence ratio can change whether the combustion of natural gas and air at stoichiometric ratios and flame stability points is premixed or diffusion controlled combustion. Compared with diffusion flames, premixed flames have a faster and more localized heat release rate, resulting in the highest heat flux generated. On the contrary, a flame structure with stable diffusion produces slower heat release and a larger overall flame structure, resulting in lower heat flux over a larger range. This is consistent with the results obtained by Tuttle et al. [31] who observed and measured the flame behavior and time average local heat flux density of an impact methane air jet flame using visible light emission photography techniques.

The gas stove uses two independent annular burners, an outer ring and an inner ring, with slots or ports arranged in the ring. Each annular burner has its own mixing tube, which allows for a wider range of adjustment of the furnace's adjustment ratio. Tamir et al. [32] developed a novel radial flow burner for household stoves. The swirl angle between the projection of the port axis and the plane of the burner cover is  $\alpha$ ; The port axis is at an angle to the horizontal plane of the

end cover  $\beta$ . Compared with traditional burners, the thermal efficiency of this new type of burner has increased by 10% to 30%.

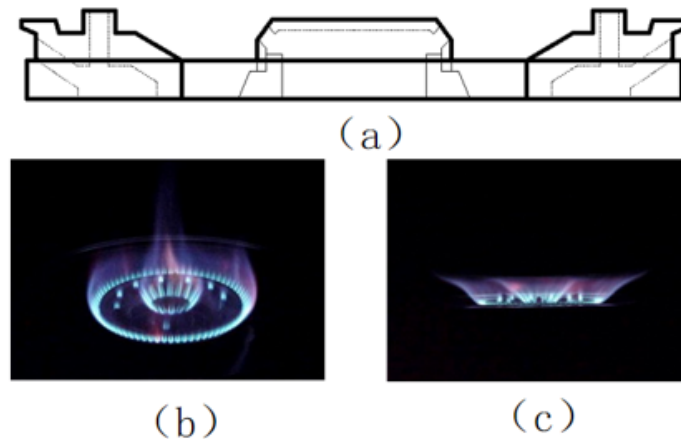
Maktool et al. [33], as shown in Figure 1 (a), use an outer ring with an outer slot and a second row of circular ports, and an inner ring with two rows of circular ports. The outer ring groove port and the inner ring circular port are arranged radially, and the outer ring and inner ring have different inclination angles, allowing the flame to impact the bottom of the container at a certain angle. Figures 1(b) and (c) show the free flame without load and the impact flame with load, respectively. Judging thermal efficiency and furnace performance through changes in flame inclination angle. Chen et al. [28] conducted experimental tests on 12 ordinary circular port gas stoves and 13 swirl bar port gas stoves, representing the main brands and structures of the Chinese cookware market. Both types of gas burners are partially premixed burners, and the main difference between the two types of gas stoves is the burner cover. Propose appropriate structural design parameters by comparing two types of ports.

The hot gas formed by the flame on the burner port stagnates near the center of the bottom of the container and flows along the bottom of the container towards the periphery of the container wall. Das et al. [34] used computational fluid dynamics simulation to systematically analyze the fluid flow and heat transfer process of the burner system, and suggested

changing the design of the furnace to improve overall efficiency. Hossein et al. [35] evaluated lateral and bottom convective heat transfer to evaluate the total thermal performance of natural gas fueled burners.

The distance between the cooking container and the top of the burner also has a significant impact on the thermal performance of the stove. As the heating height gradually increases, the thermal efficiency first increases to its maximum value and then gradually decreases [35, 36]. Therefore, there is always an optimal distance for heat transfer in the container, which can obtain the best radiation and thus achieve the highest thermal efficiency. This has been validated in almost all stove combustion operations.

When flames collide with the surface of the container, dissociated substances and free radicals diffuse towards the surface through the boundary layer. Exothermic chemical composite reactions occur on or near the surface, forming stable substances and leading to additional heat transfer to the container. Dwivedi et al. [36] conducted numerical studies on traditional and flame shielded burners from the perspective of thermodynamic properties. The shielded burner has a higher specific heat value and a higher specific heat ratio. The thermal conductivity monitored at the wall is relatively low. It can be proven that the maximum possible heat is stored below the container and near the top of the burner.



**Figure 1.** Two or more references Schematic diagram of dual row port burner [33] ((b) Free flame (c) Impact flame)

## 5. Emission Performance

Compared to traditional fuel cooking, gas typically runs cleaner. Some researchers focus on measuring the emissions of household gas stoves and determining the parameters that affect emission factors. In this regard, it is of great significance for the University of New South Wales in Australia [37], Chenggong University in Taiwan, China [38] and Tongji University in China [39] to study pollutant emissions. The types of pollutants in gas stoves are carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM2.5). Due to incomplete combustion, CO is generated during gas combustion. Among them, the main factors affecting CO emissions are the first air mixing coefficient, gas composition, loading height, heat input, and port geometry.

## 6. Control System

Many people combine microprocessor, sensor technology, network communication technology with automatic control

systems for gas stoves. Gu et al. [40] designed and tested a complete integrated thermoelectric generator system. The system includes a modified gas stove, thermoelectric generator device, and energy storage module, and is equipped with charging and discharging control circuits to store the electrical energy generated by the thermoelectric generator, achieving self-generation of ignition electrical energy. Hugeng et al. [41] used WiFi transmission on smartphones for monitoring, and gas sensors could detect gas leaks. Subsequently, the phone received a warning, and people could control the solenoid valve to close through the phone program to prevent gas leakage. The function of the gas stove control system will be modularized, with one module controlling one function of the gas stove. All modules together constitute the overall system of the gas stove, thereby achieving the development of multiple functions of the gas stove and achieving the intelligent regulation and safety control effect of the gas stove control system.

## 7. Summary

By changing the design of the burner in a gas stove, its thermal efficiency and emission performance can be greatly improved. A reasonable structure enables the gas to have a higher combustion heat value, improves the flame's residence time in the cookware, and more accurately controls the temperature and flow field, thereby achieving better combustion and heat transfer performance. Although it was found that the emissions from gas stoves were restricted at this time, emission factors can be reduced by optimizing the influencing parameters. Especially PRB has the characteristics of high power, compact structure, and low pollutant emissions, which will definitely be the focus of future burner development.

With the development of the Internet of Things, the control system of gas stoves is expected to be combined with cloud computing, machine learning, big data and other related technologies to form intelligence. The intelligentization of gas stoves not only improves performance and functionality, but also meets the needs of modern people for safety, efficiency, and environmental protection.

Gas stoves are optimized in product structure design, achieving maximum thermal efficiency while balancing aesthetics and elegance. At the level of energy conservation and environmental protection, optimizing combustion and heat transfer systems can achieve greater efficiency and energy conservation. Realize intelligence at the product functional level, including comprehensive intelligent control in multiple scenarios. In the near future, safer, more energy-efficient, and more comfortable smart gas stoves will become mainstream.

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