Analysis of CO-Emission from Domestic Gas Cooker with Variation of Natural Gas Composition

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Abstract. For domestic gas cookers, the operating safety is the most important factor for end-users. The increases of CO emission with the variable natural gas constituents will seriously influence indoor pollution and affect human health. Response of CO emission of domestic gas cooker when interchanged by variable natural gas constituents was experimentally investigated from 8 kinds of Chinese domestic gas cookers while using 11 kinds of gas sources. The applicability of Weaver and AGA index on the CO emission prediction was also analyzed. It was found that well-adjusted gas cookers were flexible enough to give satisfactory performance without materially increasing CO emission. CO emission was found to be increasing with increasing Wobbe index of gas and Yellow-tipping. When considering the change of gas components, it can use the change of gas Wobbe Index to predict the CO performance of domestic gas cookers; Some limits should be imposed on Wobbe index of gas to be delivered nationally, so as to ensure no CO-related issues will be encountered.

1. Introduction

Natural gas has been recognized as one of the most important fuels for domestic gas cookers in many countries. With the development of global natural gas trade, liquefied natural gas (LNG) begins to play an increasingly important role in those countries where gas demand steadily increases and indigenous gas production gradually declines [1]. The constituents of LNG are different from those of pipeline natural gas (PNG), particularly the heavier hydrocarbons in LNG, may lead to combustion-related difficulties. For domestic gas cookers, yellow-tip, lift, flash back and incomplete combustion (excessively high concentration of CO) have been reported to occur [2].

Due to emphasis on environmental protection, indoor air pollution (particularly CO emission) has become of great concern. CO is considered as a strong greenhouse gas and very hazardous to human health, and emissions from natural gas burners have always been strictly controlled [3]. Domestic gas cookers are individually small, but so numerous that, they could be significant influenced on CO emission. Such small-scale devices are expected to have different emission factors compared to the open, large-scale combustion. Experiences have shown that slight changes in combustion conditions can have large impacts on emission factors [4].

In China, conventional Bunsen type burner is the most popular in domestic gas cookers market, and natural gas is commonly used though its constituents vary greatly from a city to another. For example, the natural gases supplied into the distribution network of Guangdong province is from different sources, including 3 PNGs, 2 offshore natural gases (OSGs) and 6 LNGs. The variable Wobbe index may strongly affects gas cookers’ performance, including the combustion characteristics (such as yellow-tips, lifting and flash back etc.), thermal efficiency, heat input rating and pollutant emissions (especially CO emission). In order to evaluate impacts of gas constituent variations upon gas cookers
performance, an experimental research was carried out. 8 sets of gas cookers covering three types of ports, round, square and ribbon, were selected as test samples. All sampled gas cookers incorporated atmospheric burners and injectors made of cast-iron, diffusion/distribution head made of aluminum or cast-iron, together with burner head made of casting copper alloys (as shown in Figure 1). Port intensity of all the selected gas cookers falls between 7.0 and 9.0 W/mm². The results obtained in this work would help clarify the most crucial parameter influencing CO emission for variable natural gas constituents. The applicability of well-established AGA and Weaver indexes was also discussed. The experimental results are of great importance as to control the quality of natural gas to be introduced into the local gas network without causing CO emission-related problems.

Figure 1. Schematic diagram of the atmospheric burners.

2. Experiment Setup

2.1. Experimental Facilities
Test rig included two sub-systems: gas-blending and CO emission measurement system, as illustrated in Figure 2. The 11 test gases were provided by gas-blending sub-system through which methane, ethane, propane, butane, nitrogen and carbon dioxide, were blended to give exactly the same constituents as test gases. Also the same Wobbe index and combustion potential were achieved. The gas-blending sub-system includes a 5m³ storage tank. During gas-blending operation, natural gas available in the laboratory (a PNG) was used to purge the tank. Pure components such as methane, ethane, propane etc. were serially piped through a gas meter which has full scale of 10m³/h and ±0.2% FS precision to monitor gas flow into the storage tank. Gas pressure gauges and a heating circuit were incorporated to improve precision. A propelling mixer located in the top of storage tank helped mix uniformly the fed constituents. The purities of individual components involved were as follows: methane 99%, ethane 99.5%, propane 99.95%, butane 99.95%, nitrogen 99.999% and carbon dioxide 99.6%. After all the individual constituents were fed into the storage tank, the mixture remained for 3-5 hours while propeller was working. Then gas was sampled and analyzed by means of gas chromatography. When the constituents of blended gas fell within permissible limitations compared with test gases (listed in Table I) [5], the blended gases could be regarded as identical to test gases.

Figure 2. Schematic diagram of the experimental apparatus.
TABLE I.  

| Component range (mole %) | Reproducibility (%) | Precision (%) |
|-------------------------|---------------------|---------------|
| 0~0.1                   | 0.01                | 0.02          |
| 0.1~1.0                 | 0.04                | 0.07          |
| 1.0~5.0                 | 0.07                | 0.10          |
| 5.0~10                  | 0.08                | 0.12          |
| >10                     | 0.20                | 0.30          |

Gas cooker CO emission measurement sub-system was designed according to Chinese National Standard GB 16410-2007[6]. As illustrated in Figure 2, the concentrations of the combustion product components were measured continuously by exhaust analyzer (KM9106, the accuracy of CO, CO₂ and O₂ is ±10ppm), and the sampled data can be input into computer per 10 seconds. It was reported [7]-[10] that CO emission from domestic gas cooker was closely related with distance between burner head and pot bottom. CO emission would decrease with increasing distance and gradually stabilized toward a specific distance. This means impingement of flame upon cold bottom of pot can quench combustion process to some extent. The location of sampling ring, corresponding to the time required for unburned intermediate to be completely combusted, can have significant influence upon CO emission readings. In Chinese National Standard it is specified that CO emission and thermal efficiency of sampled burner should be measured simultaneously. In order to achieve reliable readings of CO emission, sampling ring should be located as close to the bottom of aluminum pot as possible, usually 20~40 mm. Meanwhile O₂ reading of exhaust should not exceed 14%. Moreover, the radial clearance between sampling ring and the pot should be 0.5~1.0 mm, so that no excessive air will be entrained during sampling process [6]. It should be pointed out that only those CO readings strictly according to this step can be comparable. Despite the thermal efficiency was measured at the same time, discussions about its changing pattern with gas constituents were not included in this paper.

Figure 3. Schematic diagram of the sample ring and test position.

2.2. Experimental Procedure

First of all, initial adjustments were made for 8 sets of gas cookers, which were the most commonly used cookers in China, under adjustment gas. The shape and hardness of an atmospheric flame depend mainly upon primary air given a fixed burner head. Inner cones will change from “soft” to “distinct” when the primary air rate increases and the color of flame will change from yellow to clear blue. The primary air shutters of 8 sets of domestic gas cookers were so adjusted that resulting flames fell between class -2 to +2 according to AGA flame code. Such flames were considered to be most flexible according to previous researches. 8 sets of gas cookers were observed to give satisfactory performance under LNG4, namely no lift, no flash-back, no yellow-tipping occurred and CO emission remained below specified limit. Secondly, the air shutters remained unchanged, CO emission under the other 10 gases were measured in sequence. The measurement procedure of CO emission was carried out according to Chinese national standard GB16410-2007 “Domestic gas stove” [6]. The CO sampling
procedure was as follows: maintaining 2kPa pressure at inlet of gas cooker, to ignite the main burner and after 15 min of ignition, taking sample of exhaust by means of sample ring where the concentration of oxygen must be lower than 14% (as shown in Figure 3).

3. Results and Discussion

For domestic gas cookers, CO emission are the most significant representatives. There exists clearly defined limits on CO emission for the sake of safety, changes in CO emission are known to be directly related to combustion chemistry. During the experiment, the most difficult aspect of CO measurement is that some of sampled cookers burned with excessively high air or that the sampled exhaust contained too high percentage of air. In order to compare values for samples with different dilution percentages of air, the CO values are corrected to a standard value (air free) The units for CO is ppm (parts per million) in the sample.

In this paper, the normalized CO (a ratio relative to CO under adjustment gas) was used for discussion in order to reveal the effect of gas constituent variations. The main advantage of “ratio” approach is that the measured CO data are normalized and more appropriate for comparison of different burner types or test conditions. Another reason is that CO measurement for domestic gas cooker depends upon ambient conditions and can be very sensitive to sample location. During experiment, several of the appliances were found to give different CO emission values for the same gas tested on different days. However, the general trend for changes in the emission was the same. In order to further investigate CO emission resulting from gas constituent variations, the measured CO and normalized CO were plotted as functions of several indexes, as shown in Figure 5~8.

3.1. Thermal Efficiency

Figure 4. Thermal efficiency changing with Wobbe index.

The thermal efficiency of gas cooker is directly affected by burner structure, secondary air supplying and some other factors. It was prescribed that thermal efficiency must not be lower than 55% (for on-top cooker) or 50% (for embedded cooker) [6]. The experiment results are shown in Figure 4. It can conclude that with the change of gas composition the thermal efficiency performance of 3 samples, Sample A, G and H, are not very satisfactory. For all 3*11=33 operation points, 21 operation points about 63% can be considered as “unqualified” in terms of efficiency which are under 50%. Meanwhile the other 5 samples are seem like to be qualified in efficiency when gas compositions were changed.

3.2. Effect of Wobbe index

Figure 5 illustrates the CO emission of all samples under different natural gas constituents. The change of CO emission with the gas constituents doesn’t follow any regular pattern, and most of samples were
smaller than 500 ppm. It was prescribed that CO emission (air-free) must not be higher than 500 ppm [6]. CO emission measurements show that CO emission of a domestic gas cooker can be related with its structure and initial adjustment. Given a suitable structure, those well-adjusted cookers, e.g. Sample A, D and H, can give quite low emission. The normalized CO is plotted as a function of Wobbe index ($J_H$), as shown in Figure 5b. It is obvious that the magnitude of CO peaks increases with Wobbe index, implying there exist authentic impact of gas quality upon CO emission of domestic gas cooker. And it was found that 5 samples can keep lower carbon monoxide emission on all natural gases, accounting for 62.5%; for all 88 operation points, 74 operation points about 84% can be considered as “qualified” in terms of CO emission. So it can be concluded that well-adjusted initial state of domestic gas cookers can be very helpful when fuelled by variable-constituent natural gases, without materially increasing CO emission.

3.3. Influence of Incomplete Combustion Index and Primary Air Ratio Index

Figure 6 shows the tendency of normalized CO for 8 sets of cookers changing with Weaver incomplete combustion index $J_I$ and primary air ratio index $J_A$ which is fairly similar with the tendency of Wobbe index ($J_H$). Because LNG5&6 have the similar constituents and properties, it can be found from Figure 6 that the highest emission in CO corresponds to the highest absolute value for $J_I$ and $J_A$. Meanwhile when $J_I$ is close to the limit value, CO emission problem tends to occur for gas cookers. So with the change of gas constituents, CO emission closely corresponds to the Wobbe index. It is very necessary to specify the range of Wobbe index to make sure that there will not be CO emission problems when gases interchange.
3.4. Effect of Yellow-tipping Index and Lift Index

Figure 7 and Figure 8 illustrate the tendency of normalized CO for 8 sets of gas cookers changing with yellow-tipping index ($I_Y$ and $J_Y$) and lift index ($I_L$ and $J_L$). The trend is complete converse since the formulae are different between AGA and Weaver. It was found that when the yellow-tipping index $I_Y$ and $J_Y$ are close to their own limit values, CO emission of gas cookers are observed to increase obviously. But the tendency for normalized CO and lift index $I_L$ and $J_L$ is absolutely different, the lowest CO emission appear in the area which lift index $I_L$ and $J_L$ are close to the limit values.

Figure 7. Normalized CO data vs. $J_Y$ and $I_Y$.

Figure 8. Normalized CO data vs. $J_L$ and $I_L$.

Seemingly yellow-tipping tends to lead to CO issues more likely than lift. Furthermore, the highest emission in CO does not correspond to the highest value for $J_Y$ or the lowest value for $I_Y$. It means that yellow-tipping is largely affected by gas constituents and it can’t be predicted only by Wobbe index or CO emission value, and vice versa.

4. Conclusion

Through the experimental study on CO emission of 8 sets of domestic gas cookers under 11 kinds of natural gas constituents, it can be conclude:

1. Well-adjusted domestic gas cookers are flexible enough to give satisfactory performance under gas constituents discussed without materially increasing CO emission.
2. With gas constituent variation, CO emission closely corresponds to the Wobbe index and it appears that CO emission increases with increasing Wobbe Index. It is very necessary to specify the range of Wobbe index to make sure that there will not be CO emission problems.
3. When substitute gas takes place of adjustment gas, yellow-tipping is more likely than lift to cause the CO emission problem. But yellow-tipping is largely affected by gas constituent, so it can’t be predicted only by Wobbe index or CO emission value, and vice versa.
For domestic gas cookers, the operating safety is the most important factor for end-users. The increases of CO emission with the variable natural gas constituents will seriously influence indoor pollution and affect human health. So it is very necessary to specify the fluctuation range of gas Wobbe index and define qualified adjustment gas to make sure that there will not be no CO emission problems when gas interchange. On the other hand, it is helpful for the manufacturers to adjust the initial combustion condition of domestic gas cooker, and make the gas cookers will not be easily impacted by changing gas constituent.

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