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Primary air ratio change and gas interchangeability index correct for domestic gas cooker burning multi-source natural gases

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ABSTRACT

In this paper, the influences of burner head temperature and gas properties on primary air ratio change of domestic gas cooker were studied, when natural gases interchange. Then though experimental test, the equation of AGA Lifting Index was modified and its interchangeability limits for Chinese natural gas interchangeability prediction was redefined. From results, when natural gases interchange, the original calculation equation of primary air ratio change should be corrected by temperature. The temperature correction coefficient m values1.1, when poor gas substitutes rich gas. As well as m values 0.9 when rich gas substitutes poor gas. And m values 1.0 when similar quality gases interchange. No flash-back and yellow tip were observed for all 17 domestic gas cookers under 11 test natural gases. Unfortunately, there were about half substitute natural gases appearing lifting, but all these gases were in the limit of AGA Lifting Index. Hence it verified that AGA Lifting Index I_L can't be totally suitable when it's used to predict Lifting for Chinese natural gas interchangeability. According to natural gas interchangeability experiment on Chinese domestic gas cookers, it corrected the interchangeable limit of AGA Lifting Index I_L as follows: total interchangeable, $I_L \leq 1.09$; interchangeable, $1.09 < I_L < 1.13$; un-interchangeable, $I_L \geq 1.13$.

1. Introduction

In China, multi-source natural gases are supplied into same gas pipeline network in many cities. Such as rich components liquefied natural gas (LNG) and poor components pipeline natural gas (PNG), the properties and compositions are so different. It definitely causes gas interchangeability issues, which will increase the expense of facilities maintenance and replacement, and seriously affects the daily operation of end-users. So natural gas interchangeability is the urgent matter for natural gas produce, supply and end-user in nowadays China.

In 1946, American Gas Association (AGA) (Fraser et al., 1946) published a research report about interchangeability of other fuel gases with natural gas. Derivation and application of mathematical equations for establishing interchangeability limits for lifting, flash-back, and yellow tips with natural gas employed as the adjustment gas, were outlined, namely, Lifting Interchangeability Index I_L, Flash-Back Interchangeability Index I_F, and Yellow Tip Interchangeability Index I_Y.

Halchuk-Harrington (Halchuk-Harrington et al., 2006) pointed out the increasing demand for natural gas has resulted in the delivery of new gas supplies to the U.S. marketplace, many of which are very different than the historical supplies. It is currently challenged to verify the sixty year old methods for today's gases and appliances and other end-use equipment. Re-examination and enhancement of existing AGA and Weaver models that reflect current burner designs and gas compositions are recommended so that these valuable tools can be utilized to develop acceptable ranges of gas quality.

Ennis (Ennis et al., 2009) provided a comparative analysis between two sets of test gases to aid in the understanding of the gas interchangeability issues relative to U.S. and Europe. The approach used in this comparison is through the application of the different methods and techniques for gas interchangeability (indices and diagrammatic) in an attempt to map out any parity/disparity between these two sets of test gases and associated standards.

In 2003, Gas Research Institute (GRI) (Johnson and Rue, 2003) prepared a report to chronicle the work completed at the Gas Technology Institute on the project entitled “Gas Interchangeability Tests: Evaluating the Range of Interchangeability of Vaporized LNG

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and Natural Gas." The project's objective was to investigate and quantify the degree to which vaporized LNG changes the performance of domestic combustion appliances when compared with their performance using typical North American pipeline gas. A series of tasks were completed to establish techniques to test the performance characteristics of appliances in terms of interchangeability issues.

Lee (Lee and Hwang, 2007; Lee et al., 2008) presented thermodynamic calculations and experimental results on burning velocity and flame stability confirmed that landfilled gas (LFG) and liquefied petroleum gas (LPG) mixed fuels may be used as interchangeable gas of LNG without any modifications of domestic combustion appliance. For the non-premixed type combustor, the flame stability of LFG-LPG mixed fuels is lower than that of LNG in the weak swirl condition. But in the strong swirl condition, the LFG-LPG mixed fuels show similar stable flame zone to that of LNG and thus, can be used as an interchangeable gas of LNG.

Qin and Chen (Zhang et al., 2013; Chen et al., 2012, 2013; Zhang and Qin, 2013a) discussed the applicability of AGA and Weaver Indices for Chinese natural gas interchangeability prediction. It found AGA and Weaver Indices are not totally suitable to predict lifting and incomplete combustion performance for Chinese natural gas interchangeability. By experimental test results, it suggests the limits of Weaver Incomplete Combustion Index J_I should be changed from $J_I \leq 0.05$ to $J_I \leq 0.04$, Weaver Lifting Index J_L from $J_L \geq 0.64$ to $J_L \geq 0.95$, and AGA Lifting Index I_L from $I_L \leq 1.10$ to $I_L \leq 1.05$. And also Qin and Chen (Zhang and Qin, 2013b; Chen et al., 2014) investigated the flame stability of partially premixed combustion for PNG and LNG interchangeability.

D.P. Mishra (Mahesh and Mishra, 2015) reported the stability limits and near blowout characteristics of unrecessed and recessed compressed natural gas (CNG) inverse jet flames (IJFs) by varying the central air jet velocity for a constant fuel jet velocity. Based on the nature of blowout events, blowout mechanisms for both unrecessed and recessed IJFs are proposed in the present work. Meanwhile the blowoff and flashback limits of laminar premixed CNG–air flames are investigated experimentally (Mishra, 2007).

Hernández (Hernández et al., 2013) studied about laminar premixed flames derived from the combustion of natural gas and producer gas (25 and 50% by volume) mixtures in an atmospheric burner and delimitated the stability diagram of the different mixtures, to evaluate the potential of these mixtures to reduce NOx emission and to study the interchangeability of the gas mixtures used.

Nowadays, it more focuses on natural gas interchangeability but pays less attention on different group gases interchangeability. Though literature review, it is very necessary to verify the sixty year old methods AGA interchangeability indices for today's gases and appliances in China. Some researchers have been corrected the interchangeability indices for Chinese natural gas interchangeability, but they are only about the interchangeability limits. In this paper, we researched the influence of burner head temperature and gas properties on primary air ratio change of domestic gas cooker, which is the main affect factor for combustion performance characteristics change, when natural gases interchange. Then though experimental test, it modified the equation of AGA Lifting Index and corrected its interchangeability limits for Chinese natural gas interchangeability prediction.

2. Experiment methods

2.1. Primary air ratio experiment

Experiment testing system is shown in Fig. 1, mainly including gas supply system, gas flow meter, a designed partially premixed burner, temperature monitoring system and sampling injector. The schematic diagram of designed partially premixed burner and the position of sampling injector are shown in Fig. 2. Three kinds of natural gas are selected as experiment gas, namely pure methane, poor pipeline natural gas (PNG-P), and rich pipeline natural gas (PNG-R), whose compositions and properties are listed in Table 1.

During experiment gas inlet pressure is kept on 2 kPa, and the air valve open rate of designed partially premixed burner is remained on same position. The primary air ratio of CH_4, PNG-R, and PNG-P are tested on three different head temperature situations, which are heated by 5 min (Test 1), 15 min (Test 2), and 30 min (Test 3), respectively. It takes flame root (fire hole exit) temperature as the reference burner head temperature, as shown in Fig. 2. Using the sampling injector to extract gas-air mixture sample from the inside space of burner head, and collect pure test gas sample in front of the burner nozzle 100 mm position. Then the compositions of both samples are analyzed by gas chromatography analysis. When the sampling injector is used to extract gas sample, it must be cleaned by 5–8 times. The sampling action must be kept uniform slowly to ensure the sampled gas is precise. During experiment, it takes flame root (fire hole exit) temperature as the reference temperature.

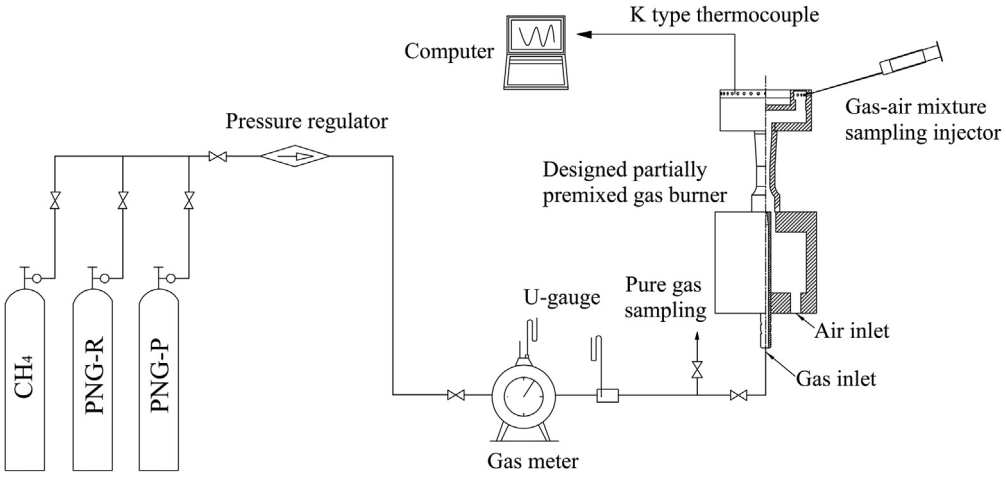

Fig. 1. Schematic diagram of primary air ratio experiment system.