ISME2010-3376

Experimental Investigation on Flame Radiation Enhancement of Methane Burners Using Pre-Heated Inlet Fuel

S. M. Javadi[1], P. Nikoueeyan[2], M. Ghazikhani[3], M. E. Feyz[4]

[1]Fedowsi University of Mashhad, Mohammad.Javadi@gmail.com
[2]Ferdowsi University of Mashhad, p.nikoueeyan@gmail.com
[3]Fedowsi University of Mashhad, m_ghazikhani@yahoo.com
[4]Ferdowsi University of Mashhad, m.e.feyz@gmail.com

Abstract
One of highly appropriate methods for increasing efficiency of natural gas furnaces is the flame heat radiation enhancement which raises the radiation heat transfer rate. In this experimental investigation, the effect of inlet gas temperature on radiative heat transfer rate is studied. For a wide range of inlet gas temperatures from 20 to 450^{o}C, combustion products and exhaust gas temperatures were measured and analyzed. Results revealed that increasing inlet fuel temperature as high as 270^{o}C, increases both NOx concentration and exhaust temperature. But by further increase in fuel temperature, NOx concentration and exhaust temperature are decreased rapidly. Furthermore, flame visualization in the experiments proved that increasing inlet gas temperature for more than 270^{o}C results in a significant change in flame color from blue to yellow which demonstrates flame radiation enhancement that implies greater heat transfer efficiency. Increasing flame radiation not only improves the overall furnace efficiency but also reduces NOx formation as a result of lower flame temperature which is followed by higher radiation rate.

Keywords: Flame Radiation, NOx Formation, Gas Preheating, Methane Burner.

Introduction
Today, great environmental pollution of liquid fuels is one of the most important problems which the industries are facing with. As a result, many of industrial boilers and furnaces are replaced by their gas fueled alternatives. Substitution of liquid fuel burners with gaseous fuel burners leads to a significant reduction in radiative heat transfer rate and consequently causes an overall decrease of furnace temperature. The increase in energy costs, concern about greenhouse gases and energy crises has increased the importance of energy efficiency in production. This is particularly important for globally-competitive and energy intensive industries related to aluminum treatment, chemicals, glass, metal casting, pulp, paper and steel.
Since flame radiation is playing an important role in combustion process, many investigations toward improving flame radiation of gas fuel burners are conducted worldwide. For instance, Grain et al. developed the idea of using miniature fragments of soot or very small droplets of liquid fuel simultaneously with the main gas fuel in order to enrich the gas flame radiation [1]. Yushida studied combustion characteristics and emission aspects of pre-heated air-methane mixture in an internal combustion engine [2] and Buck examined effects of nearby surface radiation on flame temperature distribution and NOx formation [3]. It known that the ratio of (C/H) in the fuel formula greatly affects the rate of soot formation during combustion. Since gaseous fuels have lower C/H ratio, their combustion is associated with insignificant rate of soot formation. Several experimental studies about liquid fuel combustion showed that soot formation during the combustion under the conditions that a high flame temperature is provided results in soot re-burning. This fact causes yellowness in liquid fuel flames which causes higher levels of radiative portion of overall heat transfer (about 30 to 40%) [4]. In addition, numerous studies show that in the absence of oxygen, natural gas dissociates in high temperatures and soot is produced as a result [5,6].
Accordingly, this investigation aims to raise flame radiation by increasing yellowness of flame. This goal is accomplished by increasing the inlet methane temperature beyond 270^{o}C.

Experimental Apparatus
The design objective was to develop a test setup for evaluating the effect of inlet gas temperature on several combustion parameters including exhaust temperature, NO_x formation and flame radiation. A schematic illustration of the setup is presented in Figure 1.
Setup is constituted of a boiler, a burner, measurement devices and some other devices for heating and controlling the natural gas temperature and flow rate.
At the first step gas passes through the burner's automatic valve and then it enters into a U shaped pipe. For each branch of the U shaped pipe there are 2 electric heating elements; One inside the tube and the other one out of the tube but attached to its surface. These parts are well insulated in order to reduce heat losses and providing conditions for increasing gas temperature as high as possible; Figure 2, illustrates the U shaped pipe

with details. In order to control the gas temperature a dimmer switch is placed before heating elements. The temperature of gas flows is recorded via a K-type thermometer and enters into the gas burner. The gas burner has a capacity ranges between 30,000 to 100,000 Cal/hr which is adjustable by controlling gas flow rate. AT the beginning of the test, the air damper is adjusted to meet the lowest CO concentration (about 40 PPM) in exhaust.

The Boiler unit is a 116 kW fire tube water heater which is described in the European Standard EN 676 [7]. The diameter and the maximum length of the combustion chamber were 400 and 790 mm, respectively. These values were defined from the diagram in EN 676 which gives the relationship between the dimension of combustion chamber and heat output.

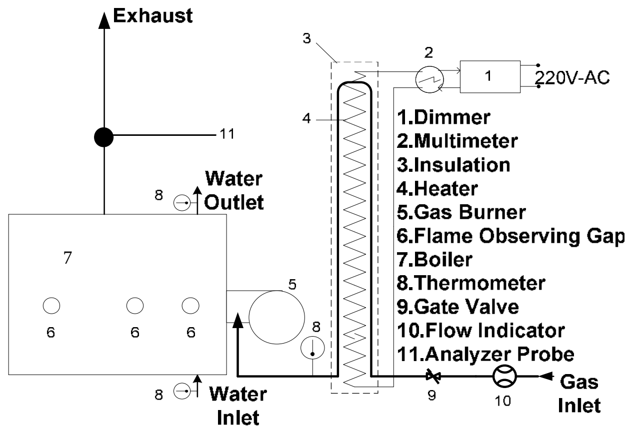

Figure 1: Schematic illustration of testing apparatus

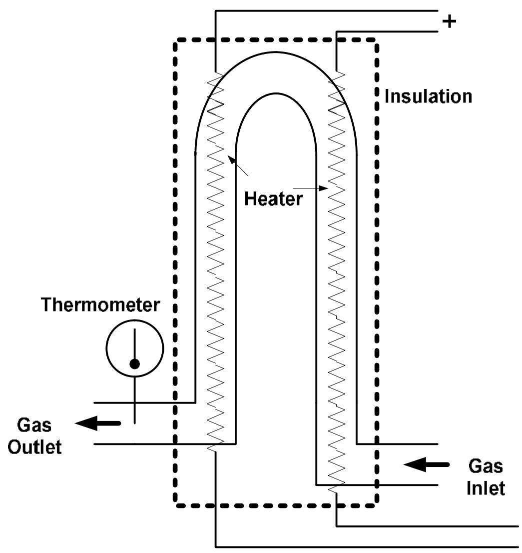

Figure 2: U shaped pipe containing electric heaters

Testing Method

As it was stated in the previous section, for increasing gas temperature, 4 heating elements are used which their overall capacity is controlled via a dimmer switch. First the experiment conducted for the normal condition without fuel preheating and all of combustion products such as O_2, CO, CO_2, NO_2, NO, H_2, excess air and combustion products temperature were measured by gas analyzer type *TESTO 350XL*.In the next step, heaters were turned on and by controlling their capacity similar tests were conducted for temperatures between 100 to 500 degree Celsius. In addition to all these data, flame heat radiations were measured for all of above temperatures by a photocell. For each test, the flame picture was captured in order to compare yellowness of flames with heat radiation rate. For making sure of repeatability of the experiments, the tests were carried out in three sequential days and in test, the data were recorded 5 times repeatedly.

Results and discussion

In this paper, for the purpose of radiation heat transfer enhancement in gaseous fuel burners, the effect of preheating of the inlet fuel gas on the flame radiation intensity and also on pollutant formation is experimentally investigated. For preheating of the intake methane a 4kw electrical heater is employed and its implementation is illustrated in Figs. 1,2.

In Table 1 the images of the flame with different inlet gas temperatures ranging from 26-310°C is depicted. As it is evident, by increasing the fuel gas temperature from 240 to 310°C the flame brightness is increasing and the yellowish color of the flame dominates abruptly. According to this result, we can predict that the flame radiation rate is boosted.

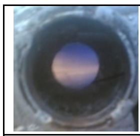	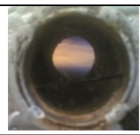	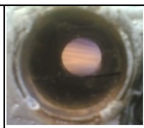	
26 °C	110 °C	240 °C	310 °C

Table 1:Flame brightness for different inlet temp. conditions

In order to compare variations of flame radiation intensity for different fuel temperatures, a photo cell is utilized which is connected to a 1.2kω resistance and fitted at the furnace hatch. Table 2 shows different recorded voltage and current at different fuel temperatures. It is clear that by increasing fuel temperature from 240 to 310 °C , the output voltage and current of the cell rapidly increases. In Fig. 3, output power of the cell versus fuel temperature is illustrated. The output power significantly increases by increasing fuel temperature.

Table 2: Recorded voltage and current at different fuel temperatures

Inlet Gas Temp. (°C)	Voltage (V)	Current (mA)
24	0.06	2±0.1
110	0.058	2±0.1
240	0.058	2±0.1
310	0.083	4±0.1

For measuring the heat transfer efficiency, the leaving water temperature from the furnace for different fuel temperatures are recorded and shown in Fig.4. It can be observed that with increasing the gas fuel temperature, the outlet water temperature gradually increases.

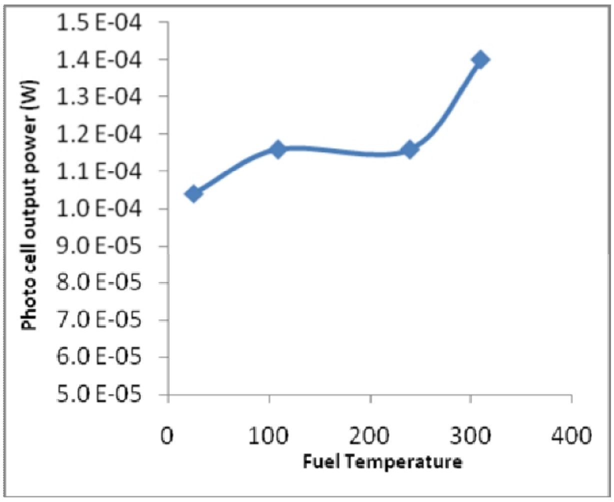

Figure 3: Output power of the cell versus fuel temperature

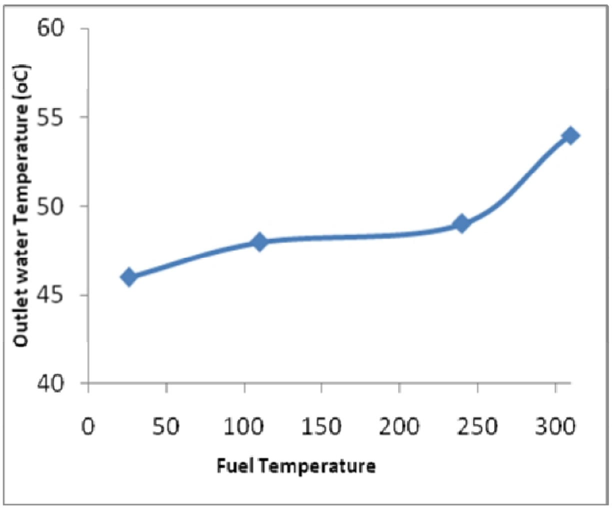

Figure 4: Outlet water temperature from the furnace for different fuel temperatures

But when the fuel temperature goes beyond 240 to 310°C, the trend of outlet water temperature sharply increases which implies higher heat transfer efficiency. The reason lies within the fact that in this temperature the influence of flame radiation suddenly grows.

In Fig.5 the input power of electrical heater and the gross transferred heat to the fuel is shown. As it was expected, fuel temperature and electrical input power are linearly dependent. The difference between input and net (gross) heat power is due to the heat dissipation to the surrounding.

As the results declare, by increasing fuel temperature, the radiation heat transfer efficiency promotes remarkably. On the other hand, the fuel temperature can greatly influence the combustion emissions.

In Fig.6 the extra air percentage and CO2 and CO concentration is presented. It is observed that by increasing the fuel temperature, the CO concentration in the exhaust gas rises. Besides, the extra air percentage in exhaust increases as well.

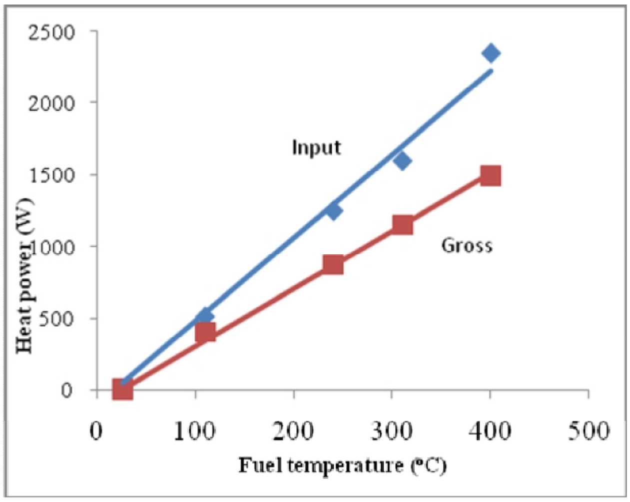

Figure 5: Dependence of fuel temperature and heating power

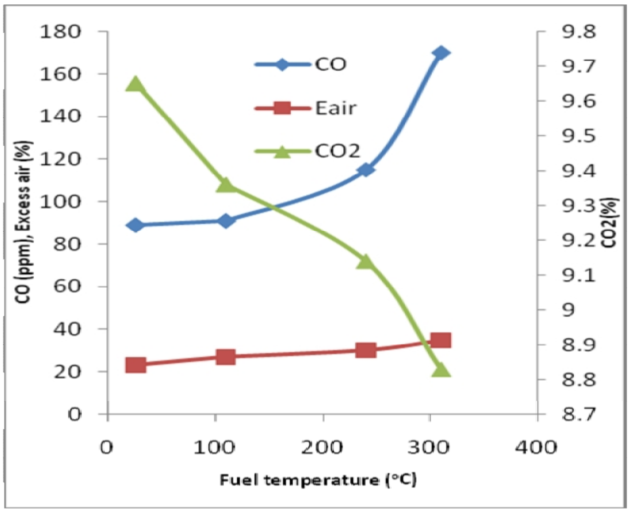

Figure 6: Variations of CO and CO2 and excess air contained in the exhaust gas.

Actually with increasing the fuel temperature, reaction rate of conversion of CO to CO2 reduces and in spite of enough air for CO combustion, this chemical specie leaves the furnace unburnt. The slight increase of excess air is caused by the additional pressure loss in gas pipe because of temperature increase.

NOx is another important emission of the combustion which is considered as a great significance. In Fig.7 NOx distribution in exhaust gases is displayed. As it can be seen, by increasing the fuel temperature to 240°C, the level of NO increases accordingly. But by further increase of fuel temperature, the NO concentration suddenly reduces. Regarding the tight dependence of nitrogen oxides formation to flame temperature, the decrease of NO concentration from 240 to 310 °C can be resulted from reduced flame temperature followed by enhanced flame radiation and brightness. In Fig.7 also the exhaust gases temperature distribution is shown. With increasing the fuel temperature to 240 °C, the exhaust temperature rises as well, but with greater increase in fuel temperature, the exhaust temperature drops significantly. As it was previously described, the reason is flame radiation improvement.

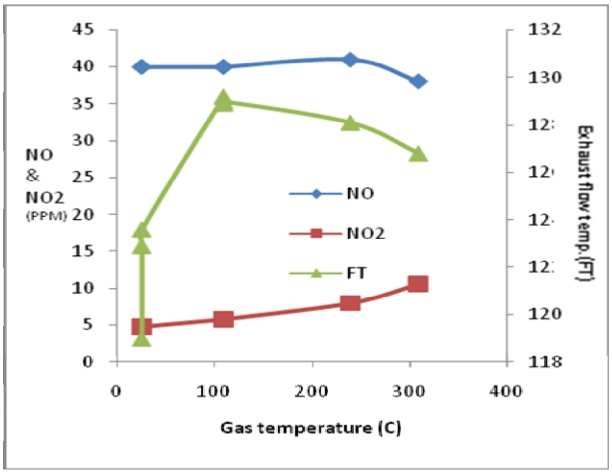

Figure 7: Variations of NO and NO2 and exhaust flow temperature.

Conclusion:

The reduced allocation of radiation heat transfer in gaseous fuel flames in comparison with liquid fuel flames is considered as a big challenge in utilizing the gas fuel burners for industrial applications like metal melting furnaces. This experimental investigation aims to boost the radiation heat transfer portion of gas burners by increasing the fuel temperature and subsequently increasing the brightness and yellowish color of the flame. According to the results, some important conclusions are in brief:

1- With increasing the inlet gas fuel temperature from 240 to 310°C, the yellowish color of the flame significantly increases.
2- The heat transfer efficiency from the flame to the furnace experiences a sharp growth in the mentioned temperature range of the fuel.
3- With increasing the fuel temperature, the CO formation rate increases too.
4- Increasing the fuel temperature to 240 °C is associated with the increase of nitrogen oxides emission but with further increase of fuel temperature, NOx formation suppresses because of the reduction of flame temperature.
5- The increase of outlet water temperature and the rapid reduction of combustion products temperature when the fuel temperature exceeds 240 °C show the enhanced heat transfer from the flame to the furnace.

In the end, all of the results imply the sudden change in flame structure while the fuel temperature alters from 240 to 310 °C.

Acknowledgment

Support for this research was provided by RAAD MASHAL TOOS© industries, department of Research and Develop, the standard lab. of industrial and domestic burners. All the rights are reserved by the mentioned industrial group.

References

[1]. Effect of the radiation surface on temperature and NOx emission in a gas fired furnace, Fuel 88 (2009) 1878–1884

[2]. Heywood JB. "Internal combustion engine fundamentals", New York; McGraw-Hill; 1988.

[3]. A. E. S. Green, B. A. S. Green, J. C. Wagner, Radiation enhancement in oil/coal boilers converted to natural gas, United States Patent 5048433, 1990

[3]. A. Yoshida, H. Naito, D.P. Mishra, Turbulent combustion of preheated natural gas–air mixture, Fuel 87 (2008) 605–611

[4]. E.P. Keramidaa, H.H. Liakosa, M.A. Fountib, A.G. Boudouvisa, N.C. MarkatosRadiative heat transfer in natural gas-fired furnaces, International Journal of Heat and Mass Transfer 43 (2000) 1801±1809

[5]. W.B. Kim D.H. Chung J.B. Yang D.S. Noh, An Experimental Study on High Temperature and Low Oxygen Air Combustion, J. of Thermal Science Vol. 9, No.2, pp 169-175. (2001)

[6]. W. Yang, W. Blasiak, Numerical study of fuel temperature influence on single gas jet combustion in highly preheated and oxygen deficient air, Energy 30, 385–398. 2005

[7] EN 676. Automatic forced draught burners for gaseous fuels. European Standards; 2003.