

Thermal Imaging of Flame in Air-assisted Atomizer for Burner System

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Abstract. Infrared thermography was used as a part of non-intrusion technique on the flame temperature analysis. This paper demonstrates the technique to generate the thermal images of flame from the air-assisted atomizer. The multi-circular jet plate acts as a turbulence generator to improve the fuel and air mixing in the atomizer. Three types of multi-circular jet plate geometry were analysed at different equivalence ratio. Thermal infrared imaging using FLIR thermal camera were used to obtain the flame temperature. Multi-circular jet 1 shows the highest flame temperature obtained compared to other plates. It can be concluded that the geometry of the plate influences the combustion, hence affects the flame temperature profile from the air-assisted atomizer.

1. Introduction

The improvement of emissions exhausted from burner is urgently required to meet the future stringent emission regulations [1-2]. Flame temperature that influence from burning process field is able to be calculated from the changed physical parameters [3-6]. Some technologies such as acoustic thermometry [3-4] and laser spectroscopy [7] are of this kind. The demands of costly facilities limit its application. Passive methods rely on the radiation of the flame. The radiation from flame is captured by sensors and shown by images. Then the temperature field is reconstructed based on those flame images. Shimoda *et al.* [8] introduced a flame temperature field measurement method, namely two-color method, which is only suitable for two dimensional cases. Wu [9] investigated the relationship between flame image brightness and flame temperature. Wang *et al.* [10] made an intensive study of reconstruction of flame temperature field as well as concentration field. Wang and Zhao [11] made important contribution to flame image process and 3D flame temperature field reconstruction. Based on reference temperature, Zhou *et al.* [12] measured the temperature distribution of combustion flame in the boiler through monochromatic flame images.



Zhang *et al.* [13] studied the quantitative relation model between temperature and flame radiation. Gilabert *et al.* [14] developed a prototype instrumentation system on the basis of digital imaging process and tomographic techniques for 3D luminous reconstruction of combustion flames. Hossain *et al.* [15] designed an optical fiber imaging based tomographic system to reconstruct the luminosity of a burner flame. Wang *et al.* [16] took the flame images with high dynamic range cameras and reconstructed the radiance field on camera band for the flame, then obtained the flame temperature field through the lookup table between radiance and temperature. In this paper, Therefore, this study tried to use image analysis technique to investigate the flame temperature of the atomizer under different multi circular jet (MCJ) geometry of the plates. The experiment used a closed chamber with the thermography methods to determine the flame temperature from the air-assisted atomizer.

2. Experimental Setup

Table 1 shows the chemical properties of diesel used in this experiment. Table 2 depicts the equipment and experimental conditions. The atomizer shown in Figure 1 was used as a component of fuel and air mixing during combustion. It has eight holes, and the diameter of the nozzle is 1 mm. A multi-circular jet plate was installed inside the premix chamber. Three different geometries, namely, MCJ 1 (8 holes with 2 mm diameter), MCJ 2 (6 holes with 2 mm diameter and 4 holes with 1.5 mm diameter), and MCJ 3 (4 holes with 2 mm diameter and 8 holes with 1.5 mm diameter), were investigated. The physical appearance of the MCJ plate is described as an open area (A_e). The percentage of the plate open area to the plate total area is $\%A_e = (A_e/A_p) \times 100$. A_p is defined as the plate's total area. The percentage of open area was calculated for MCJ 1, MCJ 2, and MCJ 3 at 17.8, 18.4, and 18.9, respectively.

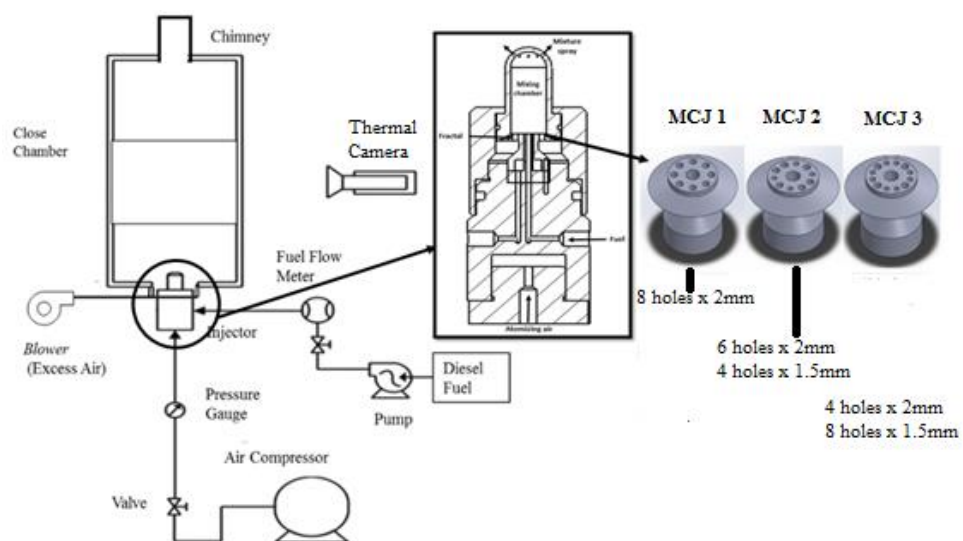
The atomizer was equipped with an air compressor to supply the primary air at 1 bar. The pump was used to supply fuel to the atomizer and the fuel was controlled by the Ono Sokki mass flow meter. The schematic diagram of the experiment is in Figure 1. In this study, the flame temperature was obtained from the IR camera. The emissivity value in the IR camera was set at 0.85 based on the previous work by other researchers. The temperature obtained from both technique showed that the thermal images can be used in temperature analysis of the flame. The investigation was conducted at five equivalence ratios from 0.6 to 1.4. The flame development was captured with color images by thermal imaging camera FLIR T-640 at 4 seconds every interval. Three images were obtained for each equivalence ratio which recorded the maximum temperature for each image.

Table 1: The chemical properties of diesel oil

Properties	Value
Density (kg/m ³)	0.8337
Kinematic viscosity (Cp)	3
Flash point (°C)	80
Water content (%)	0.00796
Acid value (mgKOH/g)	0.423

Table 2 : Experimental parameters and operating condition

Air Compressor	Model	PUMA XN2040
	Capacity, l/min	400
	Pressure, kg/cm ²	8
Fuel Pump	Model	CNY-3805
	Pressure, bar	3
	Flow rate, l/hr	115
DC Voltage Regulator	Model	Teletron TC-1206 A
	Current, A	64 (Max)
Operating Condition	Air pressure, bar	2.5
	Air density, kg/m ³	1.16
	Ambient temperature, K	300
	Water percentage	0 - 15%
	Equivalence ratio	0.6 - 1.0

**Figure 1.** Schematic diagram of experimental setup

3. Result and Discussion

Influence of multi circular jet under different equivalence ratio was firstly investigated. The parameters of primary air that kept constant is pressure at 0.1 MPa, that corresponds to fuel densities of $\rho = 0.8337 \text{ kg/m}^3$. Figure 2 shows the flame image of MCJ 1 using DSLR and IR camera. Table 3, Table 4 and Table 5 show the temperature profile of MCJ 1, 2 and 3 at different equivalence ratio. At higher equivalence ratio, the thermal image becomes larger due to an increase in the amount of fuel and air mixture and an increase in the temperature were also recorded. Therefore, the thermal characteristics show an increasing trend with equivalence ratio for each type of MCJ plate.

In addition, the comparison of all multi circular jet can be observed by the brightness of the thermal image based on the geometry of multi circular jet. This study found the multi circular jet 1 creates more turbulence of the fuel-air where it produces higher temperature profile.

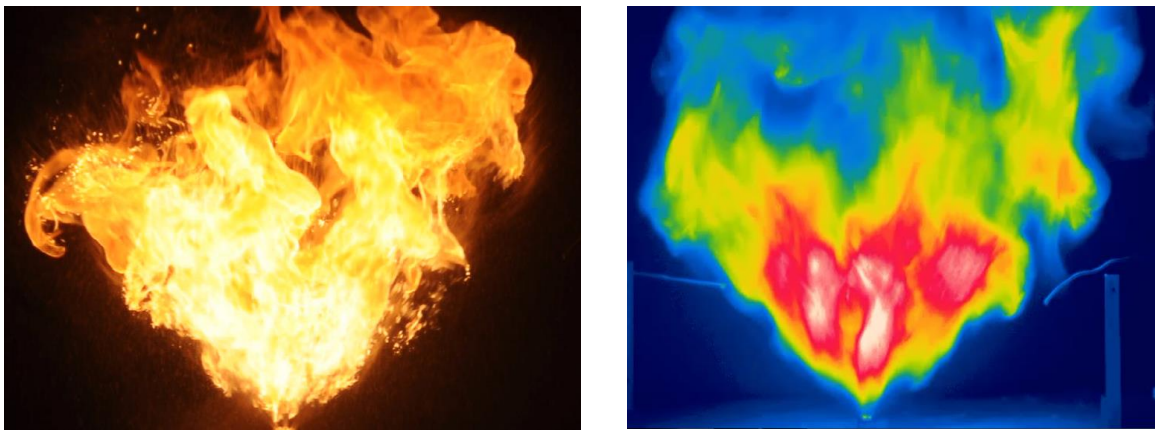


Figure 2. Flame images of MCJ 1 at equivalence ratio 1.0

Table 3: Thermal images using MCJ 1

Fuel	Equivalent ratio	Time Interval (s)		
		4	8	12
Diesel	0.6			
	0.7			
	0.8			
	0.9			
	1			

Table 4: Thermal images using MCJ 2

Fuel	Equivalent Ratio	Time Interval (s)		
		4	8	12
Diesel	0.6			
	0.7			
	0.8			
	0.9			
	1			

Table 5: Thermal images using MCJ 3

Fuel	Equivalent Ratio	Time Interval (s)		
		4	8	12
Diesel	0.6			
	0.7			
	0.8			
	0.9			
	1			

Next, the influences of the temperature development were investigated. Figure 3 shows the maximum flame temperature at different equivalent ratio. Overall results depict that MCJ 1 has higher flame temperature compared to other plates.

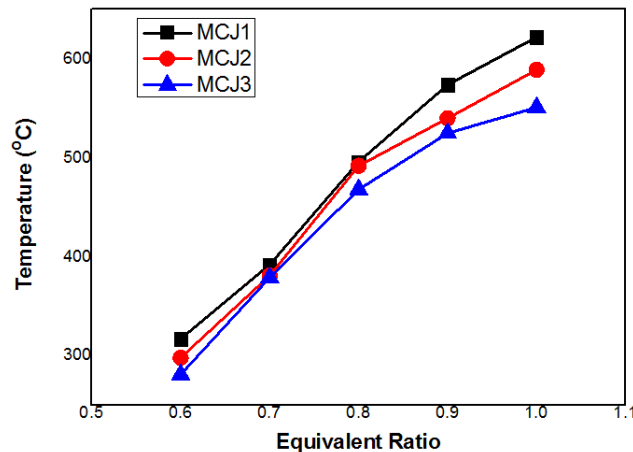


Figure 3. Flame temperature between different MCJ plates

4. Conclusion

In this research, the thermal characteristics of flame using MCJ plate as a turbulence generator in burner system was investigated. Results are summarized as followed:

1. Higher equivalent ratio will result in higher flame temperature. Temperature of the flame will affect the thermal image. An increasing of flow rates makes the intensity of flame increases.
2. Three different types of MCJ plates were used. It is found that the plate geometry gives significant impact on the combustion process. The MCJ 1 (8 holes with 2 mm diameter) is found to produce higher flame temperature compared to MCJ 2 (6 holes with 2 mm diameter and 4 holes with 1.5 mm diameter), and MCJ 3 (4 holes with 2 mm diameter and 8 holes with 1.5 mm diameter). The regular shapes of jet holes gives higher flame temperature compared to irregular jet holes. This is due to the fuel air mixing characteristics inside the chamber.

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