

Experimental study of thermal radiation from jet flame

P Satrio, R Adityo, R Agung and Y S Nugroho

Fire Safety Engineering Research Group, Department of Mechanical Engineering,
Universitas Indonesia.

E-mail: yulianto.nugroho@ui.ac.id

Abstract. This paper presents studies on the influence of the nozzle tilt angle on the thermal radiation generated by diffusion jet flame. Analysis was limited to the nozzle tilt angle, distance and height of the heat flux measurement, and nozzle diameter. The studies were conducted for three different nozzle tilt angles of 0°, 45° and 90°, three different distances 10 cm, 15 cm and 20 cm, six different heights 10 cm, 20 cm, 30 cm, 40 cm, 50 cm and 60 cm, and two different nozzle diameters 17 mm and 11 mm. The thermal radiation intensity increased with the distance and height of measurements. The variation of horizontal and vertical jet flame was found to follow a linear equation. The studies also included investigation of flame shapes influence on the thermal radiation. The obtained results are presented in a graphical and tabular form. Based on the analysis of results the conclusion are established, important not only for the theoretical considerations but also in practice, especially in the context of immediate ignition on Liquefied Petroleum Gas as fuel for household leakage.

1. Introduction

Liquefied Petroleum Gas (LPG) is commonly used for households in Indonesia. Not only is LPG a relatively clean, safe and cost-effective fuel for households, its large-scale adoption also reduces the government budgets on subsidies for traditional kerosene consumption. LPG program in Indonesia has been effective for medium and higher income households in suburban areas [1]. High pressure gas inside storage tank heightens the risk rate especially in tubes which are closer to people. Since official using of LPG as the main sources of cooking fuel, several disastrous incidents have frequently occurred [2].

A. Palacios et al. were performed experiments of propane jet flame in still air [3]. The flame height up to 10 m were obtained using different exit diameters (10mm-43.1mm). The experiments were recorded with video and thermographic camera. Flame height and lift-off distance were determined by using visible and infrared images. Flame heights were expressed as function of mass flow rate, exit diameter, Froude number and Reynolds number. The results showed that the flame height is increased with the increase of orifice diameter and the fuel mass flow rate.

Mercedes Gomez-Mares et al. were performed experiment of axial temperature distribution in vertical jet fire of propane [4]. Thermocouples were used to measure temperature along the jet fire centerline and the flame contours were determined from infrared images. The results showed that temperature along the jet fire centerline increased from the bottom of the flame, then reached a maximum value and decreased again at the top zone. The temperature inside the flame were measured around 1600 K at 90% of the flame length. However, it was decided to use the temperature of 1500 K for comparing the data of lengths.



A. Palacios et al. were performed experiments of large outdoor jet fire. Geometric and thermal data were used to estimate the thermal radiation intensity from the flames towards targets located at diverse distances [5]. The experiments were studied the vertical turbulent sonic and subsonic exit velocity propane jet fires. The flame length up to 10.3m released in still air. Infrared images processing was used to analyze the temperatures of the flame surface and the surface emissive power of the flame. Solid flame model in both one-zone and multiple-zone configurations were applied to estimate thermal radiation intensity. The flame was considered as a cylinder defined by the 800 K isotherm. Experimental and predicted thermal radiation intensity values were compared.

K. Zhou et al. were performed predictions of heat flux radiation from jet fire using line source model calculation [6]. This method describing the flame emissive power and subsequent heat flux radiated from a horizontal propane jet fire. The results were evaluated through a testing against experimental fire data and comparison against other models. Comparison of model predictions against data collected in the experiment and predictions from the point source model and multipoint source model gives encouraging results relative to the validity of model system.

This experiment studies the effect different tilt angle of the nozzle against thermal radiation. Heat Flux Sensor was used to measure thermal radiation from jet fire. A tool was designed in such a way so the nozzle could be rotating in 360° . In this experiment, the radiometer used is useful to measure the radiation received by an object and its effect on the distance and the angle of view of the heat source. The results then will be compared with the result of the theoretical thermal radiation flux calculations using line source model.

2. Line Source Model

There are four kinds of semi-empirical model that have been developed to calculate the thermal radiation from jet fires. Firstly, the point source model that commonly used to predict the far field radiation of both vertical and horizontal jet fires [7]. The second one is multipoint model and solid flame model which was used to calculate the near field radiation from a vertical methane jet fire and horizontal hydrogen jet fires [8]. The third one is cylindrical flame radiation model which was used for vertical and horizontal propane jet fires [9]. The last one is line source model which was recently developed to calculate the radiant heat flux from both small and large scale vertical jet fires [10]. The result using line source model was compared with experimental data measurement. It shows a better prediction than the other three models. Therefore, the line source model is developed to verify the thermal radiation measurement in this paper. The radiant heat flux received by a point using line source model is expressed by:

$$\dot{q}'' = \int_S^H \frac{\tau E'}{4\pi R^2} \cos\theta dx \quad (1)$$

Where \dot{q}'' is the radiant heat flux received by a point, R is the length of connecting line between the target and any point at the jet flame centreline, θ is the angle between the connecting line and the target surface normal orientation, S and H is the lift-off distance and flame length of jet fires from the nozzle to the top of the fire.

The emissive power per line length (EPPL) is the emissive power of a certain point in the centreline. EPPL is proportional to the square of the flame radius [10]. Therefore, the EPPL can be expressed by:

$$E' = E'_{0.} (b/b_0)^2 \quad (2)$$

Where b and b_0 are the flame radius and the maximum flame radius, respectively. The integral of EPPL over the full flame length result the total radiant heat output. The maximum EPPL ($E'_{0.}$) can be expressed by

$$E'_{0.} = \chi_R \dot{Q} / \int_S^H (b/b_0)^2 dx \quad (3)$$

Where χ_R and \dot{Q} are the radiative fraction and the heat release rate, respectively.

3. Experimental Method

The total experimental program consisted of 36 individual tests, where a test is defined as obtaining data at all distances for each burner diameter setting of a single burner tilt angle. For example, the heat flux data for one test consisted of the measurements taken at each of the three horizontal measurement distances for each of the burner tilt angle settings. Each test was performed in 1 minute when the temperature read on the control system stable and constant. In this test, the data were collected with LabView 2016. Figure 1 outlines the research methodology of heat flux measurement test.

The nozzle was able to be rotated to provide a different field of view to the heat flux gauges. Three different burner angles were tested. Firstly, the burner angle could be set at 0° , meaning that the sides of the burner were parallel with the face of the heat flux gauges. The burner could then be set at 45° and 90° . These three positions are shown in figure 1. The nozzle tilt angle was varied to be able to see the difference of the result of the heat flux obtained from the sensor.

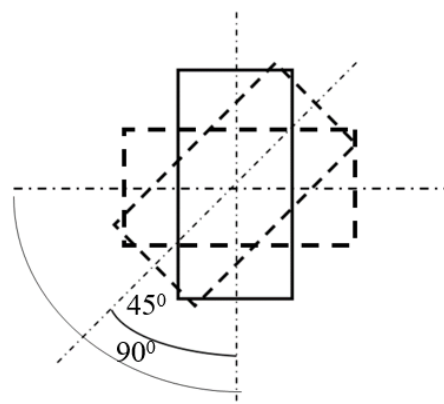


Figure 1. Relative angles of burner positions used in experiments.

The distance of the sensor with the jet flame centerline will be varied into three distances, which is as far as 10 cm, 15 cm, and 20 cm from the jet flame centerline. In this data measurement, the distance will be combined with all the variations in this test. The data variation could be collected only by rotating the gear so that the variation of sensor distance is the most basic variation in this test.

The sensor height is the length from the nozzle of the jet flame to the sensor. In this variation, the height will be varied in six heights, which is as far as 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, and 60 cm. For the 0° orientations, the data was obtained by two sensors with the same distance (from left and right direction). The average of the value will be used in the data collecting. Nozzle diameter is the length of the gas burner. In this experiment, nozzle diameter was varied in two sizes, which is 11 mm and 17 mm. For this variable, the nozzle diameter will be combined with all the variations in this test. This experiment was carried out using welding equipment which mounted to the modified table so the nozzle can be rotated 360° . Fig shows the table that are used in this experiment.

4. Results and Discussion

Figure 2 shows the comparison between the line source model prediction and the experimental data on different measurement heights. Fig a and b shows the result for the vertical jet flames with 17 mm and 11 mm nozzle diameter respectively. The results are in good agreement with the radiant heat flux prediction. Therefore, the line source model seems to be a good representative to calculate the radiant heat flux of the vertical LPG jet flames.

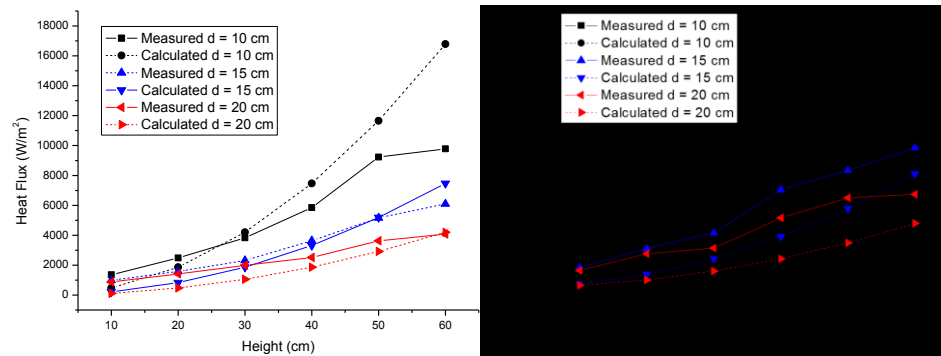


Figure 2. Comparison of Data Measurements and Line Source Model

The heat flux received by a target decreases as the distance from the flame surface increases. It is because the thermal radiation emitted by the jet flame spreads in all directions. Figure 3 shows the heat flux reaching a vertical surface (average values obtained for one minute), measured by heat flux sensors located at two different places with the same distance from the flame axis. It can be seen that the heat flux increases as the distance from the flames increases. This means that the hazards created by this thermal radiation will be higher in short distance from the flame surface.

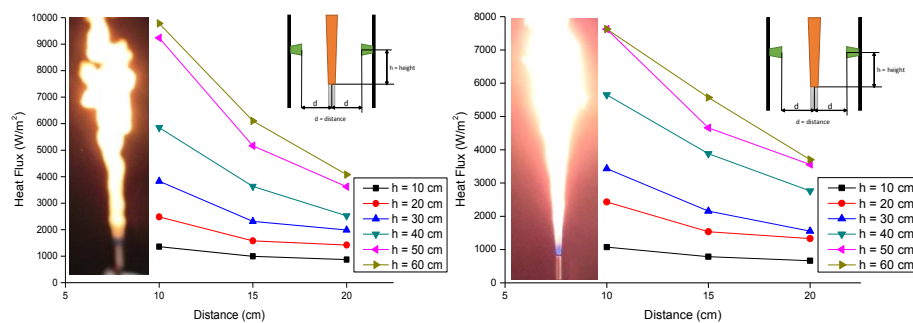
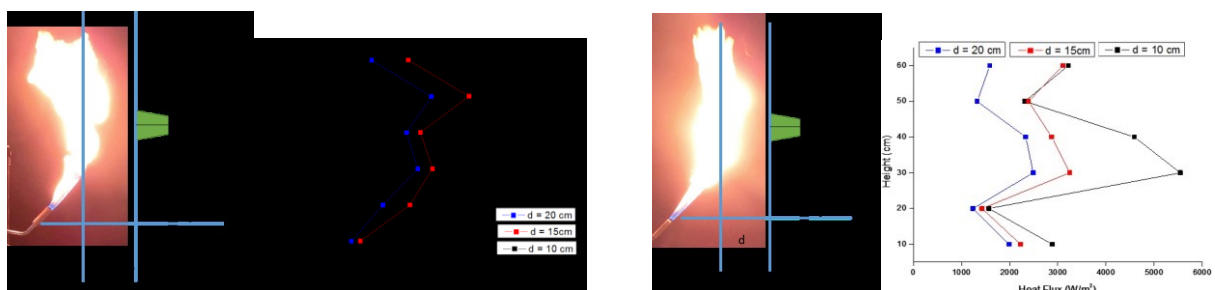


Figure 3. Variation in feasurement distance, height, and nozzle diameter for 90° tilt angle

Figure 4 presents the result of radiant heat flux measurement with 45° and 90° nozzle tilt angles. The hat flux received by a target are fluctuated as the distance from the flame surface increases. It is because flame shape of the flame was not steady. The distances of flame surface to the heat flux sensor are very affect the measured heat flux, the closer flame surface to the sensors, the higher heat flux received [11].



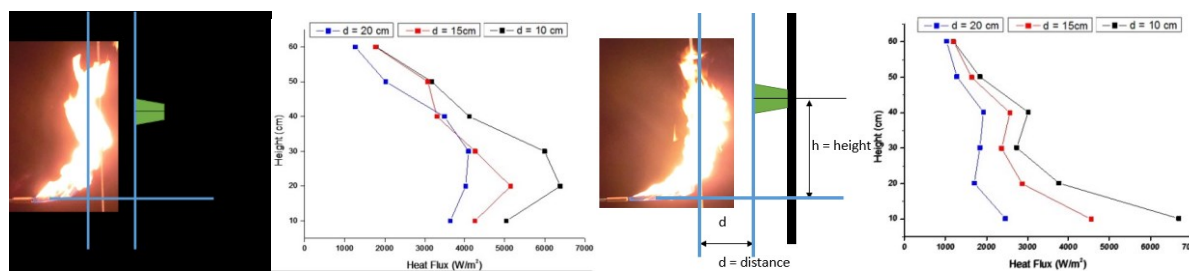


Figure 4. Variation in measurement distance, height, and nozzle diameter for 45° and 90° tilt angle

5. Conclusion

The experimental results obtained with different nozzle tilt angle jet flames have shown that the heat flux profiles of the flames depend on the fuel release. If the nozzle tilt angle is set at 0° , the heat flux received by a target increase as the height of measurements increase. Heat flux trends in experimental data from 45° and 90° nozzle tilt angles has been fluctuated depends on flame shape. Although heat flux decreases quickly with the increase of distance from flames, at short distances it can be very high, which would could cause serious hazards. The experimental results also showed the validity of line source model calculation to predict thermal radiation from jet flame. Heat flux from vertical jet flames was used to compare with the line source model calculation. A comparison of the values thus obtained with the experimental results and the use of a line source model are in good agreement.

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