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# Experimental study on propane jet fire hazards: Assessment of the main geometrical features of horizontal jet flames

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ABSTRACT

Jet fires are among the least severe fires in terms of direct effects, but are very important in terms of risk assessment due to the potential escalation of the incident by impingement or engulfment of the jet fire on the surrounding vessel, pipework or other components. This paper focuses on the determination of the main geometrical features (flame shape, length, and width) of medium-scale horizontal jet fires in air. The study is based on the experimental results of LPG jet fire released from a horizontal pipe of 1.9 cm diameter at different flow rates, with vapor flows, reaching a flame size of 1–10 m long. For each test, visible and infrared visualizations were recorded. First, the two visualization techniques are compared with each other, and with the different methods of flame shape determination available in the literature. The flame detected with each technique, both instantaneous and averaged, is then compared with basic flame shapes.



## 1. Introduction

According to the CCPS, a jet fire is "A fire type resulting from the discharge of liquid, vapor, or gas into free space from an orifice, the momentum of which induces the surrounding atmosphere to mix with the discharged material" (CCPS, 1995).

In 2008, Gomez-Mares consulted different European accident databases and identified 84 incidents involving a jet fire since 1961 (Gómez-Mares et al., 2008). Among these incidents, 61% involved LPG and occurred mostly during transportation (44%) or in process plants (36%). Based on the description of the incidents, Gomez-Maries built an event-tree and the majority of the jet fires were generated after a loss of containment, and also showed that 50% of the incidents involving jet fires will lead to at least one additional event with more severe consequences. It is therefore important to correctly model a jet fire in risk assessment, especially to identify possible domino effects.

But, according to Palacios, most of the research on jet fires was performed at a small scale, with few experimental research at larger scales (Palacios and Casal, 2011). Large scale experiments were performed using hydrogen as a fuel, with vertical flames up to 10 m in length from a 5.08 mm nozzle (Schefer et al., 2007) or horizontal flames up to 12 m in length from nozzles of 0.1–4 mm (Mogi and Horiguchi, 2009). Natural gas was also widely used for large scale jet fire experiments. Cook performed vertical jet fires up to 90 m from an outlet of 51–590 mm (Cook, 1987). Lowesmith used natural gas or a mixture of natural gas and hydrogen to generate horizontal large scale jet fires from 20 to 50 m from exit pipes of 20–50 mm (Barbara Joan Lowesmith and Hankinson, 2012). Lowesmith also simulated the rupture of a 150 mm pipeline pressurized at 70 bar containing either pure natural gas or a mixture of natural gas and hydrogen, generating flames up to 100 m right after the opening of the pipe, stabilizing around 20 m (Lowesmith and Hankinson, 2013). Large-scale experiments with other types of hydrocarbon includes vertical methane flames up to 20 m from nozzles of 38–102 mm (Mccaffrey and Evans, 1986), and vertical propane flames up to 10.3 m in length, obtained from orifice diameters of 10–43.1 mm (Palacios and Casal, 2011). These large scale experiments mostly focus on the flame length and the methodology used to determine this length from visualizations is not always provided. The jet fire shape is also very important to model the heat flux, and is not very often studied. Palacios performed a very extensive study about vertical jet fire shape (Palacios and Casal, 2011), but no similar study has been found for horizontal jet fires.

This paper is the first part of a series of three papers analyzing the experimental campaign and focuses on the assessment of the main geometrical features of medium-scale horizontal jet fires. The

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two other papers are focused on the radiation emitted by the jet fires (Zhang et al., 2015), and on the comparison of the flame geometrical properties with empirical correlations (Gopalaswami et al., 2016). In this paper, the medium-scale LPG fire experiments performed in this study are described, in addition to the image processing used to assess the flame shape, both from IR images and CCD camera images. The flame shape determined from the experiments is compared with previous experiments from the literature, and with basic shapes such as a cone or cylinder. Similar discussion will also be done for the flame length and width.

## 2. Experiments

### 2.1. Experimental setup and safety procedures

Medium-scale jet fire experiments were performed at the Brayton Fire Training Field (BFTF) in College Station, TX. Fig. 1 sketches the field tests experimental setup. Vapor or liquid LPG was taken from a reservoir located away from the test site and transported through a piping system, the flow regulation being simplified by the hexagon entitled 1. A detailed representation of the flow regulation is illustrated in Fig. 2. The globe valve V2 leads the fluid to three vapor flow meters (F1, F2, F3) that can be used by opening a valve V3 (a, b or c). The lowest flow rates were measured with a FMA1827 mass flow meter that can measure up to 10 lb/hr, the larger flow rates being measured with turbine flow meters FTB932 with a range of 9–60 lb/hr or FTB937 with a range of 72–1205 lb/hr.

The pressure and temperature of the LPG were measured at the left and the right of the flow meters (P1 and P2 in Fig. 2). The temperature was measured with K-type thermocouples and the pressure with PX5100-150GI pressure transducers with a range of 500 psi. All these instruments were provided by Omega, and acquired at 1 Hz by a DAQBoard 2000 series; module DBK90 for thermocouples, DBK15 for the pressure transducers and the mass flow meter, and DPF75A for the turbine flow meters.

The LPG vapor was measured by one of the three flow meters (F1, F2, and F3) and released from one of the nozzles attached on the pipelines by two ball valves (V1a and V1b). Nozzle A has a diameter of 3/4′ and is aligned horizontally, while nozzle B has a diameter of 1′ and is aligned vertically, as shown in Fig. 1.

The flames were recorded both with a normal CCD camera at 25 Hz with an image size of 720 × 480 px, and with an infrared camera, FLIR SC660, that can record images of size 640 × 480 px and can detect black body temperatures up to 2000 °C.

The procedure described below was followed to guarantee the safety of the personnel performing the experiments. First, all the instruments were started for recording and checked as valid. Then, an operator opened the valve V1 (a or b), and secured the test area.

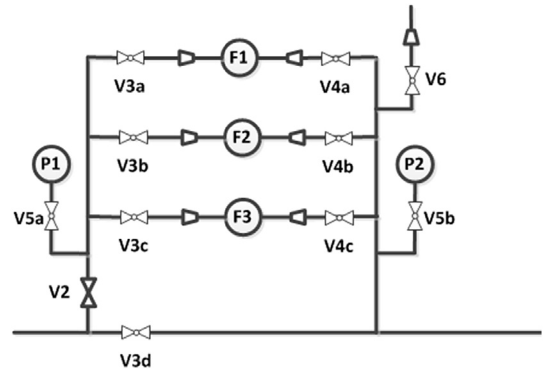


**Fig. 2.** Flow regulation.

Next, the valve V2 and V4 were opened by an operator (a, b or c depending on the desired flow rate) and the valve V3 opened in order to obtain the desired flow rate. The gas flow was ignited at the nozzle with a torch by a professional firefighter. At the end of the test, the valves V2 to V4 were closed to stop the gas flow and therefore the jet fire.

### 2.2. List of experiments

A total of 21 tests were performed over a one-day period. Different gas flow rates (ranging between 100 and 1000 lb/hr), release directions (horizontal and vertical), and release nozzle sizes were tested. As the flowrate of two-phase releases could not be measured accurately, only the vapor releases will be used in this analysis. A summary of the horizontal tests with vapor as the released fluid is provided in Table 1.

**Table 1**
Summary of experiments.

| Jet position | Nozzle diameter [in] | Fluid phase | Average flow rate [ lbs/hr] |
|---|---|---|---|
| Horizontal | 3/4 | Vapor | / |
| Horizontal | 3/4 | Vapor | 738 |
| Horizontal | 3/4 | Vapor | 729 |
| Horizontal | 3/4 | Vapor | 737 |
| Horizontal | 3/4 | Vapor | 801 |
| Horizontal | 3/4 | Vapor | 866 |
| Horizontal | 3/4 | Vapor | 372 |
| Horizontal | 3/4 | Vapor | 333 |
| Horizontal | 3/4 | Vapor | 117 |
| Horizontal | 3/4 | Vapor | 876 |
| Horizontal | 3/4 | Vapor | 532 |
| | | | 430 |
| | | | 316 |
| | | | 198 |
| | | | 130 |
| Horizontal | 3/4 | Vapor | / |

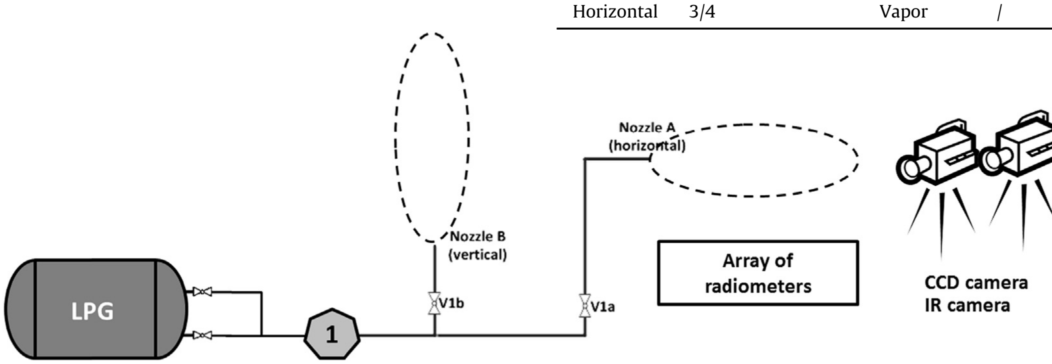


**Fig. 1.** Field tests experimental setup.