Experimental Research on the Jet Distance of FK-5-1-12 Droplets after their Discharge out of a Fire Extinguishing Nozzle

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Abstract

This scientific paper deals with the applied research on the "Jet Distance", which is a remarkable phenomenon existent at fire extinguishing nozzles for clean agent systems. The article contains the research on the sources of this phenomenon. The evaluated measurement methods to determine the Jet Distance are listed and test results with sample pictures are presented. The Jet Distance has direct influence on the installation and fitting conditions of fire extinguishing systems with FK-5-1-12, which must be considered for the design and operation of those systems.

1 Introduction

Due to the Montreal Protocol that came into effect at the 1st of January 1989 substitutes for the former used halon extinguishing agents must be found. The fluorinated ketone FK-5-1-12 is one of those developed substitutes with new requirements for successful application in fire protection systems. The former used halons e.g. Halon 1211 and Halon 1301 have boiling temperatures from 25°F [1] to -72.4°F [2]. In comparison to that the boiling temperature of FK-5-1-12 (120.6°F) [3] is much higher.

For chemical fire extinguishing systems a fast and complete evaporation is crucial for the extinguishing process. The difference in the boiling temperature and other physical properties of FK-5-1-12 cause a slower natural evaporation. For this purpose the term "Jet distance" is introduced, which indicates a distance where the extinguishing agent is mainly evaporated. This causes restrictions for the installation of chemical fire extinguishing systems. Within the range of the jet distance obstacles disturb the evaporation process and it may be problematic to achieve the requested design concentrations.

The further research on this topic is important to identify correlations between the jet distance and hydraulic parameters to control this occurring effect as desired for different applications.

2 Extinguishing Agent FK-5-1-12

The extinguishing mechanism for all chemical extinguishing agents including the Fluorinated Ketones (FK) is based on a combination of chemical and physical process. Inside the high temperature zone of the flame the large molecules are decomposed into single atoms. According to the ideal gas law the volume of the agent expands with factor x, which represents the amount of atoms. This leads to a local reduction of the oxygen concentration inside the flame zone. The molecule decomposition causes local inertization [4]. The extinguishing agent FK-5-1-12 molecule consists of 19 different atoms and therefore it has a high molecular weight. The density of the liquid at standard conditions is 1.6 kg/l or 99.9 lb/ft³ [3]. Thus the expanding effect is high.

Cooling of the protection area is induced by the molecule decomposition with subsequent recombination process. The chemical process consumes energy, therefore the ambient temperature decreases. For FK-5-1-12 the drop typically reaches 45 - 50 °F (8 – 10 °C) [4] after the flooding process. Protection of electric fire loads is a typical application for FK-5-1-12. The fire growth velocity in those environments is usually slow. Data Center hazards present the main application field for fluorinated ketones. The range of design concentration for typical hazards is 4 – 6 Vol% [3]. Saturation at ambient pressure and a common room temperature of 68-70 °F is about 32 Vol% shown in *Figure 1*.

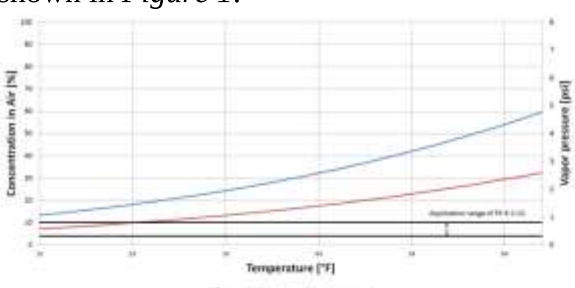

Figure 1 Vapor pressure and concentration in air

For the physical decomposition of the FK-5-1-12 molecules it is necessary to transform the extinguishing agent into gaseous state.
Within the standard conditions the agent remains liquid. Therefore, entire evaporation must be forced. The evaporation process is basically influenced by the difference between the agent temperature and the boiling point and by the degree of atomization. Small droplets increase the specific surface area between liquid and air. Thus a small temperature difference between local agent temperature and boiling point and a very fine spray is crucial for an effective evaporation.

3 Effective Evaporation

Spray nozzles for liquid stored fire extinguishing agents are designed to develop fine spray with small droplets. This enhances the evaporation of the liquid agent as soon as it has left the nozzle orifices.

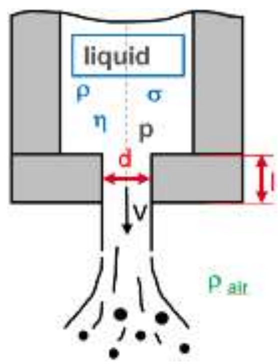

Figure 2 Turbulent jet decomposition

Several physical effects [5] destabilize the free jet and are responsible for the jet decomposition.

- Aerodynamic interaction between surface area and ambient air
- Radial velocity components due to turbulent nozzle flow
- Variation in velocity profile at the nozzle outlet
- Pressure fluctuations of the liquid within the nozzle
- Instability due to surface tension
- Physical cavitation phenomena

The most influencing parameters for the spray are the flow velocity at the outlet and the pressure difference between the pressure inside the nozzle and the ambient pressure. The significant geometry parameters of the nozzle are the diameter of the orifice and the length of the orifice channel.

The physical properties of the liquid, such as density, viscosity and surface tension, are important for the behavior of the jet and the droplets. As soon as the liquid enters the room outside the nozzle there is interaction with the surrounding gas, mostly air.

4 State of the Art

The valid nozzle (*Figure 3*) for the tests is designed for the use of the extinguishing agent FK-5-1-12. The main intention of the design is to vaporize the agent with fewest limitations concerning e.g. spray barriers and room height.

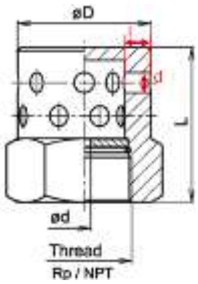

Figure 3 MX NCD Nozzle

The geometry parameters which guide the jet stream at every orifice of the nozzle head are marked in red. The nozzles are designed to cover a room that is placed around the nozzles location. Therefore a number of 16 free jets are symmetrically distributed around the body. The nozzle orifices have a diameter of 0.15 inch and the nozzle body is connected with a ½" NPT thread.

For the use of the NCD nozzle there are restrictions concerning installations and walls (see Figure 4). The jets from the boreholes throw droplets and induce turbulent movement inside the protection zone. To keep nozzle numbers low it is desirable to achieve a large operation radius, which results in a strong straight jet. As a disadvantage more large droplets with a high impulse occur and the evaporation needs more space.

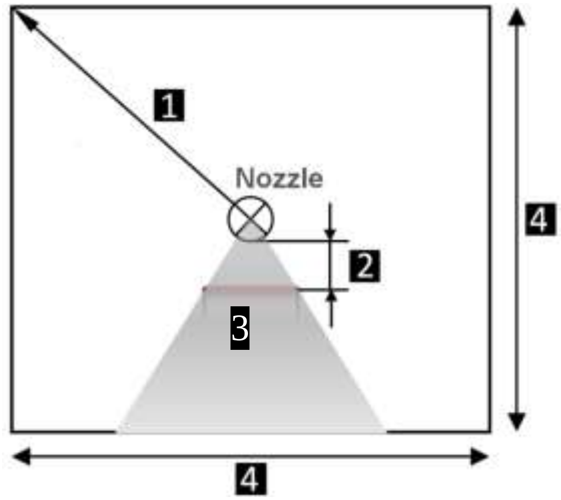

Figure 4 Restrictions Nozzle NCD

1. Operation radius
2. Minimum distance to obstacle
3. Maximum width of obstacle
4. Maximal length of room side

When there are obstacles near a strong jet with large and far flying droplets it will cut off the free path of the jet significantly. The liquid agent hits the obstacle, flows downwards and remains liquid. An obstacle with large width will stop even more agent from evaporation.

5 Test setup & Methods

The principle object of the tests is to measure the jet distance with different methods. The chosen methods for this test series combine measurement of different physical properties and are the following.

- Digital Reflex Camera
- Infrared Camera
- Thermocouples
- Tape measure (qualitative indicator)

To validate the results of a single method they are compared to the other applied measurement methods.

The camera is used to detect the droplets and differentiate between the areas where droplets or steam exists. But it is not possible to distinguish between agent droplets or water droplets out of the humidity of the ambient air. Neither can be seen, if there is evaporation in all areas where liquid drops exist.

The infrared camera measures the temperature gradient of the field. Where evaporation takes place, energy is consumed and the temperature will decrease. In areas where local saturation of the agent is reached, no more agent can turn from liquid into gas. The agent will remain liquid there and it passes the region without changing its temperature.

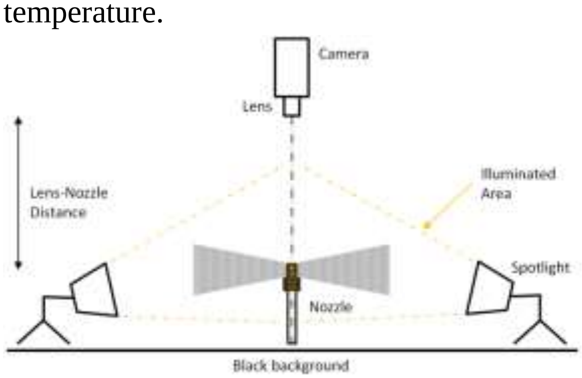

Figure 5 Test setup optical measurements

The arrangement of the test setup for the optical measurement is represented exemplary in Figure 5. Details of the hydraulic setup and other measurement spots are neglected within this figure.

The nozzle is placed in the center and the spray direction is, neglecting a certain angle due to inertia ($\alpha \leq 10°$), parallel to the ground. The discharge process is recorded by the camera from the top. In the test setup it is mounted on a moveable ceiling to adjust the field of view to the required position. Especially for the use of different cameras this is an important feature. The spotlights for the specified illumination are surrounding the test setup and focused on the nozzle.

To avoid disturbances within the picture processing it is important to illuminate only the particles in the test room. Special designed frames prevent the direct illumination of the ground and the camera. The qualitatively illuminated area is visible on Fig. 5 within the orange lines. Reducing the influence of heat from the spotlights towards the spray nozzles, they are placed in a distance where no more influence is noticeable.

The general idea of the shown setup is to illuminate the particles within the field of view and keep the rest black. For this purpose black background plates are installed and special frames for the spotlights are used. In the post processing the pictures are inverted for the evaluation of the jet distance.

Thermocouples where placed along the center line of one jet. The data of the thermocouples show the change of temperature along the line. In addition they give the temperature of the midline of the jet. The data of the thermocouples could be used as a reference point for the gradient data of the infrared camera.

6 Results of test data

The recorded pictures or data of the different used measurement methods are shown and explained subsequently. In Figure 6 the spray pictures recorded with a digital reflex camera are shown. The sample rate of the video is 25 frames per second and the optical resolution is determined with 0.1 inch per pixel. On this series of pictures the development of the nozzle jets can be observed. The visible snap shots are in a defined range from 1 to 9 seconds after starting the discharge.

A completely developed jet is reached within less than one second after the discharge of the air out of the pipe system.

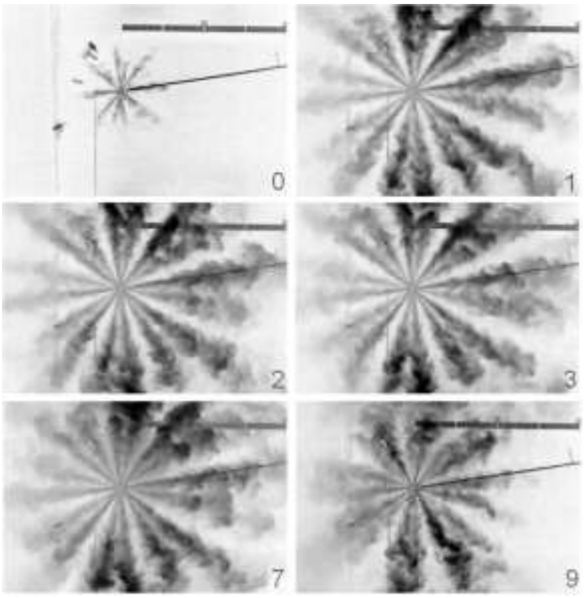

Figure 6 Jet development pictures by camera

For the determination of the jet distance from optical pictures a verified jet fragmentation is necessary. In Figure 7 the jet is divided into three different regions.

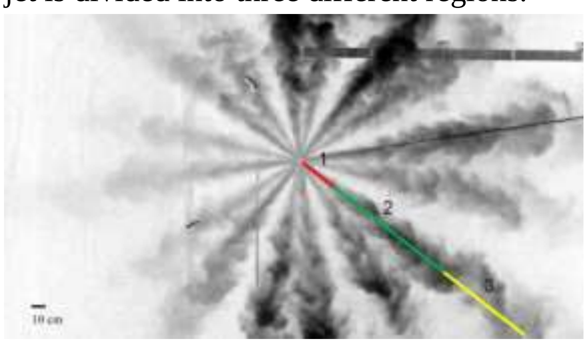

Figure 7 Jet fragmentations

There is a first region of straight jet with sharp borders between jet surface and environment. Droplets in this region have a clear main direction of velocity. The straight jet is followed by a transition zone where the jet decomposes gradually. Interactions between jet surface and ambient air become dominant. The jet decomposes in waves but the main flow direction is still recognizable.

The third region, far from the source point, is more or less an undirected gas cloud. Small droplets and steam move around with changing direction and low velocity.

Next to the pictures in Figure 6 the same tests are performed with an IR (infrared) camera and shown in Figure 8. The IR camera records a defined two-dimensional measurement field. For a time range of $t = 1 \dots 6\ seconds$ a clear-cut star shaped spray pattern is visible. After that time range a gas cloud covers the field of view and the measurement is significantly distorted. The camera observes the surface of the cloud and is not anymore able to reach the center of the jet. The minimal temperature is measured in a distance of 12 inch, towards the nozzle outlet, with a temperature of 36.6°F.

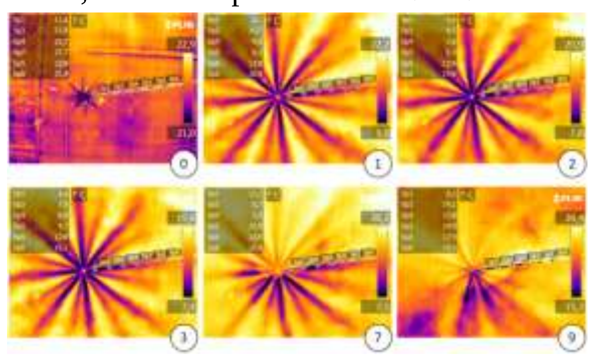

Figure 8 Jet development pictures by IR camera

As a result of the combination from recorded IR and reflex camera pictures Figure 9 is developed. The time of the composition is 3 seconds after the start of the discharge, when the jet is fully developed. The averaged visible length of the straight jet achieves values up to 4 feet. The resulting jet distance (radius) of this sample is $l_{jd} = 2\,ft$. As a consequence obstacles inside this radius should be absolutely avoided. The particles will hit obstacles or walls, flow downwards, will not evaporate properly. This amount of agent is lost for the extinguishing process.

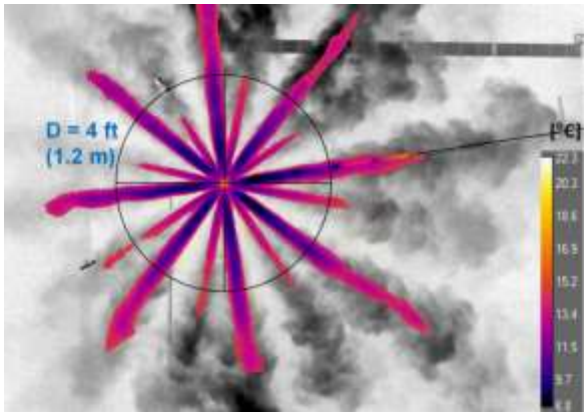

Figure 9 Jet development with both optical methods

The chart in Figure 10 shows the temperature curves in the center of a jet, monitored by thermocouples. Compared to the IR camera measurements the lowest temperature spot is about 28 inches away from the nozzle outlet with values down to 12.3°F. The obtained curve can be explained by the fact that the extinguishing agent remains mostly liquid at the nozzle outlet. The surrounding area of the nozzle is already saturated with agent vapor.

The evaporation process forms its peak at a distance of 20 to 28 inch. Within the peak zone most of the evaporation takes place. This consumes energy and causes the highest temperature drop. The higher temperature levels after the peak zone (measured at 35 inch and 43 inch) indicate that less and less energy is consumed by the evaporation of FK-5-1-12.

This leads to the assumption that the extinguishing agent is already mainly in the gaseous state. At the 4 inch distance a sudden drop in temperature can be observed after 10 seconds. This is initiated by the nitrogen following the extinguishing agent when discharge is completed. The nitrogen is already expanding and therefore cooling down during its way through the pipe system. When it reaches the nozzle the nozzle temperature drops. This indicates the end of liquid discharge.

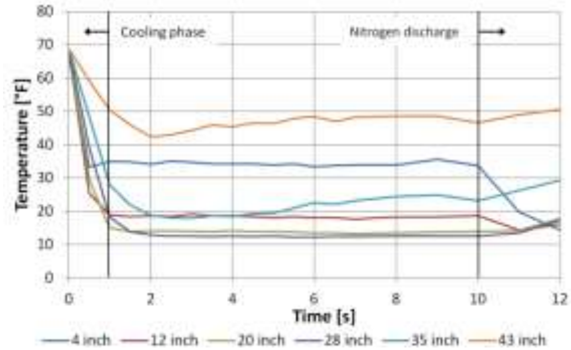

Figure 10 Temperature over time with Thermocouples

7 Conclusion

Applying new technological approaches by using infrared camera technique to record the discharge process showed on the one hand the advantage of not influencing the jet flow and a fast data evaluation. On the other hand the limitations of the surface measurement became evident. They lead to significant deviation from the measured absolute temperature in the jet midline. The investigation of measuring the jet distance with different methods is performed with success. The methods are applicable in principle and should be used to determine the jet length of other nozzle sizes and types.

8 Sources

[1] *de.wikipedia.org –Bromchlordifluormethan* (July 2015) Retrieved February 3, 2016, from https://de.wikipedia.org/wiki/Bromchlordifluormethan

[2] *de.wikipedia.org – Bromtrifluormethan* (January 2016) Retrieved February 3, 2016, from https://de.wikipedia.org/wiki/Bromtrifluormethan

[3] 3M. (2010). *3M™ Novec™ 1230 Feuerlöschmittel*. Neuss, Germany.

[4] Dr. Stahl, Peter (2005) *Neue Entwicklungen auf dem Gebiet der chemisch wirkenden Löschgase*, Switzerland

[5] Wozniak, G. (2003). *Zerstäubungstechnik - Prinzipien, Verfahren, Geräte*. Berlin: Springer-Verlag.