Daniel Ondrusik - Dalibor Balner - Adam Thomitzek

EXTINGUISHING OF POOL FIRES USING THE WATER MIST

Currently, there is progressive use of fire protection systems that use the high-pressure water mist. The extinguishing effect of water mist on flammable liquids is not sufficiently elucidated. Therefore, experiments were designed to gain new knowledge about the mechanism of the high-pressure water mist extinguishing.

As a source of the pool fire, gasoline, kerosene, diesel and ethanol were used. Flammable liquids were stored in a circular steel container with a diameter of 165 mm and a depth of 12 mm. The container was placed in an enclosed room of 2.7 x 2.7 m x 3 m. In the experiment, the time to extinguish flammable liquids was measured using nozzles of different spray characteristics of the water mist. The nozzles with orifice 400 µm, 800 µm and 1000 µm were used at a constant pressure of 70 bar.

Keywords: *water mist, pool fire, extinguishing time, flammable liquid, nozzle*

1 Introduction

Many types of transport use automatic fire protection systems (e.g. locomotives, aircrafts etc.). Currently, the trend is to move from chemical extinguishing agents (pure extinguishing agents alternatives replacing halons) to the use of the high-pressure water mist. The great advantage of water mist is easy availability and minimum damage level of devices in the case of fire. Vehicles use flammable liquids as fuel, lubrication and energy transfer (hydraulics) for their function. The mechanism of extinguishing the burning vapours of flammable liquids by means of water mist is not sufficiently described. Experiments presented in this article were designed to explain the effect of nozzle diameter on extinguishing of various types of flammable liquids. The penetration of water mist particles into the flame is influenced by the content of carbon soot particles. The content of soot particles in the flame varies for different liquids.

In extinguishing the pool fires using a water mist it is necessary to define parameters of the water mist. The main parameters of the water mist are size and velocity of droplets, which have an impact on their overall kinetic energy and mass loading of the droplets. Additionally, extinguishing is determined by the type of nozzle, i.e. the geometry of the ejected water mist [1]. It is possible to come across similar water mist parameters in attenuation of heat radiation, where water mist curtains are used [2-4]. To increase the extinguishing effectivity, it is necessary to optimally design parameters of the water mist for various types of flammable liquids. In reference to parameters of the water mist during the termination of a fire, the main extinguishing mechanisms are the cooling effect, oxygen isolation effect and attenuation of the heat radiation towards the surface of a liquid. The cooling effect has the two phases - the gas phase cooling (reduces the energy necessary for a fire chain reaction) and the liquid phase cooling (reduces the heat from the surface of the fuel) [1, 5]. Another scientific paper describes the overall extinguishing effects of the water mist: „*The main effects usually observed in water mist action are gas phase cooling, oxygen displacement, fuel vapor dilution, wetting and cooling of the fuel surface. Two secondary mechanisms have also been identified: radiative transfer attenuation and kinetic effects*“, [6]. Extinguishing of pool fires by a water mist is a subject that many authors address, where the aim should be the finding and unification of suitable parameters of the water mist for a defined flammable liquid.

Source [5] is an experimental study dealing with interaction of the water mist with pool fires contained in a stainless steel pan. The experiment was performed on a small scale in a stainless steel container with an inner diameter of 150 mm and a height of 10 mm. The container was placed 600 mm above the ground. A nozzle with a working pressure of 0.5 MPa a jet angle of 60° and flow rate of approximately 1.0 ml.s^{-1}, was placed at a height of 300 mm above the container. The water tank is under pressure by nitrogen at the required level and the nozzle creates the water mist. The Volume Mean Diameter of the mist was about 80 µm. The radiation spectra of the flames were measured by a monochromator and the radiant heat flux was obtained by a heat flux sensor before and after application of the water mist. Thermography was used to visualize the thermal field of the flame. These characteristics were measured for the liquid pool fires of kerosene, heptane and ethanol. The obtained results showed that in the case of heptane and ethanol it was easy to extinguish the fire using the main extinguishing effects

Daniel Ondrusik[1], **Dalibor Balner**[1,*], **Adam Thomitzek**[2]
[1]Department of Security Services, Faculty of Safety Engineering, VSB -Technical University of Ostrava, Czech Republic
[2]Department of Fire Protection, Faculty of Safety Engineering, VSB -Technical University of Ostrava, Czech Republic
*E-mail of corresponding author: dalibor.balner@vsb.cz

of the water mist. In the case of kerosene, the extinguishing was a lot more difficult. The authors of the study assume, that this can be explained by a greater production of soot, which prevented penetration by the mist through the buoyancy effect of the burning gases and onto the surface of the flammable liquid. Due to this, the necessary amount of water does not reach the surface of the liquid, leading to an increase in the fire intensity due to expansion of the water mist during the evaporation. A higher amount of evaporated water also further propagates the mixing of flammable vapors with an oxidative element and changes chain reactions. A sufficient mass loading of the mist jet is an important parameter in extinguishing kerosene with a water mist. As can be concluded from article [5], the process of extinguishing, just like the temporary increase of the intensity of the fire, is a key part of the interaction of the flammable liquid with the water mist. Which process prevails will depend on the type of fuel, the characteristics of the water mist (size of the droplets, concentration) and the pressure used. As is mentioned below, the source, which describes the extinguishing effect of the water mist with additives also mentions the increasing and diminishing intensity during the pool fires and divides this effect into four phases (details in source [7]). Source [1] dealt with the effectivity of extinguishing pool fires with a single-jet nozzle mist apparatus in an open space. The experiment was done using the steel containers, with diameters of 130 and 200 mm, with ethanol and kerosene as a fuel. In measuring the heat flux and temperature, authors were set to calculate the effectivity of extinguishing with reference to various working pressures (4-10 bars) on the mist system and various distances of the nozzle from the test container. They concluded from the results obtained, that the greater the distance of the nozzle from the fuel, the harder it is to extinguish the fire (especially during the pressure being below 6 bars). They also found out that extinguishing kerosene could be easier than extinguishing ethanol, under the condition that the water mist has a greater mass loading and a higher momentum of droplets. With extinguishing, it also depends on the type of the nozzle - full cone spray pattern, hollow cone nozzle. The article also mentions the oxygen isolation effect of the smoke containing soot, which can, with help of the mist, reach the fire zone and keep the oxygen out, especially in the case of kerosene. This phenomenon works with the opposite effect than the described in article [5]. The time it takes to extinguish ethanol and kerosene is also influenced by their flash points. An interesting fact is that the pulse jets of water mist can increase the effectivity of extinguishing. [1]

The research also focused on possibility of boosting the extinguishing by the water mist with additives. Article [8] focuses on differences in extinguishing the pool fires (diesel, gasoline and ethanol) with and without additives. The experiment took place in a well-ventilated room of 3 x 3 x 3 m, using a square container of 15 x 15 cm placed at a distance of 65 cm from the floor and 1 m from the nozzle. The additives used were film-forming agent AFFF, NaHCO3, a representative sample of the metal compounds and multi-component agent (MC additive). The gathered results showed, that in adding the respective additives, it is possible to increase the extinguishing effectivity of the water mist. However, it is necessary to mention that effectiveness of the additive greatly depends on the type of the fuel used [8].

The increased extinguishing effectivity of the water mist with additives is also confirmed by article [7]. The process of extinguishing pool fires with water mists with additives can be divided into four parts - flame early growth stage (flame development stage), preliminary inhibition stage, again flame growth stage and again inhibition stage. In using the water mist with additives, the extinguishing effect of the mist has the added benefit of terminating chemical reactions by pairing with free radicals, decreasing the surface tension of the water or creating a film on the surface of the fuel (depending on the type of additive) [7, 9].

The aim of experiment, presented in this article, was to determine the extinguishing time of ethanol, kerosene, gasoline and diesel using water mist.

2 Creation of a water mist

In cooperation with the company PKS Servis spol. s.r.o, a system for creating a water mist by the brand TechnoMIST was used. The system for creating a water mist consists of a high-pressure water pump with a filter, armature, a pipe system and a nozzle with different orifice. A diagram of the system for creating a water mist is shown in Figure 1.

2.1 High-pressure water pump with a filter

A pump from the brand Tecnocooling type PREMIUM was used in the system for creating a water mist (Figure 2). It is a plunger high pressure pump, which consists of a brass head and three ceramic pistons. A single-phase electric motor with 1450 (RPM) is the source of power, enabling a 70 bar working pressure of the pump. The electric motor is air-cooled and connected to the standard electric outlet 230V/50 Hz. At operating pressure, the flow of the water at ejection point from the pump is, with regards to the quality of water, around 2 $1.min^{-1}$. A water filter made from a plastic body with cellulose lining is placed at the water inlet point into the pump (Figure 2). The filter is capable of capturing mechanical impurities above 5 μm [9].

2.2 Pipe system

The pipe system is made up of a resistant black nylon hose with a thickness of 3/8” (the outer diameter 10 mm, the inner 5 mm, thickness of the wall 2.5 mm) [9]. This hose is adapted to usage at high pressures.

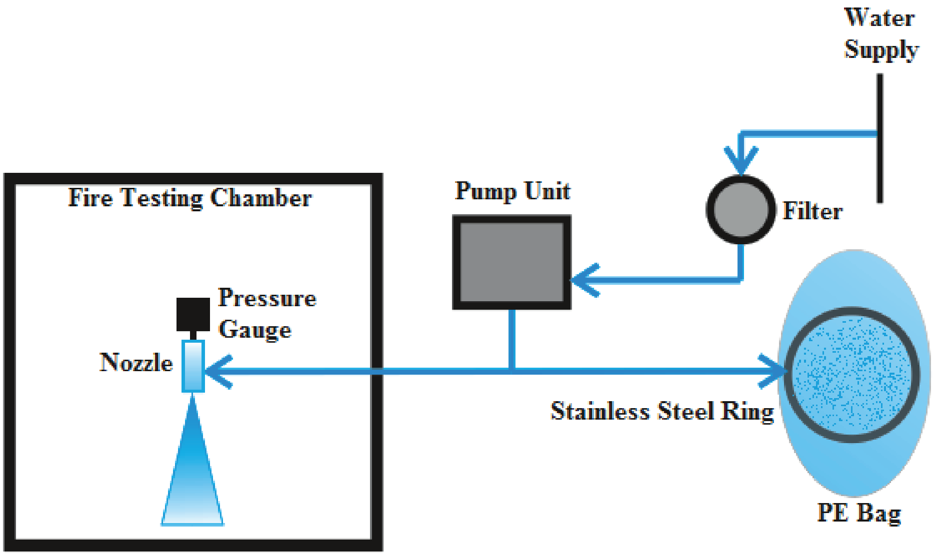

Figure 1 *System for creating a water mist*

Figure 2 *High-pressure pump and filter at the supply line*

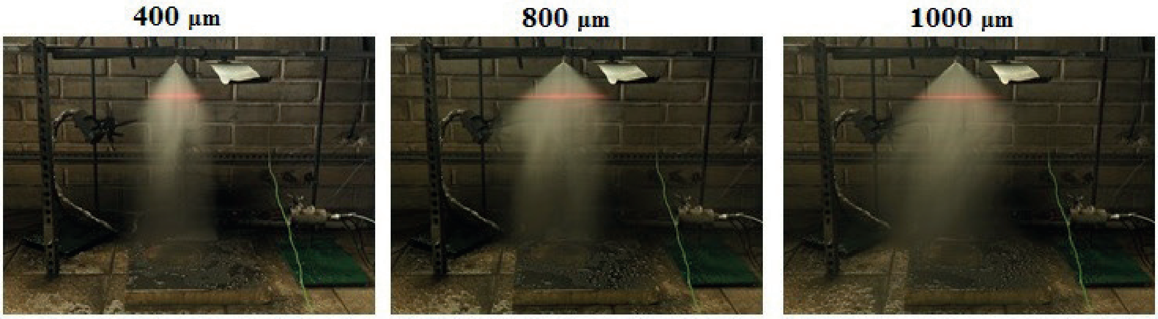

Figure 3 *The spraying characteristics of the tested nozzles*

2.3 Armatures

The hose is divided into two branches by a T-piece. The first branch leads to a stainless steel ring with a diameter of 400 mm with 5 openings for the mist nozzles. There were 3 nozzles 800 µm and 2 nozzles 1000 µm placed on the ring, enabling, together with a measured nozzle, the defined pump flow of 2 1.min^{-1}. The ring is placed in a PE bag, so that the mist would not escape into the surrounding and cause higher humidity in the area of the experiment. The second branch leads to another T piece, which enables the connection of the pressure sensor and the end holder of the nozzle, where it is possible to change the tested nozzles. The pressure sensor is connected to a connector and allows monitoring the pressure on the tested nozzle.

2.4 Nozzles

Change of the water mist parameters was achieved by nozzles with orifice diameters of 400 µm, 800 µm and 1000 µm. The nozzles created water mists of a various mass loading, size of droplets, flowrate of water and geometry of the spray cone. The shape of the spray cone of the individual nozzles used is in Figures 3 and 4 (thermogram).

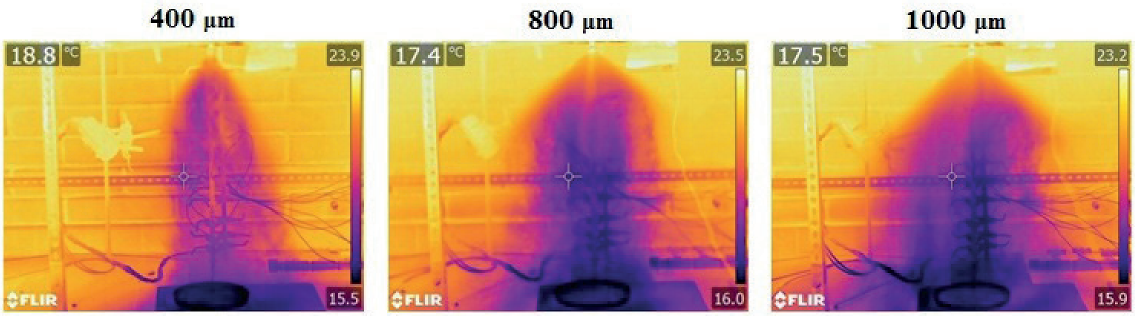

Figure 4 *The spraying characteristics of the tested nozzles (thermogram)*

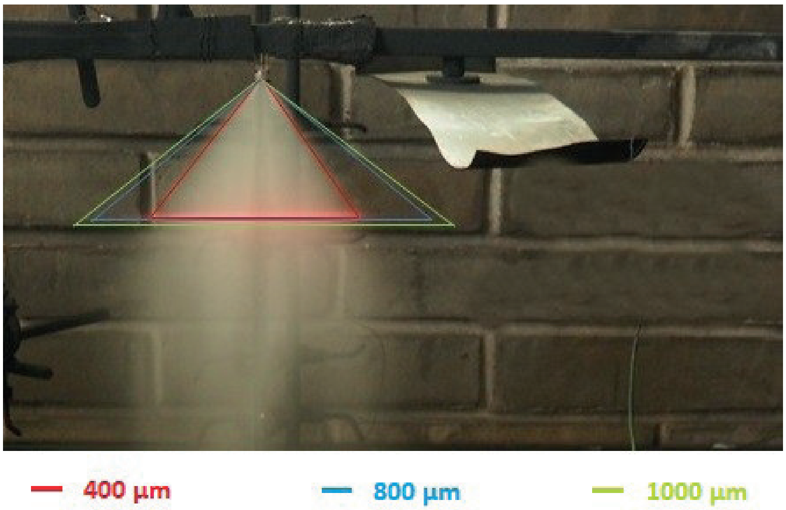

Figure 5 *Comparing the spray cones widths*

Table 1 *Measured water flowrate for individual nozzles*

Nozzle	400 µm	800 µm	1000 µm
Q_v (ml.min^{-1})	145.21 ± 0.21	343.56 ± 0.99	417.29 ± 3.08
δ (%)	0.17	0.31	0.84

From the taken images, it is evident that the spray cone of the water mist is influenced by the flow of air, which is present despite the space being enclosed. This phenomenon cannot be completely ruled out. The way in which the water mist is distributed into this space is influenced, apart from the parameters of the nozzles, by the geometry of the room and flow of air inside it and the slight fluctuations of pressure on the nozzle, as well. It is also evident, that the width of the spray cone is almost the same in nozzles 800 µm and 1000 µm, whereas in nozzle 400 µm, it is noticeably narrower. The visual comparison of the widths of the spray cone is shown in Figure 5.

For each nozzle, a measurement of the water flowrate was executed in five independent measurings. Results of the flow Q_v is represented with the standard uncertainty type A and a relative deviation δ (Table 1).

2.5 Pressure sensor

The pressure sensor was connected to the system for creating a water mist just before the nozzle in order to measure the water pressure in real time. The pressure sensor DMP_333G-01, by the company BD SENSORS s.r.o., with a range of 0-600 bars and a 0.25% accuracy, was used for measurement. Display and logging of the pressure was done by the multi-channel logger ALMEMO 5690-2 from the German manufacturer AHLBORN.

2.6 Measuring apparatus

The laboratory where the experiment was conducted was designed for performing tests, which are on the border between laboratory and large-scale tests. The room is equipped with a fire testing chamber of dimensions 2.7 x 2.7 x 3m (length x width x height, respectively), which is separately ventilated from above the roof of the premises. It is possible to measure the fire parameters with a small heat output and to try various fire safety equipment [10]. The measuring equipment (Figure 6), placed in the laboratory, consists of the following:

- A steel container with a flammable liquid placed on a concrete plate,

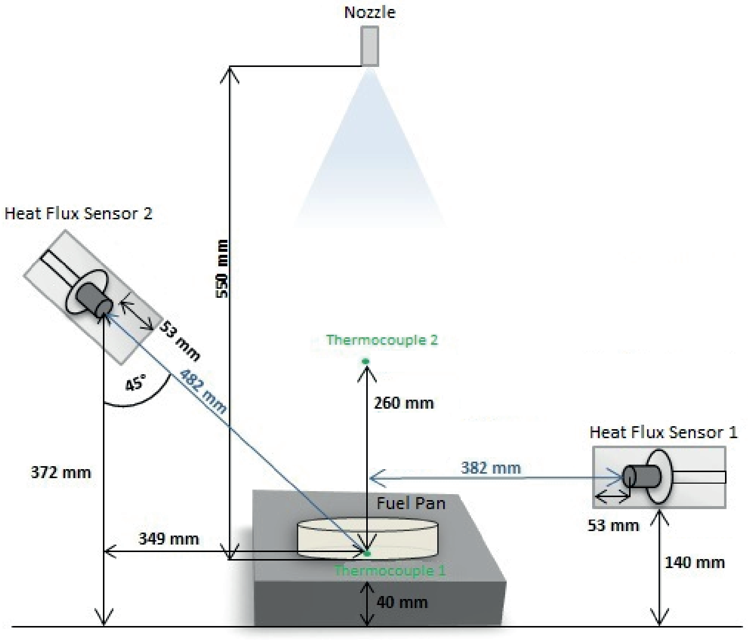

Figure 6 *Diagram of the measuring equipment*

- Two heat flux sensors Hukseflux SBG01 with measuring range of 0-10 kW.m^{-2},
- Two thermocouples for measuring temperature,
- Nozzles with orifice 400 µm, 800 µm, 1000 µm,
- Pressure sensor DMP_333G-01 (BD Sensors), range 0-600 bars, accuracy 0.25%.

The logger ALMEMO 5690-2 by AHLBORN was used for logging the measured values, to which a pressure sensor was connected along with two heat flux sensors and two thermocouples. The logger therefore noted the heat flux in one second intervals on two heat flux sensors, the pressure of the water on the nozzle and the temperature on the two thermocouples. The data was then saved onto a SD card for further processing.

The steel container of a diameter 165 mm and a depth of 12 mm was placed onto a cement pad of a height of 40 mm. The steel can was placed always at the same place during the experiment and was placed on the pad in such a way that the center of the container was on the vertical axis in reference to the nozzle. In addition, the placement of the concrete pad itself was always the same during the measuring.

The second measured parameter was the heat flux on the two sensors. Values of the heat flux especially helped to determine the optimal time for finding the constant intensity of burning the tested liquids (to define pre-burn time), based on the referenced measurements without application of the water mist. Observations of behaviour began after extinguishing with the water mist has started. The first sensor was placed at a height of 140 mm above the ground of the room, with which it was in a parallel position. The distance from the center of the container to the first heat flux sensor was 382 mm, where the sensor was, due to protection from flames and decrease of the angle of detection, inserted into an aluminium pipe to a depth 53 mm (see Figure 6). The same method of protection was used for the second heat flux sensor, as well. This particular sensor was placed 349 mm from the center of the container at a height of 372 mm. The sensor was aimed to the center of the container, where it formed an angle of 45° with the floor. The distance from the front of the sensor to the center of the steel container was 482 mm. The power supply cabling and water cooling for the heat flux sensor were further protected from heat by aluminium foils.

The next parameter measured was temperature by way of the two thermocouples. The first thermocouple was placed at the bottom of the steel container, and therefore only recorded the temperature of the flammable liquid during the experiment. The second thermocouple was placed on the center axis of the stainless steel container at a height of 260 mm above its bottom and recorded temperature of flames during the experiment. The measuring apparatus placement is shown in Figure 6.

The pipe system itself was also protected from heat by an aluminium foil. The tested nozzle was, before the start of the extinguishing process, protected from heat by an aluminium plate, which was mechanically controlled with a stretched wire. For the exact setting of the beginning of the water mist application, a switch was placed on the logger, which logged the data from this event in real-time. The switch was always manned by another person, who reacted to voice prompts. This person was also responsible for the turning on/off the pump at the required moment.

3 The course and results of the measuring

There were four standardly used flammable liquids with various physical and chemical properties used for the experiment: diesel, gasoline, kerosene and ethanol. After setting up the system for creating the water mist and the measuring equipment, it was necessary

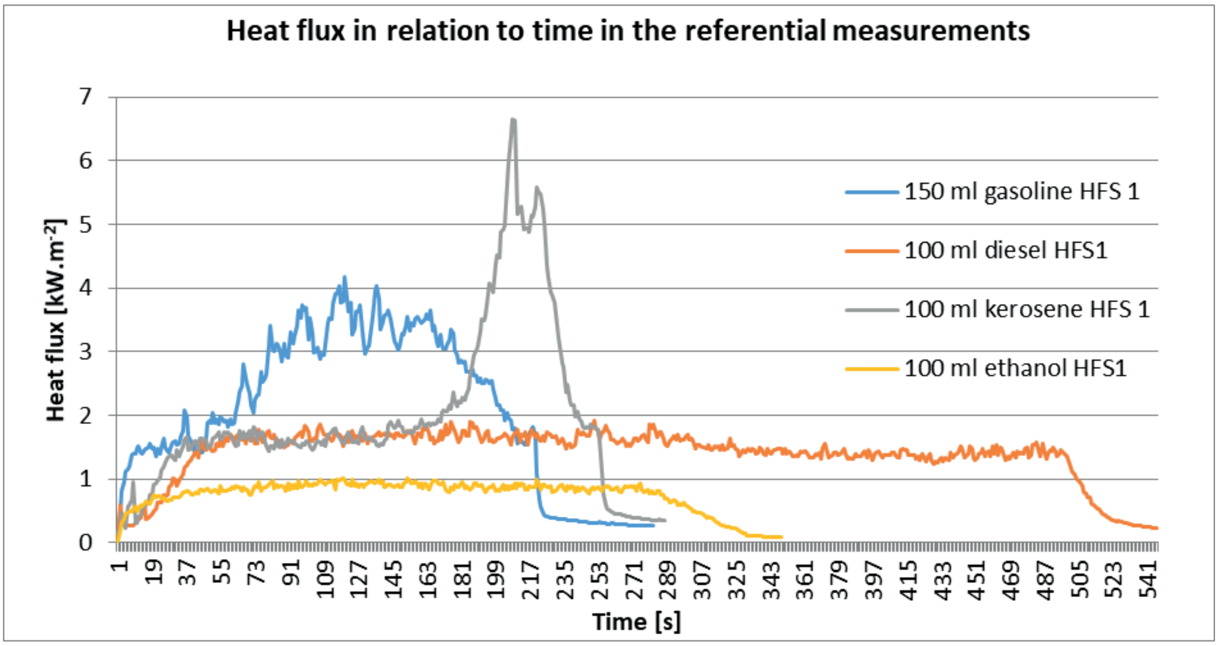

Figure 7 *Heat flux in terms of time in the referential measurements of the liquids used*

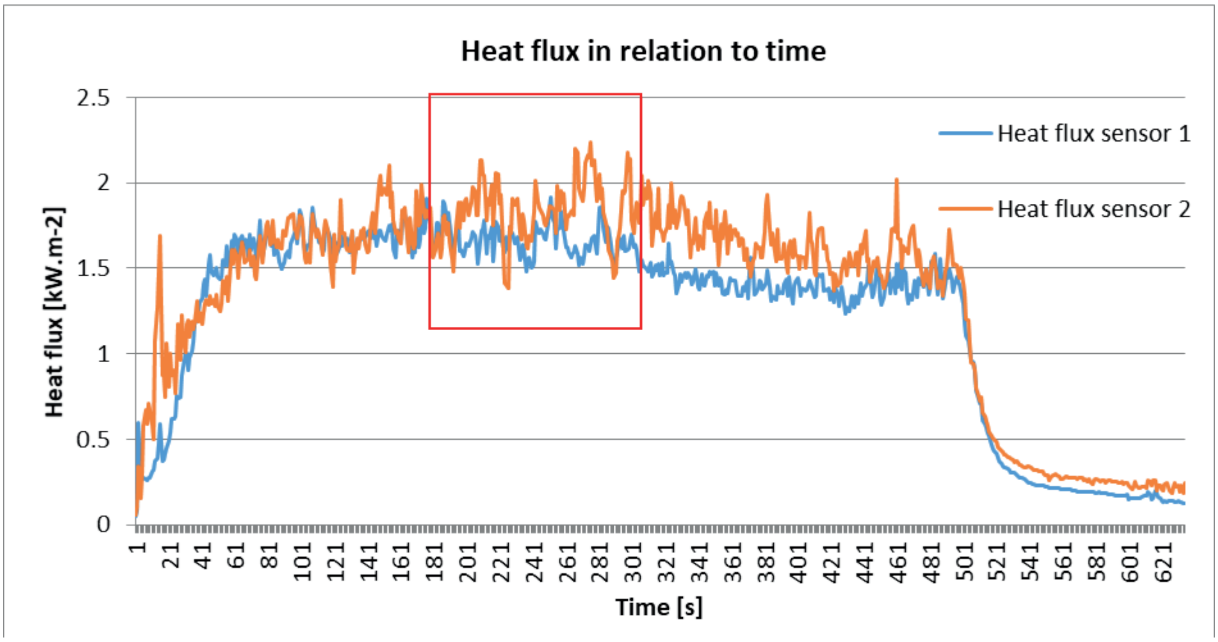

Figure 8 *Heat flux in terms of time during referential measuring of 100 ml of diesel*

to determine the method of measuring, which would provide consistent conditions for the duration of the whole experiment. The first task was to always properly prepare the equipment for measuring. Then it was necessary to set the amount of flammable liquid that would be used for burning. Each flammable liquid was set on fire for testing without application of the water mist. This test served as a reference for setting the measuring of the total burning time of the flammable liquid and setting the heat flux during the course of burning. The goal was to find the amount of flammable liquid that burned long enough to have a steady intensity and to note the time interval, when this steady burning takes place. This information was obtained from data of the heat flux sensors. Figure 7 shows the heat flux in relation to time (measured by sensor 1), in the referential measurements of the liquids used.

Figure 8 shows the measurements of diesel together with a highlighted area of consistent burning and time.

Before measuring the time to extinguish the flammable liquids, measurements were taken of the environment in the fire testing chamber by way of a pressure, temperature and relative humidity gauge of the brand Lutron, type MHB-382SD. There were relatively stable conditions in the laboratory, which should not noticeably affect the experiment; that is why the data is not provided here. For the better understanding of mechanisms during the extinguishing with the water mist, individual experiments were recorded/photographed on the digital cameras

***Table 2** Extinguishing time of flammable liquids using various nozzles*

Time (s)	Gasoline	Diesel	Kerosene	Ethanol
Nozzle 400 µm	66.99 s	51.44 s	9.09 s	2.09 s
Nozzle 800 µm	77.37 s	49.90 s	9.64 s	3.67 s
Nozzle 1000 µm	20.74 s	45.26 s	5.77 s	4.11 s

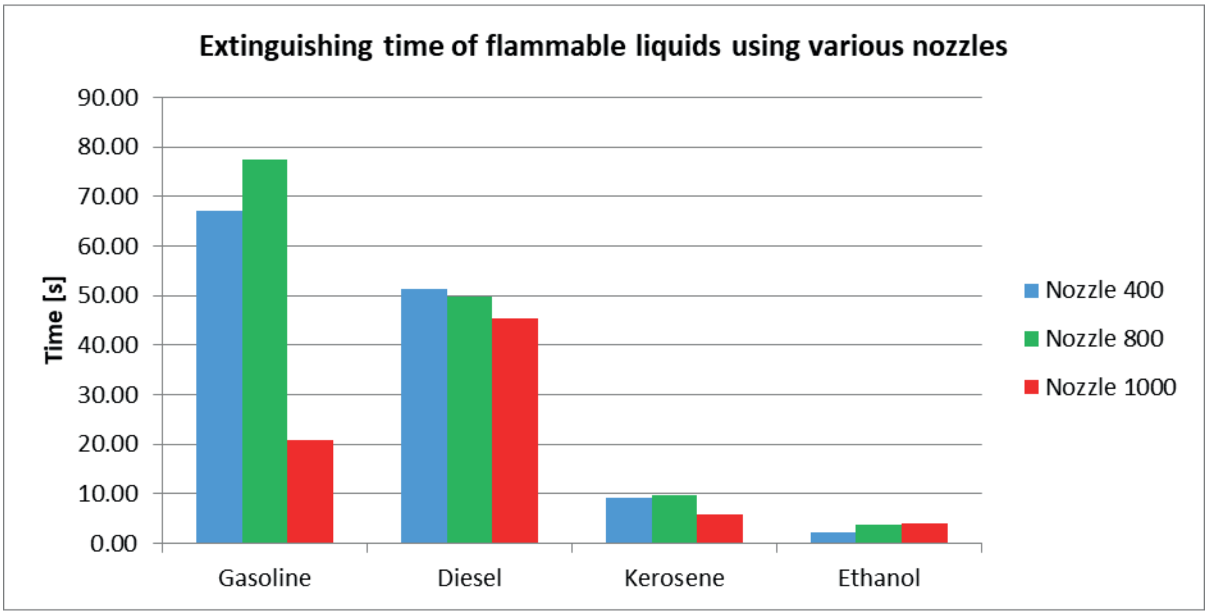

***Figure 9** Extinguishing time of flammable liquids using various nozzles*

(Panasonic HC-V500, Canon EOS 600D, Panasonic DMC-FZ20, Huawei Nova 3) and some on the thermo-camera FLIR T640.

4 Results and evaluation

Water mist extinguishing is a very complicated process, which has many variables. For that reason, the experiment focused on determining the time to extinguish the flammable liquids with water mist using various kinds of nozzles. Table 2 shows the extinguishing time of flammable liquids using various nozzles. The extinguishing time began to be measured always after the steady intensity burning phase and application of the water mist.

The extinguishing time is shown graphically in Figure 9, as well. From Figure 9 and Table 2 it is evident that the 1000 µm nozzle extinguished the fastest and did so in the case of gasoline, diesel and kerosene. On the contrary, it was the slowest in the case of ethanol; however, the extinguishing times were very short and all the three nozzles showed to be very effective here. The 1000 µm nozzle however, had the greatest flowrate, as well and that is 417.29 ml.min^{-1}. The 800 µm nozzle demonstrated the longest time to extinguish in the cases of gasoline and kerosene. The time, which a burning liquid takes to be extinguished, is, apart from the water mist characteristics, influenced by the flammable liquid. None of the used nozzles appeared to be the fastest in extinguishing of all of the used liquids.

Figure 10 compares the total volume of water needed for extinguishing the flammable liquids with the use of various nozzles. The required amounts of water measured in volume were calculated from the flowrate of the individual nozzles multiplied by the time needed for extinguishing the flammable liquids. The 1000 µm nozzle used the least amount of water in case of gasoline extinguishing, despite having the greatest flowrate. On the other hand, it used the most water in the case of diesel. The 400 µm nozzle showed the highest effectivity in terms of used water in the case of ethanol, kerosene and diesel, where it used the least amount of water. Here it is necessary to mention that due to the shape of the spray cone, not all of the water that flowed through the nozzle may have been used for extinguishing. In 800 µm and 1000 µm nozzles, which had a wider spray cone, the water mist could have had a greater oxygen isolating effect. However, due to droplets, which did not get into the zone of the fire, the entire potential of cooling was not taken advantage of. Those effects, however, were not discussed further, it would be necessary to determine the overall heat balance of the burning, in relation to effects of the water mist in using the individual nozzles, which was not the aim of the study.

The heat flux strongly correlates with the intensity of burning and, therefore, with the buoyancy of flammable gases, which has a negative effect on small water droplets. If the water droplets do not have the necessary kinetic energy, they are not able to permeate the zone of the fire and terminate it. The highest values of the heat flux were shown by gasoline (can be seen in Figure 7), which also

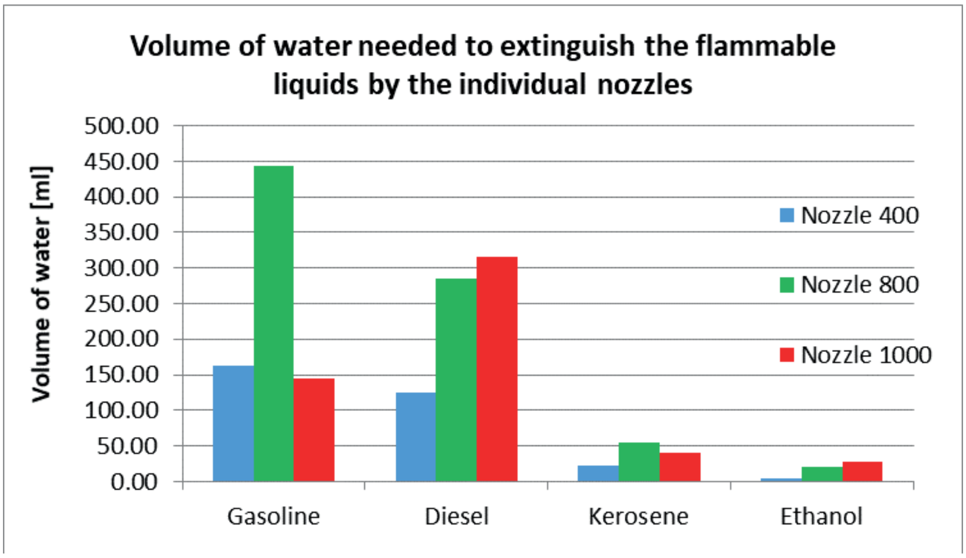

Figure 10 *Volume of water needed to extinguish the flammable liquids by the individual nozzles*

Figure 11 *The comparison of gasoline pool fire intensity at the time of 40 s and 85 s from the ignition*

Figure 12 *The comparison of diesel pool fire intensity at the time of 75 s and 175 s from the ignition*

took the longest time to extinguish. An exception was the 1000 μm nozzle, which most likely had the necessary mass loading and kinetic energy of water droplets for a rapid extinguishing of the fire. Similar values of the heat flux on sensor 1 (Figure 7) were measured in the case of kerosene and diesel. The peak of the curve of kerosene is caused by the boiling of the liquid out of the steel container and did not have an effect on the extinguishing time. Nevertheless, the times of extinguishing of both of these liquids varied noticeably. In the conditions of this experiment, the times for extinguishing kerosene were noticeably lower than the times to extinguish diesel or gasoline. The smallest values of the heat flux on sensor 1 (Figure 7) were measured in the case of ethanol, which also had the shortest extinguishing time.

Scientific papers claims of the longer time for extinguishing kerosene (in comparison to heptane or ethanol) can be attributed to a high production of soot, which prevents the water mist from penetrating through the buoyancy of the flammable gases [5]. However, another view exists, which states there is a shorter extinguishing time of kerosene (in relation to ethanol) due to the oxygen isolating effect of the smoke containing soot. Smoke can be pushed by the water mist into the fire zone and keep oxygen out, especially when the water mist consists of the high mass loading and large droplet momentum [1].

The oxygen isolating effect of smoke could have a general impact on the shorter extinguishing time of kerosene (in some references there are claims that there could be a shorter extinguishing time in the case of kerosene than ethanol due to this effect). Due to the fact that diesel also produces the large amount of soot; the soot impact on penetration of the water mist could have manifested itself here and prolonged the extinguishing time. The time to extinguish the pool fires is necessary to be considered in relation to the flash point [1].

From results of the experiment, it is evident that during the extinguishing of the flammable liquids with the water mist, it is necessary to consider parameters of the created water mist, as well as the type of the flammable liquid itself. Further, it is important to consider the space where the extinguishing takes place and many other parameters. The easiest solution, therefore, is to carry out a practical experiment. In the case of design of systems for extinguishing the pool fires on a small scale that would be, for the timely extinguishing of flames, to investigate the kinetic energy of the droplets, which is important for penetration of the mist through the buoyancy of the flammable gases. The kinetic energy of these droplets should be high enough to overcome this buoyancy of the gases, but it should also not splash the fuel on impact. Further, it would be suitable to use the higher mass loading of the droplets.

The experiment was conceived to extinguish the steadily burning pool fires and therefore it was important first to find out the time it took to reach this value in the used liquids. Authors of [8] state that in their experimental conditions the time it took to reach the steady burning for gasoline and ethanol was 40 s. In conditions of the present experiment, it is observed, however, that such a time was not enough to reach this steadily burning phase. According to these measurements, it is concluded that the time for steady burning for ethanol and gasoline has to be 90 s. In the above-mentioned literature it is also stated that the time for steady burning of diesel was 75 s [8]. In the present measurement conditions it is observed, again, that this number does not match the time it took for the steady burning, which was reached in 180 s. Figures 11 and 12 compare the intensity of burning in times given by [8] and in times right before initiation of the extinguishing.

5 Conclusion

A pump with a working pressure of 70 bars, the pipe system and various nozzles were used for creating the water mist. For the purposes of this measurement the nozzles with orifice 400 μm, 800 μm and 1000 μm were used, which enabled creation of the water mist of various parameters. The basic parameters of the water mist are mass loading, shape of the spray cone, size and velocity of droplets, which, at a defined pressure, have an impact on their kinetic energy. The nozzles used had, during the same operating pressure, various flowrates and shapes of the spray cone. The water mist varied in the mentioned parameters.

In the experiment, the extinguishing time for the chosen flammable liquids, heat flux recorded by two sensors and the temperature, were measured. For the better understanding of the interaction of the water mist with the pool fires, the experiments were recorded on a camera and some on the thermo-camera, as well.

From the obtained data, it was evident that the 1000 μm nozzle was the fastest at extinguishing pool fires in the case of gasoline, diesel and kerosene. On the contrary, it was the slowest in the case of ethanol; however, times for the fire extinguishing were very low and all the three tested nozzles showed to be very effective. The 1000 μm nozzle, however, also had the greatest flowrate. The 800 μm nozzle took the longest time to extinguish gasoline and kerosene. The 400 μm nozzle then managed to extinguish ethanol in the shortest time. None of the used nozzles appeared to be the fastest in extinguishing of all the used liquids. From the perspective of amount of the used water, the most effective was the 400 μm nozzle, which used the least amount of water to extinguish diesel, ethanol and kerosene pool fires.

These results showed that a sufficient kinetic energy of droplets in the water mist to penetrate the buoyancy of the flammable gases is a key parameter. The better results could also have been achieved if there was a greater mass loading of the water mist. An important factor influencing the effectiveness of the fire extinguishing by the water mist is also the type of the flammable liquid. This is also confirmed by literary sources, which state that parameters of the water mist are defined for the concrete type of the flammable liquid.

In the cited sources, it is written that extinguishing by the water mist is affected by the soot production, which affects penetration of the water mist through the buoyancy of the flammable gases of the liquid. This phenomenon probably took place in the case of the diesel extinguishing, which was not possible to execute in a short time. However, kerosene, which also produces a large amount of soot and is mentioned in literature, as well, was possible to be extinguished quickly. That could be due to the opposite effect of soot, which exists as mentioned in the text. Influence of the soot particles would be worth exploring further for finding the importance of the mentioned effects. That work could also help in the understanding the complex extinguishing mechanisms in extinguishing by the water mist.

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References

[1] XISHI, W., GUANGXUAN, L., JUN, Q., WEICHENG, F. Experimental study on the effectiveness of the extinction of a pool fire with water mist. *Journal of Fire Sciences* [online]. 2002, **20**(4), p. 279-295 [accessed 2019-03-28]. ISSN 0734-9041, eISSN 1530-8049. Available from: https://journals.sagepub.com/doi/abs/10.1177/073490402762574730

[2] GRANT, G., BRENTON, J., DRYSDALE, D. Fire suppression by water sprays. *Progress in Energy and Combustion Science* [online]. 2000, **26**(2), p. 79-130. ISSN 0360-1285. Available from: https://doi.org/10.1016/S0360-1285(99)00012-X

[3] YANG, W., PARKER, T., LADOUCEUR, H. D., KEE, R. J. The interaction of thermal radiation and water mist in fire suppression. *Fire Safety Journal* [online]. 2004, **39**(1), p. 41-66. ISSN 0379-7112. Available from: https://doi.org/10.1016/j.firesaf.2003.07.001

[4] RAVIGURURAJAN, T. S., BELTRAN, M. R. A Model for attenuation of fire radiation through water droplets. *Fire Safety Journal* [online]. 1989, **15**(2), p. 171-181. ISSN 0379-7112. Available from: https://doi.org/10.1016/0379-7112(89)90002-7

[5] XISHI, W., GUANGXUAN, L., BIN, Y., WEICHENG, F., XIAOPING, W. Preliminary study on the interaction of water mist with pool fires. *Journal of Fire Sciences* [online]. 2001, **19**(1), p. 45-61 [accessed 2019-03-21]. ISSN 0734-9041, eISSN 1530-8049. Available from: https://doi.org/10.1106/E23M-0NGH-3M3E-Y83J

[6] JENFT, A., COLLIN, A., BOULET, P., PIANET, G., BRETON, A., MULLER, A. Experimental and numerical study of pool fire suppression using water mist: *Fire Safety Journal* [online]. 2014, **67**, p. 1-12. ISSN 0379-7112. Available from: https://doi.org/10.1016/j.firesaf.2014.05.003

[7] MAN, CH., SHUNBING, Z., LITAO, J., XIAOLI, W. Surfactant-containing water mist suppression pool fire experimental analysis. *Procedia Engineering* [online] 2014, **84**, p. 558-564 [accessed 2019-03-21]. ISSN 1877-7058. Available from: https://doi.org/10.1016/j.proeng.2014.10.468

[8] BEIHUA, C., GUANGXUAN, L. Experimental studies on water mist suppression of liquid fires with and without additives. *Journal of Fire Sciences* [online]. 2009, **27**(2), p. 101-123 [accessed 2019-03-21]. ISSN 0734-9041, eISSN 1530-8049. Available from: https://doi.org/10.1177/0734904108095339

[9] Misting Systems - Tecno Cooling [online] [accessed 2018-03-22]. Casalgrande: Tecno Cooling, 2015. Available from: http://www.tecnocooling.com/_en/index.html

[10] Laboratories in Building C - Faculty of Safety Engineering, VSB - Technical University of Ostrava [online] [accessed 2018-03-25]. Ostrava: VSB-TUO, 2018. Available from: https://www.fbi.vsb.cz/021/cs/laboratore/objekt-C/