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STUDYING THE EFFICIENCY OF THE FINE SPRAY AND WATER MIST FIRE FIGHTING SYSTEMS APPLIED FOR THE INTERIOR FIRE ATTACK

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SUMMARY: This paper delves into the experimental comparison of the efficiency of the fine spray and water mist firefighting systems applied for the interior fire attack. The two systems such as a high-pressure firefighting module "ENEY-10/30" and a combination fire nozzle Protek 366 connected to a rescue firefighting vehicle by a firehose were compared. The interior fire attack was tested into a container based fire simulator. A special measuring system was designed to evaluate the efficiency of the systems. During the studies, humidity and temperature at different points of the fire simulator were measured. DHT22 temperature and humidity sensors were located at a distance of 1.5 m from each other at different heights of 1.0 m, 1.5 m and 2.0 m. The time-history of the humidity and temperature were investigated during the interior fire attacks. Based on the research data, it was established that it is reasonable to use the "ENEY-10/30" module at the initial stage of firefighting to suppress the fire and reduce the temperature inside the container. The Protek 366 nozzle can be used then as an effective means for a direct firefighting attack.

Key words: *fire, firefighting system, water mist, measuring system, interior fire attack, temperature, humidity, spray*

INTRODUCTION

The fire extinguish includes the actions aimed to stop combustion reaction in the source of fire, limiting the impact of its dangerous factors and eliminating conditions for spontaneous re-ignition after extinguishing *(Charter of actions...)*. Scientists pay more and more attention to fire prevention, because it is better to prevent a fire than to firefight. In particular, the works *(Korytchenko et al., 2021, Otrosh et al., 2019)* describe the studies of the specific features of structural elements of buildings and structures regarding their protection from fire effects. The authors also present theoretical and experimental studies on the danger of solid combustible materials and substances of both synthetic *(Dubinin et al., 2023*) and natural origin *(Dubinin et al., 2023, 2022)* which buildings and structures are equipped with. However, fire response measures taken by fire and rescue services for rescuing people and extinguishing fires are of great importance.

In *(Pospelov et al., 2021, 2021, 2021)*, the authors predict possible fire development and extinguishing scenarios and based on these scenarios other authors carry out investigations on the development of firefighting systems *(Semko et al., 2014, 2015)*. And in *(Dubinin et al., 2020, Pospelov et al., 2020, 2019)* the authors studied the effect of dangerous fire factors on the human

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health and how these factors affect the recovery of firefighter rescue teams for future their tasks at the place where the fire occurs *(Dubinin et al., 2022)*. Special attention is paid to the ecological effect when developing the promising means of protecting structural materials, choosing fire extinguishing agents and/or using modern firefighting systems *(Loboichenko et al., 2017, Kustov et al., 2019)*. The main firefighting goal is to limit the impact of developed fire and the action of its dangerous factors. It can be achieved by developing modern fine spray and water mist firefighting equipment.

There are many fire fighting systems which can be classified depending on the water supply pressure. So, according to American standard (NFPA 750. Standard on Water Mist Fire Protection Systems) high-pressure fire fighting systems with ultra-fine water mist operate at a pressure of 34.5 bar or more, medium-pressure systems operate at a pressure exceeding 12.1 bar, but less than 34.5 bar and low-pressure systems are connected to a pressure line of 12.1 bar or less. A plurality of firefighting equipment also includes manual high-pressure fire nozzles that supply fire extinguishing agent from fire rescue vehicles *(Rosenbauer International AG, AWG Fittings GmbH)*, mobile firefighting modules *(IFEX GmbH)* as well as an autonomous firefighting water cannon with periodic-pulse action *(Dubinin et al., 2018, Korytchenko et al., 2018)*. Such equipment has certain operating modes *(Korytchenko et al., 2020, 2023)* and technical parameters *(Korytchenko et al., 2018, 2020, 2019, 2019, Kasimov et al., 2018)*. The variety of firefighting systems raises questions about their effectiveness. This issue is resolved by measuring the efficiency indicators of the such systems and conducting their comparative assessment. Thus, in paper *(Liu et al., 2020)*, three thermocouples, one smoke detector and one gas analyzer were used as technical means to control the gas environment. The measurement of the gas analyzer was carried out using the COMFORT 3 software via a PC board. The obtained research data showed the dependence of the duration of firefighting operations on the ventilation rate during a fire. And in paper *(Santangelo et al., 2014)*, the studies conducted on the use of fine spray system for extinguishing class A fires involved the use of an experimental system that included nozzles, thermocouples, and a strain gauge. In *(Hamzehpour et al., 2024)*, experimental studies were conducted on extinguishing class B fires with fine spray system, measuring such parameters as the size distribution of water mist droplets and nozzle speed using the phase Doppler particle analyzer. Temperature was measured using thermocouples, and gas concentration was measured using a gas analyzer. To carry out investigations mentioned above, the authors used various measuring instruments to determine the efficiency of the firefighting system that allowed them to evaluate such indicators as the temperature in the combustion chamber and the local effect of nozzles when extinguishing a fire. But a change in characteristic of the atmosphere such as humidity when water mist spreads in the chamber was not studied.

In this regard, this paper will delve into experimental studies conducted using the developed measuring system to determine the effectiveness of the fine spray and water mist firefighting systems *(Dubinin, 2024)* to obtain a comparative assessment of the effectiveness of the systems by determining the change in the air humidity and temperature during the extinguishing of an interior fire. As fine spray and water mist firefighting systems, the high-pressure firefighting module "ENEY-10/30" (hereinafter referred to as the "ENEY" module); *(TOV "Spark-Protekt")* and the combination fire nozzle Protek 366 (Handbook...) were used.

SPECIFICATIONS OF THE CONSIDERED FIRE FIGHTING SYSTEMS

Technical characteristics of the high-pressure firefighting module "ENEY 10/30"

The high-pressure firefighting module "ENEY-10/30", designed to supply water mist with a droplet dispersion of 50 to 100 microns, was developed by the company "Spark Protect" (Ukraine); (TOV "Spark-Protekt"). The general view of the module is presented in Figure 1.

Figure 1. Firefighting module "ENEY-10/30"
Slika 1. Modul za gašenje požara "ENEY-10/30"

The power unit of the module is a four-stroke HONDA GP-160 gasoline engine with an effective power of 4.9 hp at 3600 rpm and a fuel consumption of 1.4 L/h. The fuel tank capacity is 3.1 L. The "ENEY" module is equipped with a "SPARK-1" fire nozzle and a 50 m high-pressure hose (Fig. 2). The special "SPARK-1" fire nozzle operates in three main modes: supplying a water jet to a distance of up to 18 m, producing a fine water spray to a distance of up to 15 m, and generating a low-expansion firefighting foam. For ease of operation, the nozzle has a smooth adjustment of the spray angle and the regulator is located on the handle of the nozzle.

Figure 2. "SPARK-1" fire nozzle and a 50 m high-pressure hose
Slika 2. Mlaznica za gašenje požara „SPARK-1" i visokotlačno crijevo od 50 m

A special tangential nozzle (Fig. 2) of the firefighting module "ENEY-10/30" and interchangeable nozzles of different diameters, together with the pump pressure regulation system, allow users to choose an optimal operating mode of the module. According to the module specifications, the consumption of extinguishing agents can be varied in the range of 10 to 30 liters per minute at a pump pressure of 40 bar.

Technical characteristics of the combined fire nozzle Protek 366

The combined fire nozzle Protek 366 (hereinafter referred to as the Protek 366 nozzle) is designed to spray a water jet with a dispersion of up to 100-1000 microns (Fig. 3) [*Posibnyk...*]. At the same time, the water flow rate at a pressure of 7 bar can be 1.9 L/s; 3.8 L/s; 6.0 L/s; 7.9 L/s. The nozzle weight is 2.2 kg.

Figure 3. Combined fire nozzle Protek 366
Slika 3. Kombinirana protupožarna mlaznica Protek 366

Water supply to the Protek 366 nozzle is carried out through a fire hose with a diameter of 51 mm using the tank fire ADC EN 1846-S-1-6-5000-10/3000-2. The maximum pressure of the pump is 10 bar, and the flow rate is 3000 L/min [*TOV «Promyslova kompanija «Pozhmashyna»*]. During experimental studies, the flow rate at the nozzle was 1.9 L/s.

INVESTIGATION OF THE FIRE FIGHTING MODULE "ENEY-10/30"

Experimental setup and conditions

The studies included spraying water into a container fire simulator (hereinafter referred to as CFS) during the fire development, followed by measuring humidity and temperature. General view of the container fire simulator is presented in Fig. 4.

Figure 4. General view of the container fire simulator

Slika 4. Opći prikaz simulatora požara kontejnera

Combined sensors were located along a line with a distance of 1.5 m from each other (Fig. 5). The height of sensors was changed and equaled 1.0 m, 1.5 m, and 2 m.

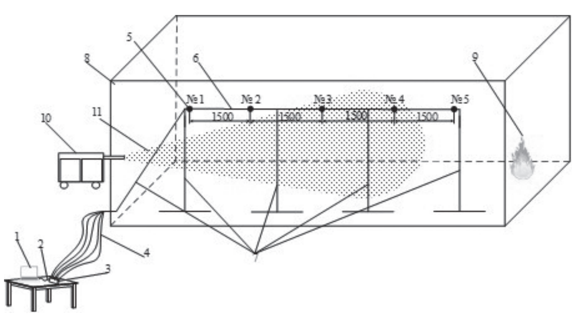

Figure 5. Diagram for conducting an experimental study using the measurement system: 1 – laptop (power bank); 2 – USB cable; 3 – data processing unit; 4 – standard cable; 5 – sensors for measuring humidity and temperature; 6 – structure made of plastic pipes, 2.0 m long; 7 – structure made of plastic tubes, 1.0, 1.5, and 2.0 m long; 8 – fire simulator; 9 – fire source; 10 – firefighting module; 11 – the fine spray

Slika 5. Dijagram za provođenje eksperimentalne studije korištenjem mjernog sustava: 1 – prijenosno računalo (power bank); 2 – USB kabel; 3 – jedinica za obradu podataka; 4 – standardni kabel; 5 – senzori za mjerenje vlažnosti i temperature; 6 – konstrukcija izrađena od plastičnih cijevi, duljine 2,0 m; 7 – konstrukcija izrađena od plastičnih cijevi, duljine 1,0, 1,5 i 2,0 m; 8 – simulator požara; 9 – izvor požara; 10 – modul za gašenje požara; 11 – fini sprej

The fine spray was supplied from the SPARK-1 fire nozzle by the operator, standing at the entrance to the CFS on the left, with the doors closed, except for the lower left part (Fig. 6). The fine spray was supplied continuously for 30 s with a flow rate of 0.5 L/s. The fine spray was not direct on the sensors of the measuring system.

Figure 6. Supply of a fine spray inside the CFS

Slika 6. Dovod finog spreja unutar CFS-a

During the investigation, a fire of class A (a fire of a stack of wooden boards in the shape of a cube) was imitated in the container (Fig. 7). The stack consisted of 6 layers of wooden boards and each layer included 6 boards. A size of each board was 40×40×500 mm. Free surface area of the model fire source was 2,35 m^2.

Figure 7. A fire of a stack of wooden boards in the container

Slika 7. Požar hrpe drvenih dasaka u kontejneru

A data processing unit and a laptop of the measuring system was located outside the CFS (Fig. 8).

Figure 8. A data processing unit and a laptop of the measuring system

Slika 8. Jedinica za obradu podataka i prijenosno računalo mjernog sustava

Measurement data was stored on a memory card. Then the obtained humidity and temperature values were processed in the form of graph using the laptop with WPS Office or Microsoft Office software.

Experimental results

Figures 9-11 show the humidity history measured in the CFS.

Figure 9 shows a change in humidity over time at 5 sensors located at a height of 1.0 m from the floor.

The number of the sensor presented in figures grows from the entrance of the CFS. According to data of sensors No. 3 and 5, we observe maximum humidity reaching 99% at the starting of the spray supply. This could have been caused by drops of water getting on the sensors. According to data of sensor No. 4 we observe a rapid increase in the humidity by 1.9 times, while the humidity by sensors No. 2 is increased by 13%. The humidity by sensor No. 1 is variable but it values is closed to initial one. Taking into account that the sensor No. 1 located near the CFS entrance, fresh outside air could have influenced the humidity at this measurement point. Thus, supply of a fine spray inside the CFS causes the growth in humidity of gas environment.

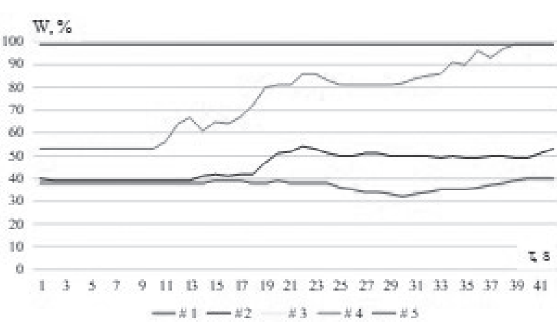

Figure 9. The humidity history by the sensor height of 1.0 m

Slika 9. Povijest vlažnosti na visini senzora od 1,0 m

Figure 10 shows a change in humidity over time at 5 sensors located at a height of 1.5 m from the floor. According to data of sensors No. 3 and 5 we observe maximum humidity reaching 99% at the beginning of the spay supply.

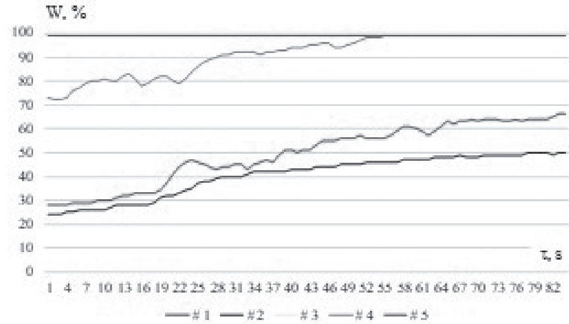

Figure 10. The humidity history by the sensors placed at a height of 1.5 m

Slika 10. Povijest vlažnosti koju su izmjerili senzori postavljeni na visini od 1,5 m

The humidity grows slowly at sensors No. 1, 2 and 4. Unlike previous results, the humidity rises in all measurement points. In particular, we observe a humidity increase at sensor No. 1 by 2.4 times and 2.1 times at sensor No. 2, while at sensor No. 4 an increase in humidity values occurs gradually by 1.3 times. A maximum humidity value is recorded by sensors No. 3, 4, and 5, and a minimum value is recorded by sensors No. 1 and 2.

Fig.11 shows a change in humidity over time at 5 sensors placed at a height of 2.0 m from the floor.

According to data of sensors No. 4 and 5 we observe a rapid increase in humidity by 2.1 times to maximum values attaining 94% - 99%, after supplying fine spay to the CFS. At the sensor No. 3 the increase in humidity occurs by 1.8 times and at sensors No. 2 we have the gradual increase in humidity by 1.2 times. At sensor No. 1 the humidity actually was not changed, and the variation occurred by only 1%. The maximum humidity value was recorded by sensors No. 4 and 5, and the minimum value was recorded by sensors No. 1 and 2.

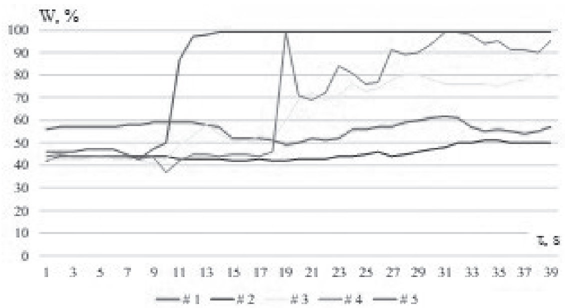

Figure 11. The humidity history by the sensors placed at a height of 2.0 m

Slika 11. Povijest vlažnosti mjerene senzorima postavljenim na visini od 2,0 m

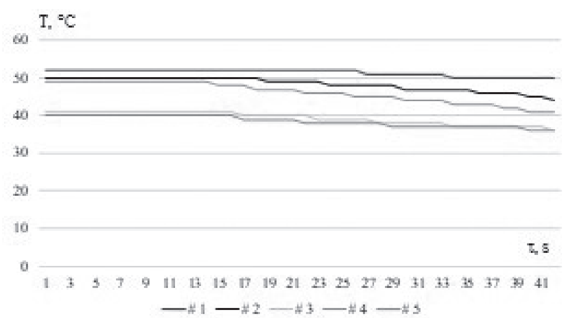

Figure 12. The temperature history by the sensors placed at a height of 1.0 m

Slika 12. Povijest temperature senzora postavljenih na visini od 1,0 m

Summing up the humidity measurement data, it can be noted that the humidity indicators acquire maximum values of 99% at sensors No. 3, 4 and 5. It means that a water mist is formed in the middle of the CFS and the mist occupies about 2/3 of the CFS. At sensors No. 1 and 2, a gradual increase in humidity values up to 66% was recorded. It is primarily due to the placement of the sensors near the entrance to the CFS. The supply of the fine spay into the middle and reaching the water jet the back side of the CFS cause increasing the concentration of water droplets in the water mist in this area. We assume that it is necessary to reduce the droplet size in the spray to have a uniform distribution of water droplets into the CFS.

Figures 12-14 show the results of temperature history in the CFS. So, in Figure 12, a decrease in temperature over time can be seen at 5 sensors located at a height of 1.0 m from the floor. So, a maximum change in temperature achieving 8 ºC was recorded by sensor No. 4, compared to other sensors. At sensors No. 2, 3 and 5, the temperature showed a decrease by 4 ºC, and at sensor No. 1 by 2 ºC, which is a minimum change in comparison to other changes in temperature.

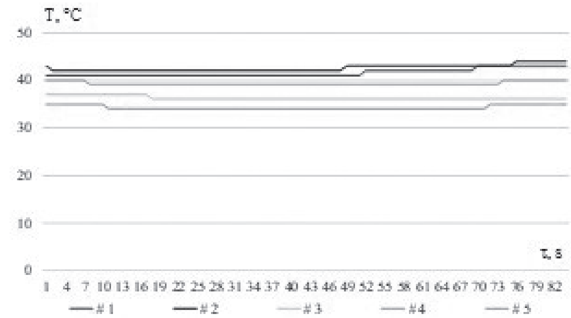

Figure 13. The temperature history by sensors placed at a height of 1.5 m

Slika 13. Povijest temperature pomoću senzora postavljenih na visini od 1,5 m

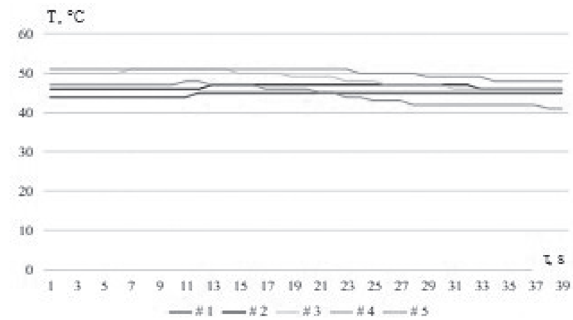

Figure 14. The temperature history by the sensors placed at a height of 2.0 m

Slika 14. Povijest temperature senzora postavljenih na visini od 2,0 m

Figure 13 shows a change in temperature over time at 5 sensors located at a height of 1.5 m from the floor. At sensors No. 4 and 5, the temperature is not changed after the supply of the fine spay to the CFS. While the temperature was 40 ºC on sensor No. 4 and 35 ºC at sensor No. 5. At sensor No. 3, a slight decrease in temperature by 1 ºCwas recorded. And at sensors No. 1 and 2, the temperature is slightly increased by 2 ºC at sensor No. 1 and by 1 ºC at sensor No. 2.

Figure 14 shows a change in temperature over time at 5 sensors located at a height of 2.0 m from the floor. At sensor No. 2, the temperature is not changed after the supply of the water jet to the CFS and it was 46 ºC. At sensor No. 1, the temperature increased slightly by 1 ºC, while at sensors No. 3, 4 and 5 a slight decrease in temperature was recorded, at sensor No. 3 by 4 ºC, at sensor No. 4 by 3 ºC and at sensor No. 5 by 6 ºC.

Summing up the results of temperature measurements, it can be noted that the temperature is decreased at all sensors when these are placed at a height of 1.0 m from the floor, in contrast to those placed at a height of 1.5 m and 2.0 m. When the sensors are placed at a height of 1.5 m, the temperature values are not changed by sensors No. 3, 4 and 5, located near the combustion center, while at sensors No. 1 and 2, located near the entrance to the CFS, the values are slightly increased, and the temperature values remain unchanged by sensors No. 1 and 2 unlike those at the sensors placed at a height of 2.0 m, and at sensors No. 3, 4 and 5, the values are gradually decreased. We think that a water mist is formed near the combustion center due to the direction of the fine spray into the middle of the CFS. As a result, the water mist occupies about 2/3 of the CFS, and at the entrance, the mist is mixed with fresh air, due to convective flows arising during the development of the fire. This explain an increase in gas temperature near the entrance, which we observe by sensors No. 1 and 2.

INVESTIGATION OF THE COMBINED FIRE NOZZEL PROTEK 366

Experimental setup and conditions

The studies involved supplying a water jet into a container fire simulator during the fire development, followed by measuring humidity and temperature.

The measurement system and experimental condition were similar to described above.

The fine spray is supplied from the Protek 366 nozzle by an operator standing at the entrance to the CFS on the left, with the door closed, except for the lower left part (Fig.15).

Figure 15. Supplying the fine spray from the Protek 366 nozzle inside the CFS

Slika 15. Dovod finog spreja iz mlaznice Protek 366 unutar CFS-a

The fine spray is supplied continuously for 30 s with a flow rate of 1.9 L/s.

Experimental results

Figures 16-18 show the humidity measurement data obtained in the CFS in case of an application of the combined fire nozzle Protek 366. Figure 16 shows the change in humidity over time at 5 sensors located at a height of 1.0 m from the floor. We observe a slight decrease in humidity at all 5 sensors after the supply fine spay to the CFS. A maximum downward change in humidity was recorded by sensor No. 2, which was 2%, at sensors No. 1, 3 and 4 the values were changed by 1%, and at sensor No. 5 there were no changes.

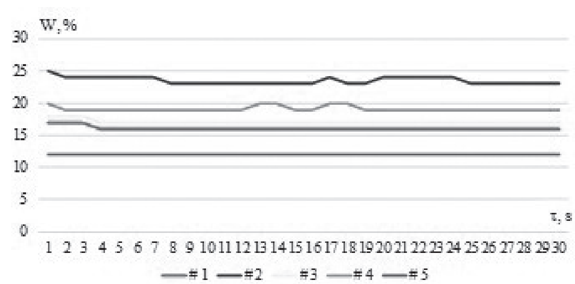

Figure 16. The humidity history by sensors placed at a height of 1.0 m

Slika 16. Povijest vlažnosti mjerene senzorima postavljenim na visini od 1,0 m

Figure 17 shows a change in humidity values over time at 5 sensors located at a height of 1.5 m from the floor. At sensors No. 3, 4 and 5, we observe a rapid increase in humidity after the supply of the water jet into the CFS.

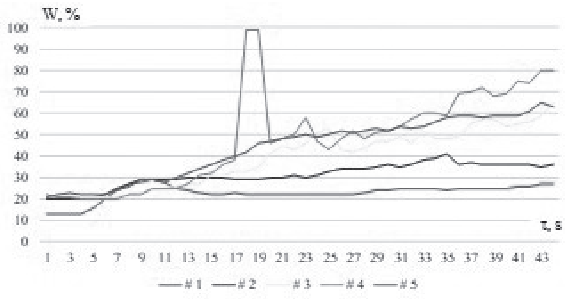

Figure 17. The humidity history by sensors placed at a height of 1.5 m

Slika 17. Povijest vlažnosti mjerene senzorima postavljenim na visini od 1,5 m

At sensors No. 1 and 2, the humidity was increased almost 2 times (sensor No. 1 by 2.1 times, and sensor No. 2 by 1.8 times) with a maximum value recorded by sensor No. 2, which is 36%, and sensor No.1 showed 27%.

Figure 18 shows a change in humidity over time at 5 sensors located at a height of 2.0 m from the floor. So, at sensors No. 1 and 2 we observe a decrease in humidity from 16% to 6%, i.e. 2.7 times after supplying a water jet to the CFS. The sensor No.2 shows a decrease in the humidity from 23% to 20%. Sensors No. 3, 4 and 5 show a slight increase in humidity on average by 2%, with the maximum humidity value being 19% (sensor No. 4) and the minimum humidity being 12% (sensor No. 5). In addition, we observe a significant increase in the humidity to 100% at sensor No. 5 for a short time. This is due to a drop of water settling on the sensor.

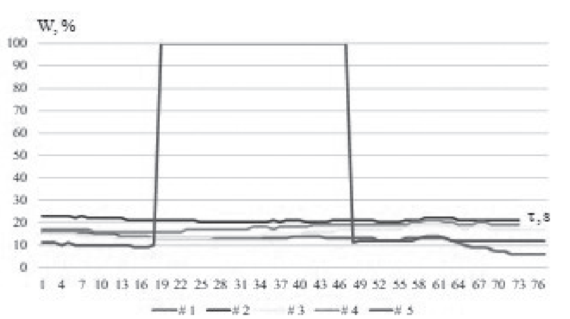

Figure 18. The humidity history by sensors placed at a height of 2.0 m

Slika 18. Povijest vlažnosti mjerene senzorima postavljenim na visini od 2,0 m

Summing up the humidity measurement, it can be noted that the humidity indicators acquire maximum values on sensors No. 3, 4, and 5, located at a height of 1.5 m from the floor, which are 65%, 80% and 63%, respectively, while sensors No. 1 and 2 show the minimum growth in the humidity to 27% and 36%, respectively. The humidity is practically not changed when the sensors are placed at a height of 1.0 m and 2.0 m after the supply of the water jet into the CFS. The tendency to a reduced humidity is observed by an average of 1–2 %, except for the sensor No. 1 at a height of 2.0 where the humidity value is decreased from 16% to 6%. At sensor No. 5, located near the combustion center, the humidity remains unchanged at heights of 1.0 m and 2.0 m where the humidity was about 11-12%. The obtained results indicate local effectiveness of the combined fire nozzle Protek 366.

Figures 19-21 show the temperature measurement data obtained in the CFS in case of an application of the combined fire nozzle Protek 366. Figure 19 shows an increase in temperature over time at 5 sensors located at a height of 1.0 m from the floor.

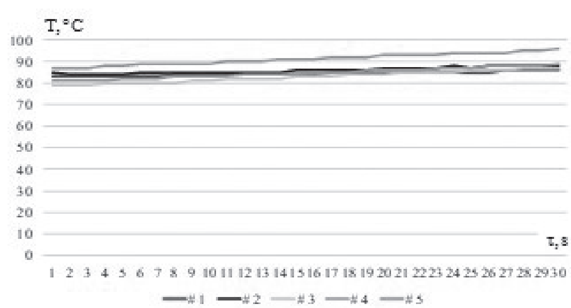

Figure 19. The temperature history by sensors placed at a height of 1.0 m

Slika 19. Povijest temperature pomoću senzora postavljenih na visini od 1,0 m

After the supply of the water jet in the CFS, an increase in temperature values by 3 ºC was recorded by sensors No. 1 and 2, and at sensors No. 3, 4, and 5, the temperature values increased by 8-9 ºC. At the same time, the maximum temperature value of 96 ºC was recorded by sensor No. 5, and the minimum value of 86 ºCwas recorded at sensor No. 1.

Figure 20 shows a change in temperature values over time at 5 sensors located at a height of 1.5 m from the floor. We observe that after the supply of the water jet into the CFS, a decrease in temperature is recorded at sensors No. 1, 2 and 5 by 2 ºC, and at sensors No. 3 and 4 by 3-4 ºC. At the same time, the maximum temperature value of 65 ºC was recorded by sensor No. 1 and the minimum value of 48 ºC was recorded by sensor No. 5.

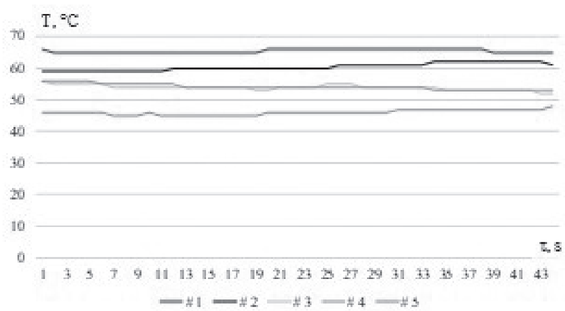

Figure 20. The temperature history by sensors placed at a height of 1.5 m

Slika 20. Povijest temperature pomoću senzora postavljenih na visini od 1,5 m

Figure 21 shows a change in temperature over time at 5 sensors located at a height of 2.0 m from the floor. We observe that after the supply of the water jet into CFS, a decrease in temperature values is recorded by sensors No. 1, 2 and 3, so at sensor No. 1 by 3 ºC, at sensor No. 2 by 4 ºC, at sensor No. 3 by 1 ºC. And at sensors No. 4 and 5, a slight increase in temperature by 1ºC was recorded. At the same time, the maximum temperature value of 102 ºC was recorded by sensor No. 5 after the supply of the water jet, and the minimum value of 86 ºC was recorded by sensor No. 1. In addition, we observe a significant increase in temperature to 128 ºC on sensor No. 5. We assume that a hot drop from a fire hit the sensor.

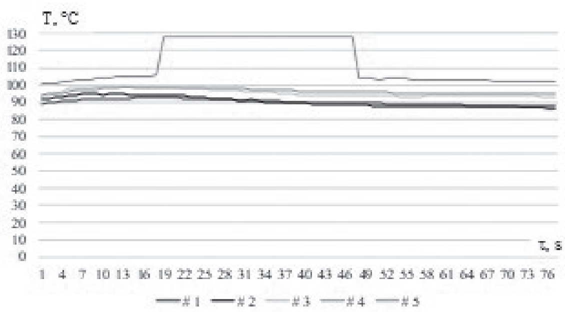

Figure 21. The temperature history by sensors placed at a height of 2.0 m

Slika 21. Povijest temperature pomoću senzora postavljenih na visini od 2,0 m

Summarizing the obtained temperature measurement data, it should be noted that the temperature in the CFS is increased on average by 6 ºC, with the sensors placed at a height of 1.0 m, and when the sensors are placed at a height of 1.5 m and 2.0 m, the temperature value is decreased for all sensors from 1 ºC to 4 ºC, except for sensor No. 5 that recorded an increase in temperature by 2 ºC. The maximum temperature value of 106 ºC was recorded by sensor No. 5 at a height of 2.0 m.

Temperature measurement results confirm the local firefighting effect of the water jet from the the combined fire nozzle Protek 366, but expressed correlations of measured values are weak and need further testing.

Discussing the research results

To compare the efficiency of firefighting systems, we analyzed the research data obtained for humidity and temperature sensors with the calculation of average finite differences in the humidity and temperature depending on the sensor placement height. If water got on the sensor, the humidity sensor showed the maximum value of 99%, before the supply of the water jet and the value recorded by this sensor was not taken into account.

Figures 22-23 show the plotted graphs with comparative characteristics of average finite differences in the humidity (ΔW) and temperature (ΔT), whereas the sign "+" indicates an increase in the indicator, and the sign "-" indicates a decrease in the indicator.

Figure 22 shows that the average finite difference in humidity is variable with changes of the sensor placement height. When the "ENEY" module was used, a significant increase in the humidity difference occurs at sensors located at different heights with a slight rise from 20.3% by the height of 1 m to 29.6% by the height of 2 m. When we used the Protek 366 nozzle, a significant increase in the humidity difference happened with the sensors placed at a height of 1.5 m only where the humidity difference attains 34.8%. It should be noted that both considered systems provided a water jet at a height of 1.5 m. It is also known that smaller droplets are more easily entrained by the air flow.

Therefore, we believe that the "ENEY" module creates an ultra-dispersed water jet, which allows water droplets to evenly fill the CFS. In contrast, the Protek 366 nozzle creates a low-dispersed water jet, which limits the spread of drops throughout the CFS.

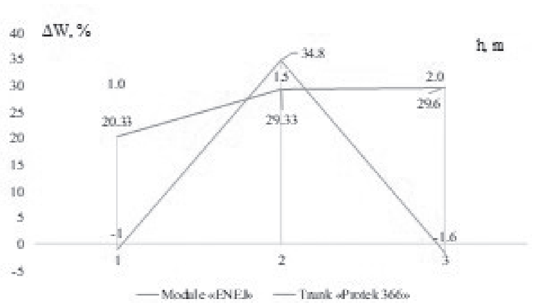

Figure 22. The average humidity difference at heights of 1.0 m, 1.5 m and 2.0 m by various firefighting systems

Slika 22. Prosječna razlika vlažnosti na visinama od 1,0 m, 1,5 m i 2,0 m kod različitih sustava za gašenje požara

The average finite difference in the gas temperature is presented in Figure 23.

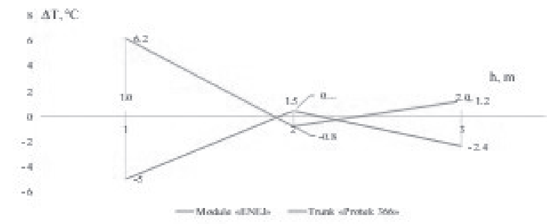

Figure 23. The average temperature difference at heights of 1.0 m, 1.5 m and 2.0 m by various firefighting systems

Slika 23. Prosječna temperaturna razlika na visinama od 1,0 m, 1,5 m i 2,0 m kod različitih sustava za gašenje požara

We observe that the temperature difference is small at heights of 1.5 m when the considered firefighting systems were applied. The gas cooling effect is observed at heights of 1 m and 2 m when the "ENEY" module was used. And a slight cooling effect took place by the fire nozzle Protek 366 at heights of 1.5 m only.

Summarizing data on the average finite differences in the humidity and temperature, we can conclude that the fire nozzle Protek 366 has a local firefighting effect in contrast to the "ENEY" module with the volume effect. These results correlate with the work *(Hamzehpour et al., 2024)*, where it was found that mist droplets spread more efficiently over a larger area than a water jet.

Based on the research data, we think that it is reasonable to use the "ENEY-10/30" module at the initial stage of firefighting to suppress the fire and reduce the temperature inside the container. The Protek 366 nozzle can be used then as an effective means for a direct firefighting attack.

It is obviously that for such dynamic phenomena, as fire extinguishing with water mist, a denser spatial (volumetric) network of sensors should be installed. That gives a better insight into the phenomenon itself and the spatial distribution of the measured quantities (humidity and temperature). The existing arrangement of sensors in one plane does restricts the possibility of high-quality processing of the results and making a relevant assessment of the extinguishing efficiency. We plan to improve the network of sensors in our future works.

CONCLUSION

A special measuring system was designed to evaluate the efficiency of the fine spray and water mist fire-fighting systems. The efficiency was estimated by an evaluation of temperature and humidity history at vari-ous points at a container based fire simulator during the firefighting systems application. DHT22 temperature and humidity sensors were used at the measuring system. The sensors were located at a distance of 1.5 m from each other at different heights of 1.0 m, 1.5 m and 2.0 m into the fire simulator. The obtained humidity and temperature values were processed in the form of graph using the laptop with WPS Office or Microsoft Office software.

The comparison of the efficiency of the fine spray and water mist firefighting systems applied for the interior fire attack was done. The two systems such as a high-pressure firefighting module "ENEY-10/30" and a combination fire nozzle Protek 366 connected to a rescue firefighting vehicle by a firehose were considered. It was found out that the fire nozzle Protek 366 has a local firefighting effect in contrast to the "ENEY" module with the volume effect. In particular, the average humidity in all space of the simulator increased by 20-29% when using the "ENEY" module, in contrast to the changes in humidity in the local region only at a height of 1.5 m with an increase in humidity of 34% when using the Protek 366 nozzle.

It has to note that for the reason of measurement accuracy, it would be better to install a denser spatial network of sensors, which would achieve stronger correlations between the measured values of humidity and temperature on the one hand and extinguishing efficiency on the other. We plan to use the designed measuring system with improved spatial network of sensors for a comparative investigation of new fine spray and water mist firefighting systems. We plan to add the dispersion measuring system to find out an influence of the water droplet size on the firefighting effect.

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ISPITIVANJE UČINKOVITOSTI GAŠENJA POŽARA FINIM MLAZOM I VODENOM MAGLICOM U ZATVORENIM PROSTORIMA

SAŽETAK: Članak se bavi eksperimentalnom usporedbom učinkovitosti finog mlaza i vodene maglice u gašenju požara u zatvorenim prostorima. Uspoređuju su dva sustava, visokotlačni modul "ENEY-10/30" i kombinirana mlaznica Protek 366 povezana s protupožarnim vozilom pomoću protupožarnog crijeva. Požar u zatvorenom prostoru ispitan je u kontejnerskom požarnom simulatoru. Izrađen je sustav mjerenja posebno osmišljen za evaluaciju učinkovitosti oba sustava. Tijekom ispitivanja mjerene su vlaga i temperatura na različitim mjestima u simulatoru. Senzori DHT22 za temperaturu i vlagu postavljeni su 1.5 m jedan od drugoga i to na visini od 1.0 m, 1.5 m i 2.0 m. Ponašanje vlage i temperature u vremenu praćeno je tijekom savladavanja požara. Temeljem dobivenih podataka utvrđeno je da je razumno koristiti modul "ENEY-10/30" u početnoj fazi gašenja kako bi se reducirao požar i snizila temperatura u kontejneru. Mlaznica Protek 366 može se zatim koristiti kao učinkovit način izravnog suzbijanja požara.

Ključne riječi: *požar, protupožarni sustav, vodena maglica, sustav mjerenja, gašenje požara u zatvorenom prostoru, temperatura, vlaga, sprej*

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