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Fire Extinguishing Efficiency of Compressed Air Foam, Water and Gel Forming Agents in a Standard Class A Test Fire

Porównanie skuteczności gaśniczej piany sprężonej, wody i związków żelotwórczych podczas gaszenia pożaru modelowego klasy A

ABSTRACT

Aim: The purpose of this article is to evaluate the extinguishing efficiency of water, compressed air foam and gel forming agents in solid materials fires.
Project and methods: Comparison of the efficiency of extinguishing water, gel forming agents and compressed air foam was performed by conducting an experimental study to determine the appropriate indicator. An experimental device of the compressed air foam system was used for the study. The model fire of class 1A was selected as the fire. Comparison of extinguishing compounds was evaluated by extinguishing efficiency indicator $I_{e.e.}$ There were two experiments, with three series in each.
Results: Extinguishing efficiency indicator $I_{e.e}$ took into account the time, and the mass of extinguishing agents needed to extinguish the model fire. Therefore, it was established that the mass of the compressed air foam used for extinguishing is 6.1 kg, which is 47% less than the mass of water used for extinguishing the test fire. With respect to the gel forming agent, the mass required for quenching was equal to 6.53 kg. This is 45% less than the weight of water and 2% less than the mass of compressed air foam. With respect to the quenching time, the greatest amount of time was observed for water. Time required for extinguishing (τ) amounted to 99 seconds. This value is 39% greater than the time it took to quench the flames using gel forming compounds, which was equal to 60 seconds. The minimum time required to extinguish the model fire (τ) was observed for compressed air foam, and was found to be 55 seconds. This is 45% less than that for water and 10% less than the time recorded for gel forming agent. Therefore, it was found that the fire extinguishing efficiency of compressed air foam is more than 80% higher than the water's, and 15% higher in relation to gel forming agents.
Conclusions: The authors analysed fire extinguishing agents that can be used to extinguish solid combustible substances. Experimental studies with standard model A fires let them to determine a quenching efficiency indicator $I_{e.e.}$ Compressed air foam was found to have the highest fire extinguishing efficiency compared to water and gel forming agents. The advantages of compressed foam are due to the technology of its formation. Such foam has a high cooling and insulating ability, which is well reflected in its fire extinguishing efficiency compared to other extinguishing agents.

Keywords: extinguishing efficiency, class A fire, water, CAF, gel
Type of article: original scientific article

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ABSTRAKT

Cel: Celem artykułu jest ocena skuteczności gaśniczej wody, piany sprężonej i związków żelotwórczych podczas gaszenia stałych substancji palnych.
Projekt i metody: Dokonano porównania skuteczności gaśniczej wody, związków żelotwórczych i piany sprężonej poprzez przeprowadzenie badań eksperymentalnych w celu ustalenia odpowiedniego wskaźnika. Do badań użyto eksperymentalnego urządzenia z pianą spreżoną. Wybrano pożar testowy klasy 1A. Porównanie środków gaśniczych oceniono na podstawie wskaźnika skuteczności gaszenia $I_{e.e.}$ Przeprowadzono dwa eksperymenty, po trzy serie w każdym z nich.
Wyniki: Wskaźnik skuteczności gaszenia uwzględniał czas i masę środka gaśniczego potrzebnego do ugaszenia pożaru modelowego. Ustalono, że masa piany sprężonej użytej do gaszenia wynosi 6,1 kg, co oznacza o 47% mniej niż masa wody użytej do gaszenia pożaru próbnego. W przypadku związków żelotwórczych wymagana masa wynosi 6,53 kg. Jest to o 45% mniej niż masa wody i 2% mniej niż masa piany spreżonej. Z badań wynika, że najwięcej czasu zajmuje gaszenie wodą. Obliczona dla niej wartość: τ = 99 sekund jest o 39% większa niż czas potrzebny do schłodzenia związków żelotwórczych, który wyniósł dla nich 60 sekund. Najkrótszy czas wymagany do gaszenia pożaru modelowego jest obserwowany dla piany sprężonej i wynosi 55 sekund.

Jest to o 45% mniej niż w przypadku wody i o 10% mniej w odniesieniu do związków żelotwórczych. Stwierdzono zatem, że skuteczność gaśnicza piany sprężonej jest większa o 80% w stosunku do wody i o 15% większa w odniesieniu do związków żelotwórczych.
Wnioski: Przeanalizowano środki gaśnicze, które można zastosować do gaszenia stałych substancji palnych. Badania eksperymentalne pozwoliły ustalić wskaźnik skuteczności gaszenia pożarow klasy A. Wynika z nich, że piana sprężona ma najwyższą zdolność gaśniczą w porównaniu do wody i związków żelotwórczych, co wynika z technologii jej powstawania. Taka piana ma wysoką zdolność chłodzenia i izolowania, co dobrze wpływa na jej skuteczność gaszenia.
Słowa kluczowe: skuteczność gaśnicza, pożar klasy A, ogień, woda, CAF, żel
Typ artykułu: oryginalny artykuł naukowy

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Introduction

Today, solids and materials are the most widespread in production, economy and everyday life [1]. In the conditions of extinguishing fires involving solid combustibles, water is the main extinguishing agent [2–4]. But despite its advantages, widespread application, ease of use and economic feasibility, only 5–10% of water is actually used to extinguish fires. In fact, the remaining 90–95% is excessively spilled, resulting in a significant loss of this precious resource [5]. The urgency of the problem of poor water use, along with the technological development and emergence of modern extinguishing agents, make it necessary to search for alternative and effective ways of extinguishing fires.

One of the modern methods that can be applied to extinguish solids more efficiently is to use gel forming agents that have several advantages over water [6–7]. According to an experimental study by O. V. Savchenko, O. O. Kiryeyev, and others [8] the efficiency of gel forming agents in the quenching of solids is 40% greater than that of water.

Also compressed air foam systems have become widespread. Compressed Air Foam (CAF) is a homogeneous, low-multipurpose foam obtained by mixing water, foam and air, or nitrogen under pressure [9–10]. Several authors have noted that CAF has the following advantages over traditional fire extinguishing agents and methods: CAF is highly structured, compact and consists of a large number of homogeneous single bubbles; the mass to surface ratio is favourable for intense heat transfer, resulting in a significant cooling effect; since CAF is formed by means of pressurized air, the use of energy from this pressure is sufficient to deliver it directly to the fire [11–18]. At the same time there is no evaporation of small droplets at the stage of delivery of the jet into the focus of the fire, which increases the coefficient of use of the extinguishing agent; CAF can be used to extinguish live electrical equipment; CAF may have an increased liquid phase composition that enhances the cooling effect, as well as high stickiness ability that allows it to be used for the fire protection of vertical surfaces; the absence of the liquid phase reduces direct damage during the extinguishing of fires in multi-storey buildings and in attics due to the lack of flooding of lower floors.

In their previous articles [19–20] the authors have conducted experimental studies to determine the effect of foam expansion ratio on its extinguishing properties, namely the effect of compressed foam expansion ratio on its dispersion and stability. They examined the change in the average diameter of foam bubbles in relation to the expansion ratio of foam. The stability of the compression foam was measured according to the methods described in standards [21–22]. The previously unknown dependencies for compressed foam, which has absolutely different properties than the foam formed by the air-mechanical method have been as follows:

– the higher expansion ratio of the foam, the greater its stability; the lowest foam stability is observed at the foam expansion ratio of 5 and equals to 4.5 minutes. Further increased foam expansion ratio values up to 12.5 are accompanied by an increase in the stability of 66% and equals to 13.16 minutes;
– with increasing the expansion ratio from 5 to 20, there is a maximum foam resistance of 21.83 min, a percentage increase in the stability of almost 80%;
– with increasing expansion ratio there is a decrease in the size of the foam bubble, which leads to an increase in the time of its existence, resulting in the formation of highly dispersed foam; increasing the expansion ratio of foam from 5 to 20 leads to a decrease in the diameter of the bubble by 15;
– with increasing foam expansion ratio, the uniformity increases, i.e. when determining the size range of foam bubbles with an expansion ratio of 12.5, the diameters of the bubbles were in the range of 0.09 mm to 0.13 mm, which is 66% less than the diameter range for foam expansion ratio of 5;
– the greatest uniformity of bubbles was observed for foam with the expansion ratio of 20, where the range of diameters varied from 0.09 mm to 0.11 mm;
– compared to the size difference of foam bubbles with an expansion ratio 6, the decrease was by 80%.

In respect to the extinguishing of solid combustibles, an experimental study was carried out by the authors in cooperation with A. I. Kodrik, O. M. Titenko [23–24] to determine the fire extinguishing efficiency of CAF, during the extinguishing of laboratory class A fires. The study used 3 foaming agent concentrations: 4%, 5% and 6%. It was determined that the expansion ratio of foam significantly affects the fire extinguishing efficiency. Thus, increasing the foam expansion ratio from 15 to 20 leads to the improvement of the quenching efficiency by 21%, whereas from 20 to 25 – by only 2%. However, the highest extinguishing efficiency was proved for a solution with a concentration of 6% foaming agent. On the basis of the results of the experiment, the fire extinguishing efficiency of the compressed foam was confirmed, as was the expediency of its use for the extinguishing of solid combustible substances in the form of laboratory class A fires.

X. Wang and colleagues conducted experimental studies on the effectiveness of extinguishing fires of solid fuels with prepared multicomponent foam premixes [25]. Fire extinguishing was carried out under various conditions, such as different foam concentrations or structure of the front of the mixing chamber and working pressure. It was found that the concentration of the foam had a sufficient influence on the effectiveness of firefighting, and there was an optimised concentration value. In case of solid combustible substances fires the working concentration of the foaming agent was about 4.0%. Increasing the working pressure in the system also had a positive effect on the extinguishing of the fire. Also the authors of a paper entitled *Experimental study on the performance of class A foam in extinguishing class A fires* conducted an experimental study to quantify the effectiveness of compressed foam in extinguishing class A fires of solid combustible substances [26]. The effect of the mixing ratio, expansion ratio, and some other parameters, on the quenching efficiency, which was compared with the characteristics of water, was examined. The results showed that the rate of extinguishing using commercial foam was 20% faster than when extinguishing with water. The best fire extinguishing effect was achieved with a mixing ratio in the range from 0.2% to 0.5% and a ratio in the range from 5 to 15. The study [27] was aimed at examining and comparing fire extinguishing efficiency of water, water with a wetting agent and compressed foam, when extinguishing standard fires of combustible substances. Its results show that compressed foam suppresses fire most effectively under test conditions.

Among extinguishing agents that can be used to supress class A fires, water, gel forming systems compounds and compressed foam have become widespread. However, there is not any known research comparing the extinguishing effectiveness of these agents. The purpose of this article is to conduct an experimental evaluation of the extinguishing efficiency of water, CAF and gel forming agents in terms of the numerical indicator of their extinguishing ability for solid fires, and to compare them with one another.

The methodology of the experiment

Comparison of the extinguishing efficiency of water, gel forming agents and CAF was performed by conducting an experimental study to determine the appropriate indicator.

Due to the fact that gel forming agents, water and compression foam are different substances, it is difficult to apply the same intensity to them. Therefore, in order to be able to compare the results obtained for these substances, the authors used the extinguishing efficiency index $I_{e.e}$, which takes into account the amount of substance applied for a certain time per unit area of the model fire. Thus, the numerical value of the extinguishing efficiency of different substances can be compared, even if they are applied to different intensities.

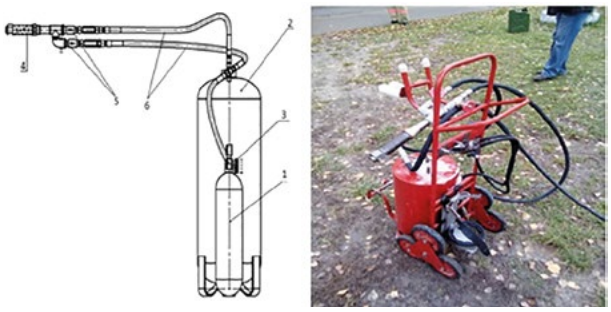
Comparison of extinguishing compositions was estimated by extinguishing efficiency indicator $I_{e.e}$ according to the already mentioned publications [2], [4]. The quenching efficiency was calculated using the formula:

$$I_{e.e} = \frac{S_f}{G_{e.a}\tau} \qquad (1)$$

where:
S_f – fire area
$G_{e.a}$ = total amount of extinguishing agent, used during τ.

The amount of substance used $G_{e.a}$ is equal to the mass of the substance used for extinguishing $_{ma}$, hence in the subsequent calculations the value $_{ma}$ was used.

An experimental device of the compressed foam feed system was used for the study [28]. Figure 1 shows a diagram (a) and a photo (b) of the experimental device.



(a) (b)

Figure 1. Scheme „a" and photo „b" of the experimental device of compressed air foam system: 1 – container for solution of foaming agent; 2 – compressed air balloon or compressor; 3 – gas reducer for regulation of pressure and consumption of air; 4 – the original foam mixer; 5 – regulating valves for the flow rate of the foam premix and air; 6 – pipelines for supplying a solution of foaming agent and compressed air

Source: S. M. Shahov, *Rozrobka eksperimentalnoyi ustanovki dlya provedennya doslidzhen vlastivostej kompresijnoyi pini, Problemi ta perspektivi zabezpechennya civilnogo zahistu*, Sbirnik tez dopovidej Mizhnar. nauk-prakt. konf., Harkiv, 2019, 185 [26].

An experimental study to determine the fire extinguishing efficiency of gel forming agents during the quenching of standard class 1A fires has been already conducted by O. O. Kireev and Y. V. Savchenko [8].

Therefore, for further comparison of extinguishing compositions the authors selected a model fire class 1A, which was a wooden pile of ordinary pine with 72 bars (40 × 40 mm) section and a length of 500 mm, enclosed in six rows. Moisture of pine timber was 10%. The total open area of the model fire was 5.99 m^2. The area, taking into account the overlap of the bars in the assembled state, was 4.7 m^2.

In the above-mentioned paper by O. V. Savchenko et al., the most effective gel forming agent for extinguishing solids was established [8]. The time spent on extinguishing the standard 1A test fire was 60 s, and the mass of gel forming agents constituted 6.53 kg. The results obtained has been sufficient to carry out the calculation and numerical expression of the gel forming agents extinguishing efficiency, in a form of a quenching efficiency $I_{e.e}$ indicator. Therefore, the experiment of extinguishing the standard class 1A model fire with gel forming agent was not conducted.

During the comparison of water and compressed foam, the study reproduced conditions that repeated the circumstances of the previous experiment [8] to determine the fire extinguishing efficiency of gel forming compositions.

The conditions of the experiment were in accordance with the standard [29, p. 33]. The tests were conducted in the open air at a wind speed of 1÷2 m/s, the air temperature was 100°C. A portable platform was installed at the designated location. Metal posts made of steel corners were used as supports. Next, a pile of firewood was stacked at the racks. The distance from the platform to the base of the stack was (400 ± 10) mm. Subsequently, a 400 mm × 400 mm × 100 mm metal deck was introduced under the stack. The deck was installed horizontally, the bottom was covered with a layer of water 30 mm thick, 1.1 litres of A-92 gasoline was filled to it.

Figure 2 shows a photo of a model fire at the beginning of the combustion and after a certain time of free combustion. The fuel in the deck was set on fire, after burning (120–160 s), the deck was removed from under the stack. The ignition time of the model fire was approximately ~7 minutes.

(a) (b)

Figure 2. Photo of the model standard fire: a) the beginning of burning, b) burning after 7 minutes

Source: Authors' own archives.

Figure 3 presents the process of extinguishing the model fire with: a) water, b) compressed air foam. The extinguishing of the fire complied with the requirements of DSTU (State standard of Ukraine) 3675-98. After burning 45% of the mass of the stack, (400–440 s with free combustion), extinguishing began.

(a)

(b)

Figure 3. Fire extinguishing process with: a) water, b) with the use of the experimental system for supplying compressed air foam

Source: Authors' own archives.

According to DSTU 3675-98, after extinguishing, a model fire was observed for 10 minutes for reignition. If it did not occur, the model fire was considered extinguished.

Figure 4 shows photos of model fires after extinguishing with a) water, b) compressed air foam.

(a)

(b)

Figure 4. Photo of the model fire after extinguishing with a) water, b) compressed air foam

Source: Authors' own archives.

The mass of the extinguishing agent m_a was determined by weighing the container with the extinguishing agent before extinguishing and after complete elimination of the flames at the model site. The time τ was fixed from the beginning of the direction of the extinguishing jet towards the centre of the fire, until the moment of complete extinguishing. There were 2 experiments, 3 series in each. The average mass of the extinguishing composition and the time to extinguishing were then calculated.

Results of experimental studies

Summarised results of the experiment are given in Table 1.

Based on the experimental data obtained and the results of the study by O. V. Savchenko et al., Ie.e quenching performance for water, compressed air foam, and gel forming compounds was calculated [8]. The results of the calculations are given in Table 2.

Table 2. Calculated $I_{e.e}$ data for different fire extinguishing compositions

Extinguishing agent	$I_{e.e} \times 10^{-3}, \frac{m^2}{kg \times s}$
Water	4.12
Gel forming agents	11.9
CAF	14

Source: Own elaboration.

Discussion of results

Figure 5 shows a graph of the mass of extinguishing agents required to extinguish the class 1 A model fire.

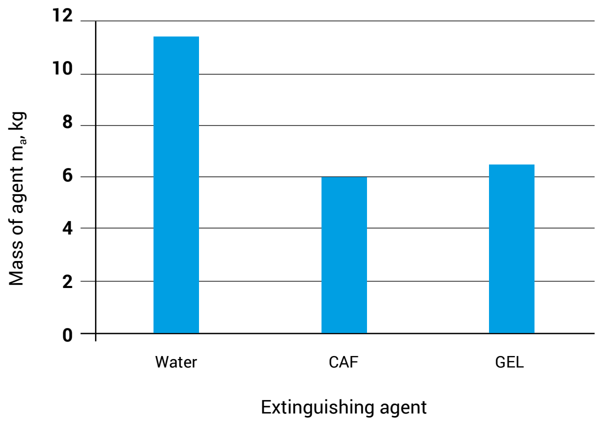


Figure 5. The mass of water, gel forming agents, and compressed air foam required for extinguishing class A fires

Source: Own elaboration.

The mass of CAF used for extinguishing is m_a= 6.1 kg, which is 47% less than the mass of water used for extinguishing the model fire. With respect to the gel forming agents, the mass required for quenching was m_a= 6.53 kg. This is 45% less than the weight of water and 2% more than the mass of compressed air foam.

Table 1. Results of the extinguishing of class A fire with water and compressed air foam

Extinguishing agent	Mass of agent m_a, [kg]				Extinguishing time τ, [s]				S, [m²]
	1	2	3		1	2	3		
	m_1	m_2	m_3		$τ_1$	$τ_2$	$τ_3$		
Water	10.3	13.2	11	11.55	105	97	95	99	4.7
CAF	5.8	6.5	6	6.1	63	52	50	55	
Gel forming agents	6.53				60				

Source: Own elaboration.

Figure 6 is a graph showing the amount of time it takes to extinguish a class 1A model fire.

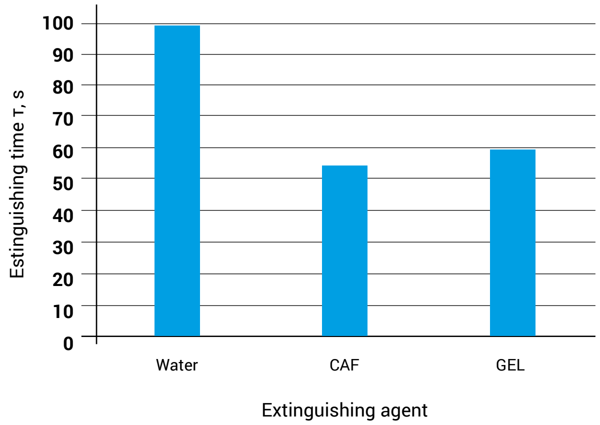


Figure 6. Amount of time required to extinguish a Class A fire with water, gel forming agents and compressed air foam

Source: Own elaboration.

Based on the graph data (Fig. 6), the largest amount of time to extinguish the model fire is required for water. It constituted 99 seconds. This value is 39% greater than the time it took to quench the flames using gel forming agents (τ = 60 seconds). The minimum time required to extinguish model fire was observed for compressed foam and was equal to 55 seconds. This is 45% less than for water, and 10% less than the time to for gel forming compounds.

Figure 7 shows a graphical comparison of $I_{e.e}$ quenching performance for water, compressed air foam and gel extinguishing agents.

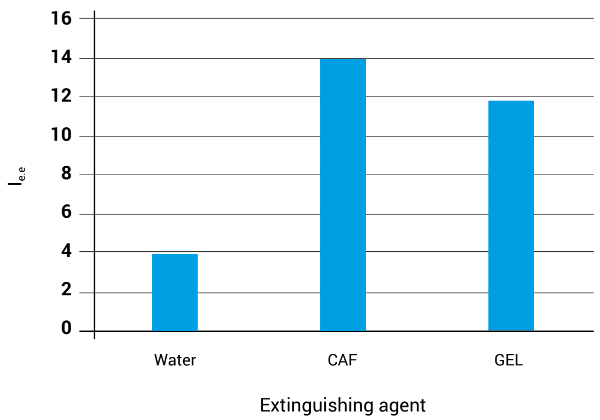


Figure 7. Graphic representation of the $I_{e.e}$ quenching performance for water, gel forming agents, and compressed air foam

Source: Own elaboration.

By analysing the graph (Fig. 7) it can be stated that the highest extinguishing ability in terms of quenching efficiency $_{Ie.e}$ was observed for compressed air foam, and its numerical value is $I_{e.e} = 14 \times 10{-}3 \frac{m^2}{kg \times s}$. Based on the graph, the fire extinguishing efficiency of compressed air foam is greater than that of water by 80% and greater than that of gel forming agents by 15%.

The advantages of compressed air foam over water and gel forming agents are due to the technology of its formation. During the process of its generation, a large number of homogeneous bubbles of small size are formed. This leads to the formation of a homogeneous fine foam, which makes it more stable. Such foam has a high cooling and insulating ability, which is well reflected in its fire extinguishing efficiency compared to other extinguishing agents.

Conclusions

The authors analysed the use of extinguishing agents for extinguishing fires of solid combustible substances. The main fire extinguishing substances that can be used for extinguishing class A fires were identified. An experimental study to extinguish standard model fires 1A with water and compressed air foam was conducted. The study compared the extinguishing efficiency of water, compressed air foam and gel forming agents, which was numerically evaluated by the $I_{e.e}$. During extinguishing of the model fire with water, the value of the quenching efficiency index was $I_{e.e} = 4{,}12 \times 10{-}3 \frac{m^2}{kg \times s}$, but after extinguishing the model hearth, after 5 minutes there was a reignition. The indicator for the gel forming agents was $I_{e.e} = 11{,}9 \times 10{-}3 \frac{m^2}{kg \times s}$, which is 65% more than the extinguishing efficiency of water. The highest extinguishing efficiency in terms of quenching efficiency was observed for compressed foam and was $I_{e.e} = 14 \times 10{-}3 \frac{m^2}{kg \times s}$, which is 80% more than water and 15% more than gel forming agents.

Therefore, this experimental study made it possible to establish the most effective extinguishing agent for the extinguishing of solid combustible substances. In terms of quenching efficiency, compressed air foam has the highest fire extinguishing capacity compared to water and gel forming agents.

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