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NUMERICAL STUDIES OF THE BREAKUP OF THE WATER JET BY A SHOCK WAVE IN THE BARREL OF THE FIRE EXTINGUISHING INSTALLATION

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SUMMARY: This scientific paper delves into the numerical studies of the process of filling the barrel with water and the subsequent breakup of the water jet and water atomization in the barrel of the fire extinguishing installation. The numerical model of the process of water injection into the barrel with the subsequent breakup of water by a shock wave was substantiated. To simulate these processes, the ANSYS software was used. VOF (volume of fluid) method-based model was applied where it is assumed that there is no penetration of one medium into another. The solution is based on the surface tracking method applied to a fixed Eulerian grid. According to the results of the numerical study, it was established that the water injection time significantly exceeds the duration of the gas detonation cycle in the fire extinguishing installation. In particular, we found out that it takes 8 ms just to spread the water jet from one side of the barrel to the other. It was observed that a high quality of water atomization under the action of a high-speed gas flow including the water located along the barrel wall. We stated that it is unreasonable to use the pulse injection of water into the barrel in the designed fire extinguishing installation due to a high fregiency of the shock wave generation exceeding 23 Hz.

Key words: *numerical model, finely atomized water, and fire-extinguishing installation, breakup of water by a shock waves*

INTRODUCTION

Today, water is the most common fire extinguishing agent *(Eisenberg, Kauzmann, 2005)* used for fire-fighting *(Pospelov et al., 2021)*. Fires occur in a variety of places and these can be divided into external and internal fires. The first type of fires takes place in open space, the second occurs in the places that have physical boundaries, such as apartments, houses, other buildings, installations, technological lines and the structures of a similar type *(Bielicki, 2004)*. Ecological consequences of fires result in the pollution of air *(Sadkovyi et al., 2020, Pospelov et al., 2019, 2020, Vambol et al., 2017)* with carbon dioxide, products of incomplete combustion, pyrolysis (thermal decomposition) of synthetic *(Dubinin et al., 2023)* and organic *(Dubinin et al., 2020, 2023)* substances and materials. And fire-extinguishing substances, such as powders, refrigerants, have a negative effect on the environmental ecology, including water resources *(Rybalova et al., 2018, Loboichenko et al., 2017)*. Special attention should be paid to the effect of dangerous fire factors and dangerous fire extinguishing

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substances on human life and health *(Dubinin et al., 2020, 2022)*.

At the same time, water, as a fire-extinguishing agent, is characterized by a high specific heat capacity, latent heat of vaporization, and it is chemically inert to most substances and materials, and it is also cheap, ecologically friendly and affordable. The greatest fire-extinguishing effect is achieved when fluid is supplied in the form of finely-dispersed water (hereinafter referred to as FAW); *(Karki, Rao, 2023, Tanaka, Kato, 2023)*. FAW is characterized by a small impact force and a range of firefighting actions. But FAW irrigates a large surface or fills the entire space of the room. The FAW supply creates the most favorable conditions for its evaporation, while the cooling effect is increased and the combustible medium is diluted with non-combustible steam. It is known that with the same intensity of water supply for cooling metal structures, the total coefficient of heat transfer in the case of the use of FAW is 2–3 times higher than that of cooling with a water jet *(Sadkovyi, 2021)*. An increase in the cooling effect of water is conditioned by an increase in the heat dissipation due to the enlargement of the total surface of the droplets through which the heat transfer occurs, in comparison to that of a compact jet. The use of FAW provides a decrease in water consumption for fire extinguishing by 5 to 10 times, and secondary losses due to the flooding of buildings *(Korytchenko et al., 2018, Handbook..., 2016)*. Taking into account the above, it is advisable to use finely-dispersed water for extinguishing internal and external fires *(Pancawardani, 2017, Li et al., 2019)*, flammable and combustible liquids *(Abramov et al., 2018)*, house electrical installations *(Vambol et al., 2017)*, as well as for lowering the temperature in rooms, and as radiant barrier (water curtains) for cooling the heated surfaces of construction structures *(Otrosh et al., 2019)* and installations, as well as for the settling of smoke and radioactive substances *(Kustov et al., 2019)*.

The parameters of technical means used for generating FAW influence on FAW fire extinguishing effectiveness. So, the dispersion of finely-dispersed water droplets is a determining fire extinguishing parameter that should be within 100–150 μm. Accordingly, the development and improvement of technical means for FAW generation and delivery is an urgent task. For example, in papers *(Semko et al., 2014, 2015)*, the authors proposed to use a powder hydrogrenade for extinguishing gas fountains. The principle of the hydrogrenade operation is implemented due to the supply of pulsed high-speed water jets. For use, it is necessary to have a gunpowder charge and a fire extinguishing agent (water). This device meets, first of all, the requirements regarding the dispersion of water droplets, but it does not satisfy the requirements regarding the fire-fighting productivity and safety of the operator.

In paper Shrigondekar et al. *(2021)*, the authors investigated the effectiveness of the FAW system for fire extinguishing in small containers. FAW injection was realized using water nozzles symmetrically arranged in different points around the edges of the laboratory installation (container). At this research the variable parameters were the diameter of the nozzle opening, the number and position of the nozzles, and the injection pressure. The FAW system shows a high level of efficiency. But the main disadvantage of this system is that feeding through nozzles requires the use of filtered water due to the small size of nozzle holes. And this primarily complicates practical implementation of the considered system.

In Poplavski et al. *(2020)*, the authors carried out experimental studies and numerical modeling of the interaction of a drop of water with a shock wave. The numerical approach was based on the use of the method of the volume of fluid (VOF) to determine the phase boundary, and the large eddy simulation (LES) to describe the turbulence and also an adapted dynamic grid. The structure of the flow was considered near and behind the droplets, and also the features of the flow around the droplet, the type of evolution of the droplet shape and the nature of mass transfer. However, the issue of dispersion of water droplets was not considered in the studies.

In paper Petrel *(2017)*, a study was conducted on the interaction between streams of water droplets and smoke during a fire in a closed and ventilated room. The investigated parameter was the fire heat release rate when the water supply was varied from 50 to 124 l/min. It should be noted that a rise in the water consumption rate from 50 to 124 l/min results in an increase of the collateral damage due to flooding of premises with excess water. That is impractical for use in residential buildings.

In paper Prasad et al. *(2002)*, numerical studies of extinguishing large-scale fires in compartments by FAW were carried out. The consideration of two discrete phases is used, in which the gas phase and the FAW are described by Euler equations. The FAW model is combined with pre-developed codes based on the Chimera grid embedding technique to simulate fires. At the same time, it should be noted that the numerical model does not take into account the technical means that generate the FAW, it only takes into account the process of filling and FAW distribution in the room.

In paper Dubinin et al. *(2018)*, a number of experimental studies were carried out using the periodic pulsed installation (hereinafter - fire extinguishing installation) presented in Figure 1.

This installation provides the water breakuk and atomization in the barrel under the periodic action of shock waves. The principle of operation and operating parameters of the fire extinguishing installation are considered detailly in Korytchenko et al. *(2018, 2019, 2020, Kasimov et al., 2018)*. In addition, the gas detonation technology when using the installation is also considered in the scientific papers devoted to aluminum oxide coating *(Korytchenko et al., 2020)*, application of fireproof coating *(Korytchenko et al., 2021)* and generation of combustible charges *(Dubinin et al., 2017)*. Breakup of water and atomization by a shock wave is one of the promising methods to effectively generate FAW.

Figure 1. Fire extinguishing installation of a periodic pulsed action

Slika 1. Instalacija za gašenje požara periodičnog impulsnog djelovanja

The purpose of this research is to carry out a numerical study of injection processes with further breakup of water in the barrel of the pulsed fire extinguishing installation, described in *(Korytchenko et al., 2018, Dubinin et al., 2018)*, for further optimization of the operation parameters of the installation.

MATERIALS AND METHODS

The pressure-basic method was used for numerical modeling of the process of water injection to the barrel of the pulsed fire extinguishing installation with breakup of its in the barrel by a shock wave. The calculation was carried out using the ANSYS software. The time of water injection and a duration of breakup of water in the barrel by a shock wave were avaluated to chose a pulsed or continuous regime of the water injection.

RESULTS AND DISCUSSION

Formulation of the problem of breakup of water by a shock wave in the barrel of a fire extinguishing installation

The process of the FAW formation was studied under conditions similar to those of breakup of fire extinguishing agents in a pulsed fire extinguishing installation. Accordingly, the process of the FAW formation took place in the barrel of the fire extinguishing installation with a diameter of 20 mm (Figure 2).

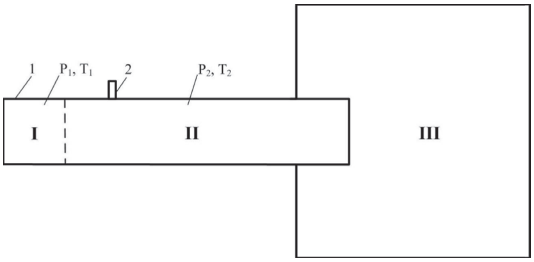

Figure 2. Diagram of the statement of the research problem: 1 is the barrel (pipe) d = 20 mm; 2 is the water supply hole, d = 2 mm; I is the domain of high gas pressure; II is the domain of low gas pressure; III is the chamber

Slika 2. Dijagram tvrdnje problema istraživanja: 1 je bačva (cijev) d = 20 mm; 2 je otvor za dovod vode, d = 2 mm; I je domena visokog tlaka plina; II je područje niskog tlaka plina; III je komora

The task was subdivided into two subtasks, in particular filling the barrel with water and studying the effect of the shock wave on the stream of water in the barrel. According to the first half-task, water was fed into the barrel through a hole with a diameter of 2 mm for 60 ms. This duration of water supply corresponds to the time difference between the detonation pulses of the designed installation.

The water was supplied at a distance of 100 mm from the closed end of the barrel (area of shock wave generation) and 300 mm from the open end of the barrel. The open end of the barrel was located in a chamber with a diameter of 150 mm and a length of 250 mm. The barrel entered the chamber to a depth of 60 mm. After the barrel was partially filled with water, a shock wave was generated in the barrel. To create a shock wave in the simulation region I, the availability of compressed gas was preset. The initial gas pressure in region I was 1.9 MPa, and its temperature was 300 K. The length of this region was 600 mm. In region II, the gas had a pressure of 101.3 kPa and a temperature of 293 K under the initial conditions of the second stage of simulation. The length of this barrel section was 400 mm. According to the second half-task, the formation of a shock wave occurred as a result of the development of gas-dynamic processes. This process corresponds to the origination of a shock wave in the shock barrel. The outlet of the barrel was connected to chamber 2. The size of chamber III was 250×150×150 mm^3. The size of the chamber was determined based on the range of action of the FAW jet outcoming from the barrel.

The pressure and temperature in region I (Figure 2) were determined based on the state of gas detonation products in the fire extinguishing installation. In particular, in the case of combustion of a stoichiometric mixture of propane and air in a closed volume at the initial atmospheric pressure of the gas mixture, we observe an increase in gas pressure in the combustion products of up to 0.9 MPa. At the same time, the temperature of the combustion products reaches 2200 K *(Bheekhun et al., 2014)*. Gas compression in the detonation barrel of the installation results in an increase in the initial gas density by 2 to 2.5 times. As a result, the average pressure in detonation products is increased to 2 MPa *(Korytchenko et al, 2023)*.

During the filling of the barrel with water, it was assumed that there were no external air disturbances in the barrel (the velocity of the gas flow at the barrel input and output is zero). It was assumed that the barrel is located parallel to the earth's surface, that is, the force of gravity is directed perpendicular to the axis of the barrel. Water is supplied from the hole located on top of the barrel.

Numerical model of breakup of water in the barrel of the fire extinguishing installation

The ANSYS software allows us to calculate the two-phase flow under the considered conditions. The calculation was carried out separately in relation to the process of filling the barrel with water and in relation to the breakup of water by a shock wave. To study these processes, the VOF model (volume of fluid methodl) was used, according to which there is no penetration of one medium into another. This model is based on the surface tracking method applied to a fixed Eulerian grid. The VOF model uses a single set of momentum equations for fluids, and the volume fraction of each fluid in each computational cell is tracked over the entire domain. The field of application of the VOF model includes, inter alia, filling a gaseous medium with liquid and prediction of the disintegration of a liquid jet in a gaseous medium.

The continuity equation for the volume fraction of each phase (gas/liquid) takes the form:

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}\left(\alpha_q\rho_q\right)+\nabla\cdot\left(\alpha_q\rho_q\vec{v}_q\right)\right]= = S_{\alpha_q}+\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right), \qquad [1]$$

where $\dot{m}_{pq}$ is the mass transfer from phase q to phase p; $\dot{m}_{qp}$ is the mass transfer from phase p to phase q; α_q is the volume fraction of the q^{th} phase; ρ_q is the density of the q^{th} phase; t is the time; S_{α_q} is the source term of the mass; and $\vec{v}_q$ is the speed of the q^{th} phase.

The volume fraction of the primary phase was calculated based on the following constraint:

$$\sum_{q=1}^{n}\alpha_q=1 \quad . \qquad [2]$$

The volume fraction of the phase was determined based on the implicit time discretization scheme using the equation:

$$\frac{\alpha_q^{n+1}\rho_q^{n+1}-\alpha_q^n\rho_q^n}{\Delta t}V+\sum_f\left(\rho_q^{n+1}U_f^{n+1}\alpha_{q,f}^{n+1}\right)= =\left[S_{\alpha_q}+\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right)\right]V \quad [3]$$

where n is the index for the previous time step; $n+1$ is the index for the next time step; $\alpha_{q,f}$ is the face value of the volume fraction of the q^{th} phase ; V is the volume of the computational cell; and U_f is the volumetric flow through the surface under the normal speed.

The averaged fluid density was derived from the equation:

$$\rho=\sum\alpha_q\rho_q. \quad [4]$$

The equation of the quantity of motion is expressed as:

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla\cdot(\rho\vec{v}\vec{v})=-\nabla\rho+ +\nabla\cdot\left[\mu\left(\nabla\vec{v}+\nabla\vec{v}^T\right)\right]+\rho\vec{g}+\vec{F}, \quad 5]$$

Where p is the pressure; μ is the molar mass; g is the gravitational constant; and $\vec{F}$ is the pulse source term.

The energy equation is expressed as:

$$\frac{\partial}{\partial t}(\rho E)+\nabla\cdot\left(\vec{v}(\rho E+p)\right)=\nabla\cdot\left(k_{eff}\nabla T\right)+S_h, \quad [6]$$

Where E is the averaged value of energy; T is the averaged temperature; S_h is the energy source term; and k_{eff} is the coefficient of the effective thermal conductivity.

In this case, the averaged energy is derived from the equation:

$$E=\frac{\sum_{q=1}^{n}\alpha_q\rho_qE_q}{\sum_{q=1}^{n}\alpha_q\rho_q}. \quad [7]$$

The viscosity of the liquid was calculated using the model of turbulence with the shear stress transfer (SST k-ω Menter model), which allows us to study also the transient shock wave that is formed under the given conditions of the study. The model contains a refinement of the mass transfer equation [1], to which the components of turbulent kinetic energy and effective diffusion are added. The mass transfer equation according to the SST k-ω model has the form similar to that of the standard k-ω model:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\Gamma_k\frac{\partial k}{\partial x_j}\right]+ +G_k-Y_k+S_k, \quad [8]$$

and

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_j}(\rho\omega u_j)=\frac{\partial}{\partial x_j}\left[\Gamma_\omega\frac{\partial\omega}{\partial x_j}\right]+ +G_\omega-Y_\omega+D_\omega+S_\omega, \quad [9]$$

where G_k is the component of kinetic energy reproduction; G_ω is the generation component ω; Γ_k and Γ_ω are the components of the effective k and ω diffusion; Y_k and Y_ω are the components of k and ω dissipation caused by turbulence; D_ω is the cross-diffusion coefficient; and S_k and S_ω are source components.

$$\Gamma_k=\mu+\frac{\mu_t}{\sigma_k}, \quad 10]$$

$$\Gamma_\omega=\mu+\frac{\mu_t}{\sigma_\omega}, \quad [11]$$

where σ_k and σ_ω are turbulent Prandtl numbers for k and ω, respectively.

Turbulent viscosity μ_t is calculated as follows:

$$\mu_t=\frac{\rho k}{\omega}\frac{1}{\max\left[\frac{1}{a^*},\frac{SF_2}{a_1\omega}\right]}, \quad 12]$$

where S is the value of the deformation rate.

$$\sigma_k=\frac{1}{F_1/\sigma_{k,1}+(1-F_1)/\sigma_{k,2}}, \quad [13]$$

$$\sigma_\omega=\frac{1}{F_1/\sigma_{\omega,1}+(1-F_1)/\sigma_{\omega,2}}, \quad [14]$$

$$F_1=\tanh\left(\Phi_1^4\right), \quad [15]$$

$$\Phi_1=\min\left[\max\left(\frac{\sqrt{k}}{0,09\omega y},\frac{500\mu}{\rho y^2\omega}\right),\frac{4\rho k}{\sigma_{\omega,2}D_\omega^+y^2}\right], \quad [16]$$

$$D_{\omega}^{+} = \max\left[2\rho\frac{1}{\sigma_{\omega,2}}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}, 10^{-10}\right], [17]$$

$$F_2 = \tanh\left(\Phi_2^2\right), \quad 18]$$

$$\Phi_2 = \max\left[2\frac{\sqrt{k}}{0,09\omega y}, \frac{500\mu}{\rho y^2 \omega}\right], \quad [19]$$

The system of equations was calculated using the pressure-basic method in the Lagrangian coordinate system.

Results of a numerical study of the process of filling the barrel of the fire extinguishing installation with water.

The display of the process of filling the barrel with water is monitored by a change in the volume fraction of water in the two-phase gas-liquid mixture. The calculation data are given in (Fig. 3–5).

The color scale of the volume fraction of water from 0 (0%) to 1 (100%) is displayed on the left side in the Figures. We observe the beginning of water injection into the barrel of the fire extinguishing installation (Figure 3).

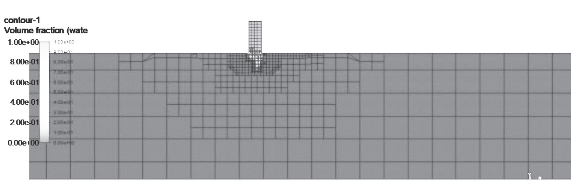

Figure 3. Distribution of the volume fraction of water in the calculation domain for the time of 1ms

Slika 3. Raspodjela volumnog udjela vode u računskom području za vrijeme od 1ms

Based on the calculated interval between the start of water injection and its reaching the opposite end of the barrel, which is equal to 8 ms, and a distance equal to the diameter of the barrel of 20 mm, we have the speed of spreading of the water stream equal to 2.5 m/s.

Based on the data of experimental studies in *(Parham et al., 2011)*, it was found that the speed of the water jet in the nozzle reaches about 10 m/s at high injection pressure. Hence, the obtained results coincide in their order of magnitude, which confirms their reliability.

Stopping water injection into the barrel is reflected by the zero volume concentration of water in the injection tube (Figure 4). We also observe the spread of water along the lower wall of the barrel.

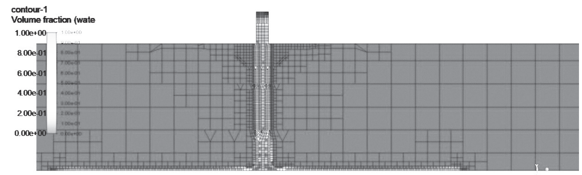

Figure 4. Distribution of the volume portion of water in the calculation domain for the time period of 60 ms

Slika 4. Raspodjela volumnog udjela vode u području proračuna za razdoblje od 60 ms

We observe that throughout the period of more than 60 ms after the disintegration of the water stream, the water remains on the lower wall of the barrel in an almost unchanged state (Fig. 5).

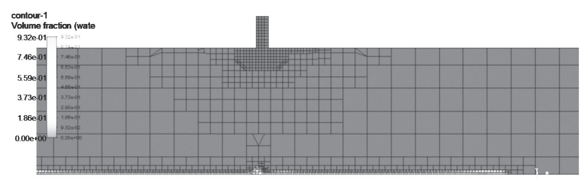

Figure 5. Distribution of the volume portion of water in the calculation domain for the time period of 140 ms

Slika 5. Raspodjela volumnog udjela vode u računskom području za razdoblje od 140 ms

The obtained research results demonstrate a relatively high duration of the water injection processes in relation to the gas detonation processes taking place in the installation. In particular, the time interval between detonation cycles in the installation operating at a frequency of 23 Hz is about 43.5 ms where the duration of the gas detonation cycle does not exeed 1 ms. If we discard the purge cycle of the installation, then we have a time interval of 21 ms, during which it is necessary to inject water into the barrel. Based on the results of the above studies, we can state that it takes 8 ms just to spread the stream of water from one side of the barrel to the other. Technical limitations in the speed of electromagnetic valves should be added hereto. For example, the fast-acting valve of the Festh company, type VZWD, has an opening time of 20 ms and a closing time equal to 18 ms. Hence, the open/close time delay of this valve fails to ensure pulsed injection of water into the barrel. Thus, it is not advisable to use pulsed injection of water into the barrel for the FAW generator.

The calculation data are indicative of the spread of water along the bottom wall of the barrel. The results of experimental studies carried out by other researchers, shows that the water is "captured" during the propagation of the shock wave along the surface of the water with its further breakup of. It gives reason to believe that the process of water spreading will not result in the deterioration of the quality of water spraying. We simulated this process to check efficiency of the water dispersion in this case.

The results of numerical studies of the breakup of water stream in the barrel of the fire extinguishing installation under the action of a shock wave

The calculation data obtained to define the impact of the shock wave and the accompanying gas flow on the water stream in the barrel at different times are given in Fig. 6–11. The results are displayed as a liquid/gas phase transition surface in the static gas pressure field. The color pressure scale is shown in the Figures on the left side.

At the beginning of the impact of the shock wave on the liquid, we observe that the main portion of water is spread along the lower surface of the barrel, and the partially sprayed water is almost symmetrically distributed along the axis of the water stream.

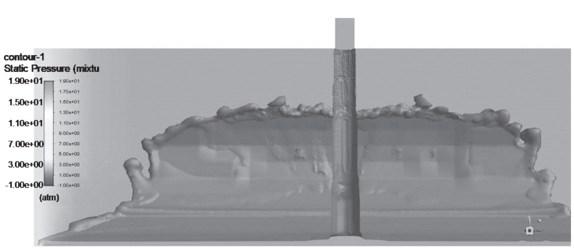

Figure 6. Initial spread of the liquid in the barrel prior to the action of the shock wave for a time period of 10 μs

Slika 6. Početno širenje tekućine u bačvi prije djelovanja udarnog vala u razdoblju od 10 μs

At a time of 5 ms from the start of the shock wave action (Figure 7), we observe a redistribution of the pressure in some sections of the calculation space. There is practically no movement of water at the front of the shock wave. At the same time, water movement appears in the accompanying gas flow behind the wave front.

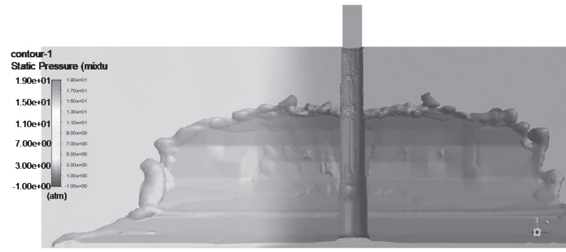

Figure 7. Distribution of liquid in the barrel for a time of 25 μs from the start of the action of shock wave

Slika 7. Distribucija tekućine u bačvi za vrijeme od 25 μs od početka djelovanja udarnog vala

We observe the arrival of the shock wave to the stream of water (Figure 8).

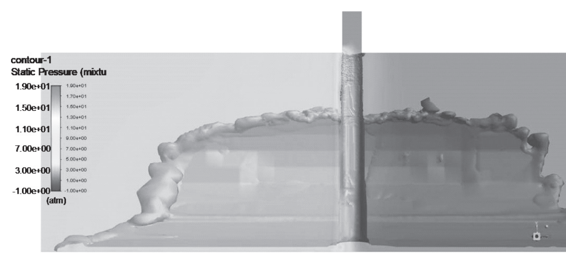

Figure 8. Distribution of liquid in the barrel for a time period of 40 μs from the start of the action of the shock wave

Slika 8. Raspodjela tekućine u bačvi za razdoblje od 40 μs od početka djelovanja udarnog vala

The increased density of the medium in the water stream area results in the gas-dynamic resistance to the movement of the medium, which is reflected in an increased pressure in this area. In particular, the pressure in the area where the shock wave collides with the water stream is increased to 1.9 MPa. We also observe further movement of liquid from the right side. To the left, the state of the liquid has practically not changed before the shock wave front.

We also observe that the process of breakup of water occurs more slowly compared to that of the shock wave propagation along the barrel.

We observe the displacement of the liquid under the action of the gas flow moving behind the shock wave front (Figure 9). In addition, large-scale vortices in the gas flow condition the separation of water from the surface of the barrel, as shown in the lower left corner.

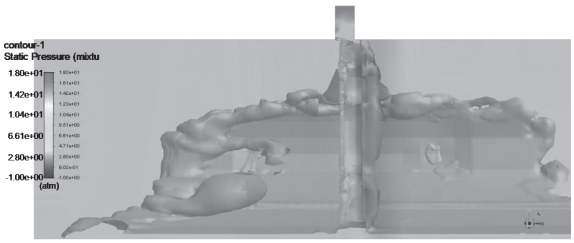

Figure 9. Distribution of liquid in the barrel for a time period of 100 µs from the start of the action of the shock wave

Slika 9. Raspodjela tekućine u bačvi za razdoblje od 100 µs od početka djelovanja udarnog vala

Then we have the acceleration of the liquid movement under the action of the gas flow (Figure 10).

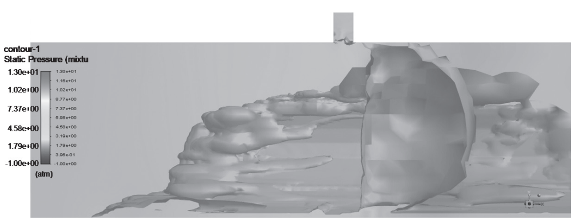

Figure 10. Distribution of the liquid in the barrel for a time period of 250 µs from the start of the action of the shock wave

Slika 10. Raspodjela tekućine u bačvi za razdoblje od 250 µs od početka djelovanja udarnog vala

Figure 11. Distribution of the liquid in the barrel for a time period of 700 µs from the start of the action of the shock wave

Slika 11. Raspodjela tekućine u bačvi za razdoblje od 700 µs od početka djelovanja udarnog vala

There is also a redistribution of liquid with movement across the entire cross-section of the barrel. The separation of water from the lower wall of the barrel is continued.

For a time of up to 0.5 ms from the start of the impact of the shock wave on the water in the barrel, we observe a complete displacement of the liquid in the gas flow to the right side relatively the point of water supply to the barrel. We also observe the spray of water that continues to be fed into the barrel. At the same time, water does not remain on the walls of the barrel, and it is indicative of the high quality of water spraying under the action of a high-speed gas flow.

According to the requirements, smoke settling can be provided by finely atomized water, and a decrease in temperature can be achieved by supplying cooling fire-extinguishing agents to the zone of increased temperature, cooling heated building structures and technological equipment. Taking into account the proposed numerical model and the obtained results of numerical studies, it can be noted that the use of finely atomized water generated by technical fire extinguishing means will increase the efficiency when in use.

CONCLUSION

A numerical study of the technology developed for extinguishing a fire by finely atomized water was carried out by dividing it into two studies: the study of the process of water supply to the barrel of the fire extinguishing installation and the breakup of water by a shock wave in the barrel. The use of a numerical model in the ANSYS software for simulating the processes of water injection into the barrel with its subsequent breakup of by a shock wave has been substantiated. To simulate the processes of water injection and breakup of water in the barrel, a VOF model (volume of liquid method) is used, that presupposes no penetration of one medium into another, and which is based on the surface tracking method applied to a fixed Eulerian grid.

Based on the results of a numerical study of the process of filling the barrel with water, a relatively high duration of the water injection processes was established in relation to the gas detonation processes taking place in the fire extinguishing installation. In particular, the time interval between detonation cycles in a fire extinguishing installation operating at a frequency of 23 Hz is about

43.5 ms. If we discard the purge cycle of the fire extinguishing installation, then we have a time interval of 21 ms, during which it is necessary to inject water into the barrel. Based on the results of the above studies, we observe that it takes 8 ms just to spread the water stream from one side of the barrel to the other. Then we also observe the spread of water along the lower wall of the barrel.

Based on the results of the numerical study of the process of breakup of the water stream fed to the barrel under the action of a shock wave, it was established that a high quality of water atomization under the action of a high-speed gas flow is conditioned by the removal of water from the walls of the barrel. It was found that the main process of water breakup of occurs not under the action of a shock wave, but under the action of a high-speed gas flow moving behind the shock wave. On the basis of the above, we can state that it is unreasonable to use the pulse injection of water into the barrel in the FAW fire extinguishing installation.

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NUMERIČKA TESTIRANJA RASIPANJA VODENOG MLAZA UZROKOVANOG UDARNIM VALOM U VATROGASNOJ CISTERNI

SAŽETAK: Istraživanje se bavi numeričkim pokazateljima procesa punjenja cisterne vodom i posljedičnog rasipanja vodenog mlaza i atomizacije vode u vatrogasnoj cisterni. Prikazan je numerički model procesa punjenja vode u cisterni i rasipanje vode uzrokovano udarnim valom. U simulaciji procesa korišten je ANSYS program. Model VOF (volumen tekućine) primijenjen je kada se pretpostavljalo da nema penetracije jednog medija u drugi. Rješenje se temelji na metodi površinskog praćenja primijenjenog na fiksni Eulerov grafikon. Iz rezultata dobivenih numeričkim ispitivanjem, utvrđeno je da je vrijeme punjenja vode značajno dulje od trajanja detonacijskog ciklusa plina u opremi za gašenje. Autori su utvrdili da je potrebno 8 ms samo kako bi vodeni mlaz stigao s jedne strane cisterne na drugu. Primijećena je visoka kakvoća atomizacije vode pri dotjecanju plina velikom brzinom, uključivo i vodu uz rub cistrne. Navedeno je da je nerazumno koristiti pulsno injektiranje vode u cisterni i to zbog visoke frekvencije stvaranja udarnog vala od preko 23 Hz.

Ključne riječi: *numerički model, fino atomizirana voda, oprema za gašenje požara, razbijanje mlaza udarnim valom*

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