UDC 629.5.067.8
DOI: 10.15587/1729-4061.2024.313114

DETERMINING WORKING CHARACTERISTICS OF THE EXCESS AIR PRESSURE SYSTEM IN AN EMERGENCY HATCH BASED ON JET WATER-GAS EJECTORS

Serhii Hrynchak
PhD
Research Center of the Armed Forces of Ukraine "Derzhavnyi Okeanarium"
Naval Institute of the National University "Odesa Maritime Academy"
Didrikhsona str., 8, Odesa, Ukraine, 65029
E-mail: grinserg69@gmail.com

The object of this study is jet water and gas ejectors in the fire safety system of ships. The problem solved relates to the fact that in the event of a fire in the area of the exit from the ship's emergency room, the heat energy increases dangerously and a large amount of smoke spreads throughout the ship's rooms. These factors require immediate sealing of the emergency room, which limits the immediate access of emergency teams to the room. Installation of a local excess air pressure system in the emergency hatch on the basis of jet water and gas ejectors could make it possible to shield thermal energy and localize smoke gases in the emergency room without sealing it to ensure prompt access of emergency teams to it. The following results were achieved – the adequacy of theoretical studies of the processes of localization of flue gases in the emergency room without its sealing was confirmed by the experimental method. The investigated problem was solved by optimizing processes: the rate of change in the natural indicator of the weakening of environment during the start-up of the local excess air pressure system in the emergency hatch based on jet water and gas ejectors; the effectiveness of reducing the temperature of heated gases in the superstructure during the operation of the excess air pressure system in the emergency hatch based on jet water-gas ejectors. Special feature of the results was the formation of an air curtain obtained by the selection of a part of high-temperature flue gases in the housings of jet water-gas ejectors, their heat-mass exchange processing and output back into the flow. This created conditions under which thermal energy is shielded with an efficiency of 85–88 %. The scope and conditions of practical use of the results are shipbuilding and ship fire safety design

Keywords: water-gas jet ejector, emergency hatch, natural attenuation index, thermal energy

Received date 22.07.2024
Accepted date 08.10.2024
Published date 30.10.2024

***How to Cite:** Hrynchak, S. (2024). Determining working characteristics of the excess air pressure system in an emergency hatch based on jet water-gas ejectors. Eastern-European Journal of Enterprise Technologies, 5 (5 (131)), 90–99. http://doi.org/10.15587/1729-4061.2024.313114*

1. Introduction

In work [1] it is stated that the spread of smoke complicates the fight against an accident, which in turn requires sealing the emergency room. Sealing occurs by closing doors and hatches, by turning off ventilation. However, during the period of time between the start of the fire (ignition and the beginning of the formation of combustion products) and the moment of sealing, a significant part of the high-temperature flue gases exit the emergency room through openings.

In addition, the energy saturation of the ship's premises, as well as the presence of personnel at combat posts, requires depressurization to carry out evacuation and fire fighting activities.

Therefore, the use of a technique for sealing the emergency room creates problems regarding access to the room itself. Moreover, the need to open a door or a hatch can cause conditions for sudden access of oxygen to the fire and fanning the fire with new force. In addition, it is necessary to take into account that the ship's compartments are not gas-tight, unlike the compartments of a submarine, so the specified sealing technique will not meet the requirements for limiting the spread of smoke throughout the ship.

It follows from the above that among the set of tasks related to providing fire protection, one of the most important is the task to reduce gas exchange through open holes. Therefore, the question arises regarding the need to find technical solutions that could make it possible to meet the task of preventing drafts and gas exchange with adjacent rooms without actually closing doors and hatches.

The search for ways to solve this problem, theoretical justification, and experimental confirmation of gas exchange management methods during a fire will lay the foundation for designing technical means and will raise the issue of updating the tactics of combating ship fires. Therefore, the search for conditions for reducing gas exchange through an open hole, created with the help of technical means, in which there is no gas exchange with the environment, is a relevant task.

2. Literature review and problem statement

Attempts to protect ship hatches from smoke and high temperatures were made repeatedly. There is a well-known technical solution for the safe evacuation of personnel from the power compartment (PC), which is used on some vessels [2]. So, to ensure this, a watch and ladder irrigation system is provided, which is a pipeline with sprinklers connected to the water fire protection system. The principle of operation of the system is based on the supply of coarsely dispersed water spray (0.6...1.2 mm) in the area of emergency ladders [2]. The main disadvantage of this technique is that it cools the structure of the staircase and slightly cools the gas-air environment but does not exclude the spread of smoke gases through the open hatch outside the emergency room. Also, the implementation of this design solution on ships with a displacement of 1,000–2,500 tons is rather difficult to implement. The difficulty is the fact that the PCs of such ships are cluttered with equipment and, in the lower part, do not have continuous platforms, and the exit from the PC is not protected by structural means.

A known technical solution [3] is a means of reducing the intensity of the spread of smoke and toxic gases outside the emergency room. The solution includes two parallel U-shaped collectors, which are placed parallel to the emergency hatch. One collector is located on the inside of the perimeter of the emergency hatch, and the second on the outside – at a distance of 0.1–0.15 m from the inside. The collectors are connected to the water fire-fighting system and equipped with centrifugal-jet sprinklers with an inclination to the plane of the collectors at an angle of 30°. Curtains are fixed between the collectors on rotary rods that can rotate around their longitudinal axis and are irrigated when the working fluid is supplied.

A significant drawback of these technical solutions [2, 3] is that during their application, sprayed water is used in an open manner, which causes significant damage to the ship's electrical equipment and the failure of necessary systems.

There is a known technique of excess air pressure in emergency rooms during a fire [4], which involves the ejection of hot flue gases from the upper part of the emergency PC into the body of a jet water-gas ejector. In the case, they are processed on a highly developed heat-mass transfer surface of the working fluid. After processing, the cooled inert mixture with increased moisture content and low percentage of oxygen is fed to the lower part of the room. The disadvantage of the specified technique and device [4] is that the device was not intended to create excess air pressure in the opening of the emergency room and is not able to effectively form a excess air pressure flow.

An option to overcome related difficulties is to design a ship's hatch with the installation of an excess air pressure system based on JWGE in its opening. This is the approach used in works [5, 6], which evaluate the efficiency of jet water and gas ejectors (JWGE) as technical means for smoke localization in the emergency room, as well as prevention of draft and gas exchange with adjacent rooms.

In works [5, 6], a technique for reducing the intensity of the exit of smoke gases through open emergency hatches from the emergency room is theoretically substantiated. Thus, the reduction in intensity occurs due to the creation of excess air pressure, which is formed by the flow of steam-gas-air mixture directed into the emergency room by the system based on JWGE. The essence of the theoretical justification is reduced to the task of reducing gas exchange through an open hole during a fire and finding conditions under which gas exchange with the environment is absent (hermetic room). To this end, a special case of the zone model of fire development processes and the formation of gas exchange between the ship's emergency room and the superstructure through the emergency hatch, in which the excess air pressure system based on JWGE works, was developed.

However, the adequacy of the theoretical justification of the specified technique should be confirmed by experimental studies.

The lack of technical solutions for the development of smoke localization systems in the emergency room gives reason for conducting scientific research aimed at solving the specified problem.

Therefore, it is advisable to conduct a study aimed at establishing the regularity of decrease in the intensity of flue gas exit through the open emergency hatch owing to the excess air pressure system installed in it on the basis of JWGE.

3. The aim and objectives of the study

The purpose of this work is to define patterns in the formation of an air curtain obtained by the selection of a part of the high-temperature flue gases into the JWGE housing, their heat and mass exchange treatment, and output back into the flow. This could confirm that the excess air pressure system in the emergency hatch on the basis of JWGE is an effective means of reducing the intensity of smoke entering the superstructure, which makes it possible to change the direction of movement of smoke gases, thereby ensuring their effective shielding.

To achieve the goal, the following tasks were set:

– to determine the shielding properties of the excess air pressure system in the emergency hatch based on JWGE as a parameter for optimizing the change in the natural indicator of the attenuation of the medium when the JWGE system is started depending on time t;

– to determine the dynamics of temperature decrease in the heated gases as a parameter for optimizing the average volume temperature in the superstructure at the time point t.

4. The study materials and methods

The object of research is jet water and gas ejectors in the fire safety system of ships (vessels).

For planning the experiment, the hypothesis was accepted that the current model of the system based on JWGE would have an excess air pressure system in the emergency hatch.

An assumption was adopted that the processes of JWGE operation when used in the hole located in the horizontal ceiling (deck hatch) could make it possible to control the processes of formation of concentration and temperature fields during a fire in the area of the emergency hatch.

A measuring system for the model of a ship's room was designed for hardware support to conducting experiments on determining the dependences of reducing the intensity of smoke entering the superstructure (scheme in Fig. 1).

The model of the ship's room included:

1. Fire compartment (1×1×1 m) – in which an emergency hatch (0.3×0.3 m) was placed in a horizontal overlap with a working model of the excess air pressure system based on JWGE, a model fire source, sensors of control and measuring equipment.

2. Superstructure (1×1×1 m) – in which the sensors of the control and measuring equipment were arranged.

Experiments on determining the dependences of shielding properties of the excess air pressure system in the emergency hatch on the basis of JWGE were provided with a system for measuring the transparency of the gas-air environment (Fig. 1). The specified system consisted of a selenium photocell 4, a light source 2 (incandescent lamp, KPZH 220-500), and a self-writing device KSP-4 "D".

Experiments on determining the dependences of the dynamics of temperature reduction of heated gases were provided by the system of temperature measurements. The system of temperature measurements consisted of a standard thermometer and chrome-plated thermocouples. Two thermocouples provided temperature measurement in the superstructure, and three in the fire compartment. Continuity of temperature measurement in the model premises was ensured by the use of the thermoelectric measurement method. To this end, chrome-copel thermocouples were installed at 5 points (Fig. 1, positions $T_1 - T_3$, T_{b4}, T_{t4}) and connected to self-recording devices KSP-4 "T".

To control the pressure of the working fluid in the pipeline during the experiments, a suitable manometer was used (Fig. 1, position 9). Readings from the scale of the manometer were read out before starting and after stopping the pump for supplying the working fluid NCV 63/80.

Time indicators, such as the time of research, were measured using a stopwatch.

In accordance with the technical solution [7] and the procedure for calculating the structural characteristics of the jet water-gas ejector [4], an operational model of the excess air pressure system in the emergency hatch on the basis of JWGE was designed and built.

The excess air pressure system in the emergency hatch consisted of two heat exchangers (diagram in Fig. 2). Each heat exchanger included JWGE of cylindrical form from galvanized steel sheet 1 mm thick with a cross-section diameter of 165 mm and a length of the working part of the body of 300 mm. In the upper part, on the same axis as housing 3, there was a multi-jet nozzle 4, which had 14 nozzles with a cross section of 0.7 mm on a disk and was connected to the pipeline of the working fluid 5. The guide pipe of the inlet part 8, connected to the inlet manifold 9, was attached to the cut of the upper part of the body. In the lower part of the body, there is distributor 1 with pipeline 4 for the removal of the spent working fluid. The guide pipe 2 was connected to the distributor and connected to the outlet manifold 6. The outlet manifold was equipped with nozzles inclined to the deck.

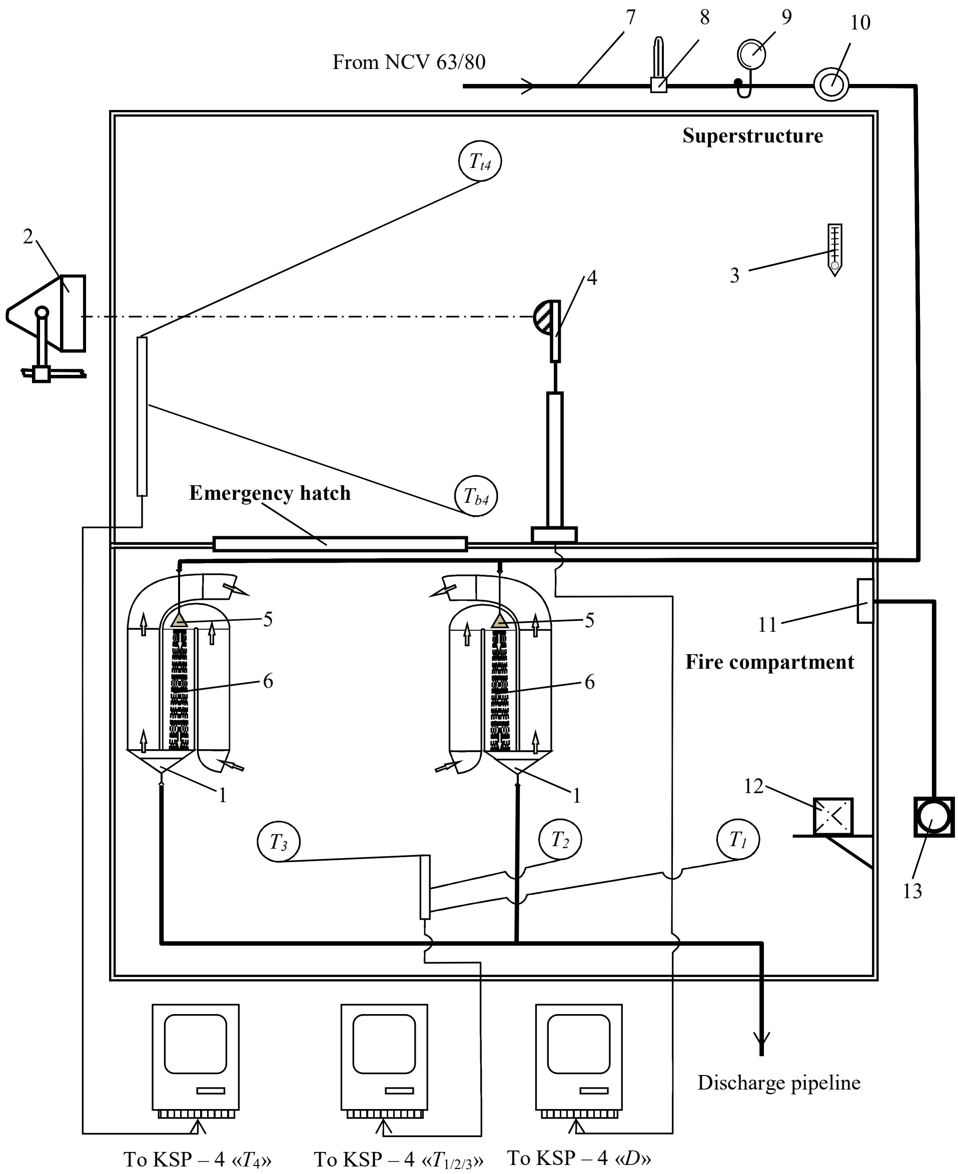

Fig. 1. Measuring system of the experimental model for shielding flue gases and thermal energy of the jet water-gas ejector in the opening between the emergency room and the superstructure: 1 — reservoir; 2 — light source; 3 — laboratory mercury thermometer; 4 — selenium photocell; 5 — spraying device; 6 — jet water and gas ejector; 7 — pipeline of working fluid; 8 — laboratory mercury thermometer; 9 — sample manometer; 10 — flow meter; 11 — air flow speed generator; 12 — smoke source (fire source); 13 — exhaust fan

Fig. 2 shows the direction of movement of the gas phase in the body of the jet water-gas ejector by arrows 7. The device for implementing the technique of excess air pressure in the emergency hatch was located so that the output collectors of both ejectors were placed directly under the emergency hatch along the outer part of its perimeter (Fig. 1).

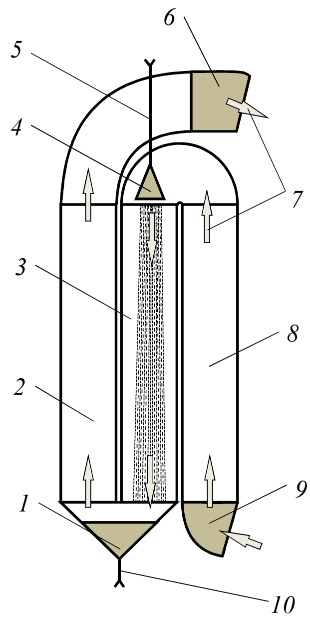

Fig. 2. Heat exchanger of the device for excess air pressure in the emergency hatch based on the water-gas jet ejector: 1 – separator; 2 – guide pipe; 3 – JWGE housing; 4 – multi-jet nozzle; 5 – pipeline of working fluid; 6 – output collector; 7 – movement of the gas phase in the housing of the jet water-gas ejector; 8 – guide nozzle of the inlet part; 9 – input collector; 10 – a system for removing the spent working fluid

The processing of the results of the tests carried out in the model of the ship's room was carried out according to a similar procedure used in work [1]:

a) the natural attenuation index of the medium (hereinafter referred to as NAIM) was determined by the photoelectric technique based on the Lambert-Bouguer-Behr law [8]:

$$\mu' = \frac{1}{r}\ln\frac{E_0 - E_f}{E_1 - E_f}, \quad (1)$$

where μ' is NAIM, m^{-1};

r is the distance from the photocell to the light source, m;

E_0, E_1 – energy illuminance of the photocell, determined respectively during the passage of light in a non-smoky or smoky model room, mV;

E_f is the energy illumination of the photocell at the background value, mV.

Assuming that E_f=0 and E_0=100 mV, E_1=$E_n(t)$ where $E_n(t)$ is the energy illumination of the photocell at time t; formula (1) after substituting the specified data will take the form:

$$\mu'_n(t) = \frac{1}{r}\ln\frac{100}{E_n(t)}, \quad (2)$$

where $\mu'_n(t)$ is the NAIM of the nth experiment, m^{-1};

b) the relative change in the attenuation coefficient of the environment in the room determined the evaluation of effectiveness of shielding the flue gases in JWGE, where:

$$F_\mu = \frac{\mu'_0 - \mu'_t}{T}\cdot 100\,\%, \quad (3)$$

where μ'_0 is the average value of NAIM before shielding of flue gases in the superstructure, m^{-1};

μ'_t – average value of NAIM in the superstructure after a certain time from the start of the excess air pressure system in the emergency hatch, m^{-1};

c) assessment of the intensity of smoke temperature reduction in the superstructure was carried out in comparison with the efficiency of the excess air pressure system in the emergency room:

$$F_t = \frac{T - T_{\text{med}.i}}{T}\cdot 100\,\%, \quad (4)$$

where T is the average temperature in the model room at time t, created by the excess air pressure system based on JWGE, C;

$T_{\text{med}.i}$ is the average temperature in the fire compartment at time t in the i-th experiment;

d) assessment of the effectiveness of smoke temperature reduction was performed based on the relative change in the average temperature in the model of the ship's room after a certain time:

$$F_{tef} = \frac{T_{\text{med.fir}.i} - T_{\text{med.mea}.i}}{T_{\text{med.fir}.i}}\cdot 100\,\%, \quad (5)$$

where $T_{\text{med.fir}.i}$ is the average temperature in the model room at time t during the i-th experiment, °C;

$T_{\text{med.mea}.i}$ is the average temperature in the model room at time t in the i-th experiment, °C.

Statistical processing of the results was performed in accordance with the theory of experimental planning [9–12]. In this case, a scheme with uniform duplication of experiments was used in the following sequence:

1. For each row of the planning matrix, the average arithmetic value of the optimization parameter is calculated:

$$\bar{y}_j = \frac{1}{n}\sum_{u=1}^{n} y_{ju}, \quad (6)$$

where:

n is the number of parallel experiments;

y_{ju} is the result of a separate experiment.

2. After that, the variance of each experiment in the planning matrix is calculated S_j^2:

$$S_j^2 = \frac{1}{n-1}\sum_{u=1}^{n}\left(y_{ju} - \bar{y}_j\right)^2, \quad (7)$$

and mean square deviation S_j:

$$S_j = \sqrt{\frac{1}{n-1}\sum_{u=1}^{n}\left(y_{ju} - \bar{y}_j\right)^2}. \quad (8)$$

3. The hypothesis of homogeneity of the variances of the experiments was tested using the Cochran criterion:

$$G = \frac{S_{\max}^2}{\sum_{1}^{N} S_j^2}, \quad (9)$$

where G is the Cochran criterion;

$S_{\max}^2$ – maximum variance;

N is the number of experiments.

In the conclusion, it is noted that if the calculated value $G_l<G_t$ (tabular) for the adopted level, then the experimental model is considered adequate. If $G_l>G_t$ – the experimental model is rejected.

The number of degrees of freedom $f_1=n-1$ and $f_2=N$ are related to the Cochran criterion.

4. In the case when the variances of the experiments are homogeneous, the variance of the reproducibility of the experiment is calculated:

$$S_{\{\overline{y}\}}^2 = \frac{1}{N(n-1)} \sum_{j=1}^{N} S_j^2. \quad (10)$$

5. The coefficients of the regression equation were determined according to the following expressions:

– for the free term b_0:

$$b_0 = \frac{1}{N} \sum_{j=1}^{N} \overline{y}_j; \quad (11)$$

– for regression coefficients characterizing linear effects:

$$b_j = \frac{1}{N} \sum_{j=1}^{N} \overline{y}_j x_{ij}; \quad (12)$$

– for regression coefficients characterizing interaction effects:

$$b_{il} = \frac{\sum_{j=1}^{N} y_j x_{ij} x_{lj}}{nN}, \quad (13)$$

where il – numbers of factors;

x_{ij}, x_{lj} – encoded values of factors i and l in the jth experiment.

6. The variance of the regression coefficients was calculated using the expression:

$$S_{\{b_j\}}^2 = \frac{S_{\{\overline{y}\}}^2}{nN}. \quad (14)$$

7. Determining the value of the confidence interval Δb_j:

$$\Delta b_j = \pm t_\tau \cdot \sqrt{S_{\{b_j\}}^2} = \pm t_\tau \cdot S_{\{b_j\}}, \quad (15)$$

where t_τ is the Student's criterion (tabular value) at the time of determining $S_{\{\overline{y}\}}^2$ with the selected number of degrees of freedom and level of significance;

$S_{\{bj\}}$ is the squared error of the regression coefficient.

With uniform duplication of experiments, the number of degrees of freedom depends on $f=(n-1)\,N$, where N is the number of experiments in the planning matrix, and n is the number of parallel experiments;

8. Checking the statistical significance of the regression coefficients.

The coefficient is significant if its absolute value is greater than the confidence interval. The confidence interval is given by the upper and lower limits $b_j+\Delta b_j$ and $b_j-\Delta b_j$.

The coefficient is significant if its absolute value is greater than the confidence interval.

9. Checking the adequacy of the model.

Adequacy variance or residual variance characterizes the dispersion of empirical values $\overline{y}$ relative to the estimated values $\tilde{y}$, determined from the found regression equation. Adequacy variance is determined from the formula:

$$S_{ad}^2 = \frac{\sum_{j=1}^{N} \left(\overline{y}_j - \tilde{y}_j\right)^2}{f}, \quad (16)$$

where $\overline{y}_j$ is the average arithmetic value of the optimization parameter in the j-th experiment;

$\tilde{y}_j$ is the value of the optimization parameter, calculated by the model for the conditions of the jth experiment;

f is the number of degrees of freedom $((N-(k+1))$, k is the number of factors).

10. Verification of the hypothesis of adequacy of the found model.

Testing of this hypothesis is performed by Fisher's F test:

$$F_l = \frac{S_{ad}^2}{S_{\{y\}}^2}. \quad (17)$$

If the value $F_l<F_t$ for the accepted level of significance and corresponding numbers of degrees of freedom, then the model is considered adequate. When $F_l>F_t$, the hypothesis of adequacy is rejected.

The use of the Cochrane and Fisher tests assumes a normal distribution of the results of the experiment.

5. Results of experimental studies on the prevention of draft and gas exchange with adjacent rooms

5. 1. Determining the shielding properties of the jet water-gas ejector in the opening between the emergency room and the superstructure

As a parameter for the optimization of the process of reducing the intensity of smoke entering the superstructure through the hole, μ' was taken when the time t changed from 1 to 540 s. The natural rate of attenuation of the environment was estimated by the change in energy illumination of the photocell. Experiments were carried out for three working pressures of water supply to JWGE spraying device: 0.3 MPa, 0.4 MPa, and 0.5 MPa.

During the experiment, the set of the operational model of JWGE (Fig. 1) was started manually (through the door of the fire compartment) using an ignition source (torch) to ignite the combustible load. After ignition and the start of self-burning, the torch is removed, while the doors of the fire compartment remain closed.

After that, on second 180 of ignition of the combustible load, the set of the operational model of JWGE was put into operation, for which pump 9 was turned on (Fig. 1). With the help of a special valve on the manometer 9, the set pressure of the working fluid is set.

The start of the experiment is considered to be the time of starting the recorders of KSP-4 "D" and KSP-4 "T" devices.

The controlled factor was the energy illumination of the photocell, the readings of which were taken using the system for measuring the transparency of the environment in the model room (Fig. 1).

Experiments in experimental studies of the shielding properties of JWGE in the hole between the emergency room and the superstructure were performed three times for each indicator of the pressure of the working fluid.

5 minutes after the start of the pump (second 540 after the burning of the combustible load) at the start of the experiment, the stopwatch, recorders, and the set of the working model of JWGE stopped.

Determination of the shielding dependences of the excess air pressure system in the opening between the emergency room and the superstructure was carried out in the values of NAIM, μ'. To this end, the conversion of the experimental values of the energy illuminance of the photocell E1mid. was carried out into the value of NAIM according to expression (2). The results of experimental studies, taking into account the conversion of the experimental values of the energy illuminance of the photocell into the value of NAIM, are given in Table 1.

Fig. 3 shows the dependences of NAIM on time.

The evaluation of effectiveness of reducing the entry of smoke into the superstructure through the emergency hatch was performed by the relative change in NAIM according to expression (3).

Table 2 gives the results of statistical processing of experimental results. Processing was carried out in the Mathcad 11 environment.

The selected optimization parameter (NAIM, μ') depends on the following factors [5, 6]:

$$\mu' = f\left(\alpha, K, \omega, G_l, G_g, V, H, \varphi\right), \quad (18)$$

where α – angle of inclination of the excess air pressure flow to the plane of the deck (hatch), °;

K – JWGE ejection coefficient;

ω – speed of air flow, m/s;

G_l, G_g – volume flow rate of liquid and gas, respectively, m^3/s;

V – volume of the adjacent compartment model, m^3;

H – door height, m;

φ – air humidity in the model of the ship's room, kg/m^3;

m – mass of combustible load, kg.

The factors G_l, G_g are determined by the characteristics of JWGE nozzle, were taken as constant and excluded from consideration.

The factor ω was assumed to be constant.

Factors V, H, φ are fixed during experiments and were excluded from consideration. Therefore, two factors α, K were considered the most significant, the influence of which had to be tested experimentally, i.e.:

$$\mu' = f\left(\alpha, K\right), \quad (19)$$

Table 2 shows that the estimated value of the Cochran criterion is less than the tabulated value. Therefore, the homogeneity of variances in the experiments is confirmed.

The calculated value of the Fisher criterion (17) is F_p=0.011, while the tabular value is F_m=18.5. Therefore, the theoretical model is adequate.

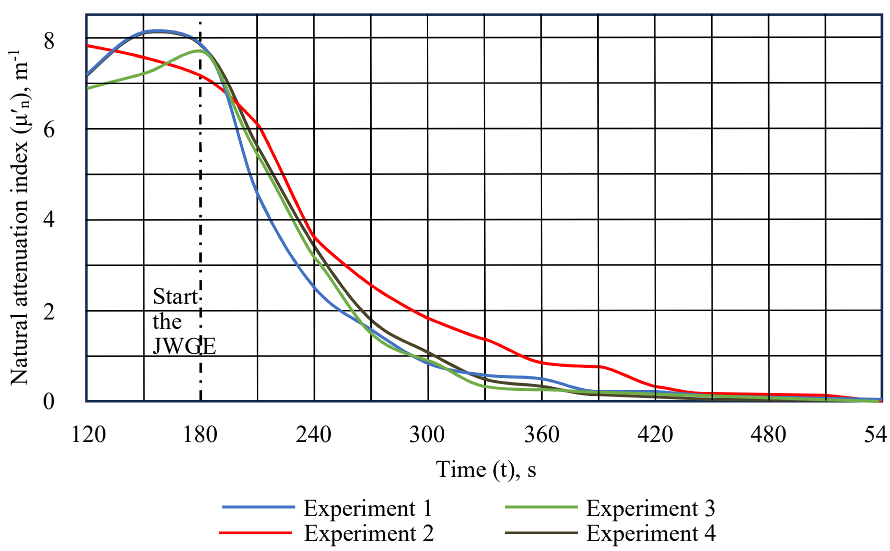

Fig. 3. Dependence of NAIM on time

Table 1

Results of experimental studies taking into account the conversion of the experimental values eof energy illuminance of the photocell into the value of NAIM

	Time, s	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540
D-1	E1mid.(t) mV	0.08	0.03	0.04	1.13	8.08	19.6	43.6	60.4	68.3	89.2	90.6	92.4	99.2	100	100
	NAIM, 1/m	7.09	8.01	7.82	4.48	2.52	1.63	0.83	0.50	0.38	0.11	0.10	0.08	0.01	0.00	0.00
D-2	E1mid.(t), mV	0.04	0.05	0.07	0.22	2.49	7.08	14.7	23.3	40.4	46.9	75.1	88.9	85.6	85.6	100
	NAIM, 1/m	7.82	7.67	7.31	6.13	3.69	2.65	1.92	1.46	0.91	0.76	0.29	0.12	0.16	0.16	0.00
D-3	E1mid.(t), mV	0.10	0.07	0.04	0.45	4.28	22	40	71.6	78	89.4	98.6	98.5	100	100	100
	NAIM, 1/m	6.91	7.31	7.82	5.41	3.15	1.52	0.92	0.33	0.25	0.11	0.02	0.02	0.00	0.00	0.00
D-4	E1mid.(t), mV	0.08	0.03	0.04	0.34	3.35	15.8	33.5	63	69.3	87.0	96.5	96.5	98.5	99.3	100
	NAIM, 1/m	7.09	8.01	7.82	5.70	3.40	1.85	1.09	0.46	0.37	0.14	0.04	0.04	0.02	0.01	0.00

Table 2

Results of statistical processing of the experiment to optimize the process of reducing the intensity of smoke entering the superstructure through the hole

Experiment No.	Factor		Response function	$\overline{y}_j$, °C	s_j^2	s_j	Cochran criterion	$s1^2_{\{\overline{y}\}}$
	x_1, °	x_2, m	y_j, °C					
1	60	0,3	42	44	15	3.57	G_l=0.328 G_t=0.7679 G_l<G_t	11.25
			47					
			44					
2	60	0,1	15	14	2	3		
			12					
			16					
3	0	0,3	59	68	12	5		
			76					
			68					
4	0	0,1	62	60	14	3.72		
			60					
			57					

The evaluation of effectiveness of JWGE operation in reducing the intensity of smoke entering the superstructure through the emergency hatch shows that in 3 minutes of operation in a completely smoky room, visibility of up to 2.5 meters is achieved at a pressure in the main line of 0.3 MPa.

5. 2. Determining the effectiveness of reducing the temperature of heated gases in the superstructure during the operation of a jet water-gas ejector

When studying the effectiveness of reducing the temperature of heated gases in the superstructure, it was accepted that the installation should be started after three minutes of free burning. This is due to the fact that the area of the opening was small and only in the case of placing the combustion center at the top point of the emergency room in the superstructure, a significant increase in temperature was observed already on the first minute of combustion. In the case of placing the fire site in the middle and at the bottom point, a significant increase in temperature occurred on the third minute.

The results of experimental studies are given in Table 3.

The dynamics of temperature changes in the superstructure are shown in the plot (Fig. 4).

Statistical processing of the results of experimental studies was carried out in the Mathcad 11 environment.

When determining the optimization process of dynamics in lowering the temperature of heated gases in the adjacent room, the average volume temperature was taken.

The selected optimization parameter depends on the following factors [9, 10]:

$$T_{mid} = f(\alpha, K, \omega, G_l, G_g, V, H, \varphi), \quad (20)$$

Therefore, two factors α, K were considered the most significant, the influence of which had to be tested experimentally, i.e.:

$$T_{mid} = f(\alpha, K). \quad (21)$$

The results of statistical processing of the experiment to determine the effectiveness of reducing the temperature of heated gases in the superstructure are given in Table 4.

Table 4 shows that the calculated value of the Cochran criterion is less than the tabular value. Therefore, the homogeneity of variances in the experiments is confirmed.

Based on the results, it was established that the decrease in the average volume temperature in the adjacent room occurs already under the 0.3 MPa mode. This is explained by a decrease in the intensity of gas exchange through the open hole in which JWGE works.

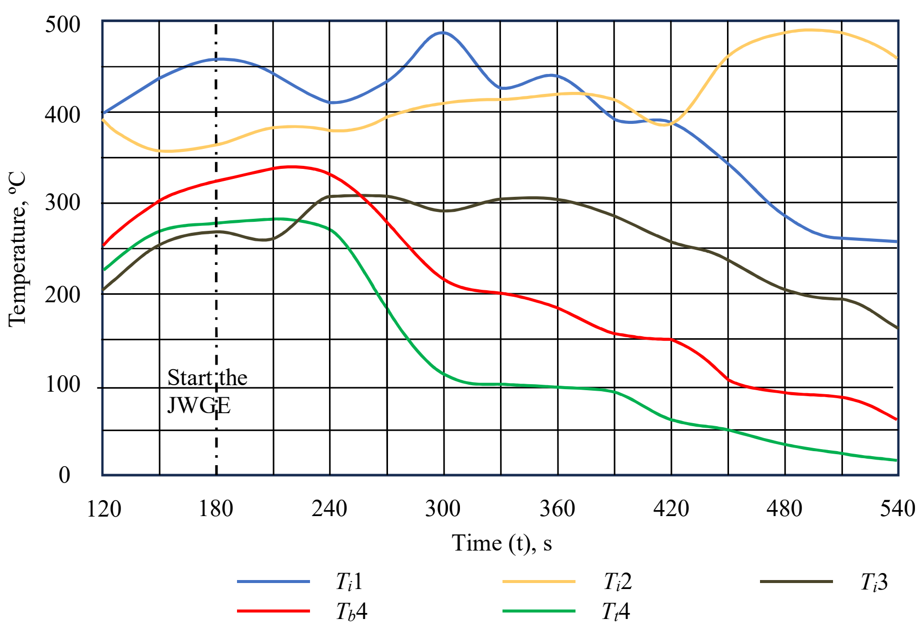

Fig. 4. Dynamics of temperature changes in the emergency room and in the superstructure during operation of JWGE in the emergency hatch (mode – 0.3 MPa). Notes: *Ti*1, *Ti*2, *Ti*3 – temperatures in the corresponding zones of the emergency room, °C; *Tb*4, *Tt*4 – temperatures in the upper and lower parts of the superstructure, °C

Table 3

Summary table of studies when using JWGE in the emergency hatch

Time, s	$Tt(i1)$	$Tt(i2)$	$Tt(i3)$	$Tv(i4)$	$Tn(i4)$
120	396	388	204	252	241
150	441	353	256	322	254
180	469	363	273	335	257
210	441	375	260	348	259
240	410	369	302	333	234
270	434	392	302	275	174
300	498	416	298	224	128
330	430	424	313	202	104
360	447	435	308	188	98
390	394	425	289	164	86
420	393	441	268	152	65
450	348	470	239	112	52
480	284	489	208	97	48
510	257	491	182	86	42
540	224	473	164	68	34

Table 4

Results of statistical processing of the experiment on determining the effectiveness of reducing the temperature of heated gases in the superstructure

Experiment No.	Factor		Response function	$\overline{y}_j$, °C	s_j^2	s_j	Cochran criterion	$s1^2_{\{\overline{y}\}}$
	x_1, °	x_2, м	y_j, °C					
1	15	0.3	36	36	0.44	0.8	G_f=0.427 G_t=0.7679 G_f<G_t	2.653
			37					
			36					
2	30	0.1	41	42	4	1.9		
			44					
			41					
3	60	0.3	26	28	4	1.6		
			29					
			29					
4	0	0.1	29	31	5	3		
			33					
			31					

Evaluation of the efficiency of JWGE after 3 minutes from the moment of its implementation shows that the speed of reaching the required temperature in the adjacent room depends on the ejection coefficient. At the same time, it should be noted that the ejection coefficient determines the capacity of JWGE in terms of heat removal and the start-up time of the installation.

It was also found that the slope of the nozzles of the outlet collectors of the heat exchangers is most appropriate at 15–20° from the deck.

6. Discussion of results of experimental studies on the prevention of draft and gas exchange with adjacent rooms

The main result has been achieved in the work, namely, the adequacy of theoretical studies of the processes of formation of the thermal energy shielding effect and localization of flue gases in the superstructure without its sealing was confirmed by the experimental method. Special feature of the results is the formation of an air curtain obtained by the selection of a part of high-temperature flue gases in the housings of JWGE, their heat and mass exchange processing and output back into the flow.

The experiments performed in this study are a continuation of work [1]. The results are aimed at confirming by experimental method the adequacy of theoretical studies on the processes of forming the effect of thermal energy shielding and localization of smoke gases in the emergency room without its sealing.

The difference in the works is the tasks assigned to the system with JWGE. Thus, in previous work, the system performed the task of forming the effect of shielding thermal energy and localization of smoke gases in an emergency room equipped with an opening in vertical fences (doors). In the case of this work, the system executed the task of forming the effect of thermal energy shielding and localization of smoke gases in an emergency room equipped with an emergency hatch.

The effectiveness of the shielding properties of the excess air pressure system in the emergency hatch based on jet water-gas ejectors has been proven experimentally. The evaluation of effectiveness of reducing the gas exchange between the emergency room and the superstructure through the emergency hatch was performed based on the relative change in the natural indicator of the attenuation of the environment in the superstructure (1). The results are represented by the dependence of the natural indicator of attenuation of the environment on time, which is shown in Fig. 3.

The dynamics of lowering the temperature of heated gases in the superstructure have been proven experimentally.

During the experiment, a linear model was built, which is expressed by the dynamics of temperature changes over time at the pressure of the working fluid (Fig. 4). The model allows me to state that the main factor affecting the optimization parameter is JWGE ejection coefficient; the results of statistical processing of the experiment are given in Table 4.

Studies on the application of the excess air pressure system in the emergency hatch on the basis of JWGE according to the specified methods were carried out for the first time. An essential feature of the current design of JWGE for the emergency hatch is that the heat exchanger housing was equipped with an inlet pipe, with the help of which gas-air medium intake into the heat exchanger housing was carried out directly from the upper part of the emergency room. This design feature affects the working characteristics of JWGE, which in turn makes it necessary to take into account the additional hydraulic resistance when calculating the working characteristics of JWGE and choosing the ejection coefficient.

The section of the outlet part of JWGE differed from the previous case [1] in that it was located with an inclination of the axis of the outlet pipe by 15–20° relative to the deck. This feature affects the processes of gas exchange through the hole but does not affect the operating characteristics of JWGE.

Research on the provision of local excess air pressure in the emergency hatch on the basis of JWGE gives reason to assert the possibility of further development of the method for limiting the spread of fire and smoke from the emergency room and systems for its implementation. This makes it possible to develop technical solutions during the design of the general safety system of the ship (vessel) aimed at new fire fighting methods. Optional sealing of an emergency room equipped with the indicated local excess air pressure system by closing the door can be included in such methods.

The study was aimed at confirming the adequacy of theoretical studies by experimental method [5, 6]. According to them, the output part of JWGE is able to ensure the creation of equilibrium in the emergency hatch in order to reduce the intensity of air entering the emergency room from the superstructure. Therefore, their results are adequate only for proving the workability and effectiveness of the technique for preventing the spread of smoke on the ship based on JWGE system installed in the horizontal ceiling (emergency hatch). These results cannot be used to determine the effectiveness of the system of local excess air pressure based on JWGE in vertical fences (doors).

This study is the completion of a series of experiments aimed at proving the adequacy of theoretical studies on preventing the spread of smoke throughout the ship based on JWGE system installed in the ship's hatches.

The results are adequate only for proving the workability and effectiveness of the method of preventing the spread of smoke throughout the ship based on the local support system based on JWGE in horizontal overlaps (hatchways). These results cannot be used to determine the efficiency of JWGE system installed in the doorway.

This research may be advanced by taking into account the limitations and by designing an experiment aimed at proving the adequacy of theoretical studies on preventing the spread of smoke on the ship based on portable JWGE systems that can be quickly deployed in ship openings (doors and hatches).

7. Conclusions

1. The shielding properties of the excess air pressure system in the emergency hatch on the basis of JWGE have been determined. Thus, the launch of JWGE kit allows for 3 minutes of operation in a completely smoky room with a volume of 0.65 m^3 to achieve a visibility of up to 2.5 meters at a pressure in the main line of 0.3 MPa. The reduction in superstructure smoke was observed almost immediately, even when the location of the fire source is at the very top point of the emergency room when JWGE is started. This is due to the fact that the flow of inert steam-gas-air medium from the outlet nozzles of JWGE contributed to the change in the direction of the movement of flue gases and the mixing of the gas phase inside the fire compartment. Under the operation modes of JWGE of 0.4 and 0.5 MPa, the superstructure smoke is significantly lower. It was established that the shielding of thermal energy for all experiments occurs with a high efficiency of 85–88 %. Moreover, in all experiments, a decrease in the burning intensity of the fire was observed.

2. The dynamics of temperature reduction of heated gases in the superstructure during the operation of the excess air pressure system in the emergency hatch on the basis of JWGE were determined. Thus, it was established that the inertia of temperature reduction in the superstructure is due to the heat transfer from the horizontal overlap between the emergency room and the superstructure. At the same time, the presence of thermal insulation on the body of the superstructure also has an additional effect. The specified factors influenced the decrease in the intensity of heat loss to the environment. But already on the fourth minute of operation of JWGE, the temperature in the middle part of the room dropped to 65 °C. Such a decrease in temperature can be explained by the fact that the flow of the steam-gas-air mixture from the outlet nozzles of JWGE captured the inside of the emergency room and the gas-air environment from the superstructure.

Inside the emergency compartment, temperature changes at the initial stage of operation of JWGE occur insignificantly, with the exception of the lower part of the emergency room. Again, special feature of the flow of the gas phase in the area of the emergency hatch contributes to the intensive mixing of the gas-air environment in the fire compartment, which leads to an increase in the temperature in the lower part of the room.

Shielding of thermal energy for all experiments occurs with an efficiency of 85–88 %.

Conflicts of interest

The author declares that he has no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The author confirms that he did not use artificial intelligence technologies when creating the current work.

References

1. Hrynchak, S. (2024). Determining performance characteristics of jet water-gas ejectors for an opening in a vertical fencing structure. Eastern-European Journal of Enterprise Technologies, 3 (10 (129)), 21–32. https://doi.org/10.15587/1729-4061.2024.305828
2. Miroshnichenko, V. N., Sokolov, V. V., Sheverev, E. Iu. et al. (2002). Issledovanie dymoosazhdaiushchei i okhlazhdaiushchei effektivnosti ustroistv UDP GIBK. 065289.001. Naukovii visnik UkrNDIPB, 1 (5), 76–82.

3. Zatcarinnaia, T. G. (2004). Lokalizatciia gazovozdushnogo potoka (dyma) vodianoi zavesoi reguliruemoi tolshchiny orosheniia. Zbirnik naukovikh pratc, 1 (4), 238–243.
4. Kuripko, O. V., Nikitin, E. V., Anokhin, G. A. (2002). Povyshenie ognestoikosti korabelnykh ograzhdaiushchikh konstruktcii: puti i metody issledovanii. Zbirnik naukovikh pratc, 1, 164–169.
5. Blintsov, V., Hrynchak, S. (2017). Development of the improved methods of fight against distribution of smoke on ship with systems of jet water–gas ejectors. EUREKA: Physics and Engineering, 6, 35–41. https://doi.org/10.21303/2461-4262.2017.00498
6. Blintsov, V. S., Hrynchak, S. O. (2017). Theoretical substantiation of the method for designing ship apertures with the use of the air suppression system based on the jet water-gas apparatus. Collection of Scientific Publications NUS, 470 (3), 11–20. https://doi.org/10.15589/jnn20170302
7. Hrynchak, S. O. (2016). Pat. No. 110777 UA. Sposib pidporu povitria v avariinomu liuku i prystrii dlia yoho realizatsii. MPK A62C 3/00. No. a201206290; declareted: 24.05.2012; published: 25.02.2016, Bul. No. 4, 4.
8. Mayerhöfer, T. G., Pahlow, S., Popp, J. (2020). The Bouguer-Beer-Lambert Law: Shining Light on the Obscure. ChemPhysChem, 21 (18), 2029–2046. https://doi.org/10.1002/cphc.202000464
9. Oehlert, G. W. (2010). A first course in design and analysis of experiments. Minneapolis: University of Minnesota Press, 679.
10. Jiju, A. (2014). Design of Experiments for Engineers and Scientists. Elsevier Ltd, 276. https://doi.org/10.1016/c2012-0-03558-2
11. Design of Engineering Experiments. Available at: https://www.studysmarter.co.uk/explanations/engineering/professional-engineering/design-of-engineering-experiments/ Last accessed: 08.04.2024
12. Roy, R. K. (2001). Design of experiments using the taguchi approach: 16 Steps to product and process improvement. John Wiley & Sons, Inc., 544.