Determination of training conditions of fire-fighters in mobile training complexes

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Abstract. The conditions created during training of firefighters in the mobile training complex of the Polish company «Egeria group» are considered. Currently, the determination of the parameters of the gas environment created by the combustion of pure propane (C_3H_8), vaseline oil and nitrogen oxide (N_2O) over a period of time remains a problematic issue. At the same time, the conditions, which are created when combustion in such cameras, namely, the approximate temperature, the composition of combustion products, their volume during training in mobile training systems remain unexplored. The determination of the amount of combustion products was carried out by solving the equations for determining the material balance of the process of combustion of propane at the maximum temperature created by the mobile training complex and room temperature. As the calculations performed in the mobile training complex during the burning of propane to obtain a high temperature, the oxygen concentration in the air will remain safe – 20.16%. This will gradually increase the content of CO_2, N_2 and H_2O vapour, since the composition of the products of combustion in the percentage ratio will be: CO_2 = 11.63%; H_2O = 15.5%; N_2 = 72.87%.

1 Introduction

It is hard to imagine the extinguishing of fires and the elimination of emergency situations without the use of the self-contained breath apparatus (SCBA), because in the course of evolution, humanity has invented many different materials which are now used in everyday life, combustion of which produces toxic combustion products that are capable of poisoning the human body - almost instantaneous. Therefore, the rescuers must work in the means of personal protection equipment of the respiratory and vision organs (hereinafter referred to as the PPE and SCBA) in order to avoid the risk of poisoning.

In order to carry out assignments, the firefighters must be in constant physical and psychological readiness. This is achieved by training and practical work on fires and emergency situations, in which the firefighters are exposed to considerable physical activity and psychological stress. [1, 2].

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After analysing some types of mobile training systems (Combined training system (Dräger), KIO), Russian (PTT Grotto, PTS Lava) and Polish (Mobile Fire Trainer ML 2000), the most optimal version was chosen for the ratio of versatility, efficiency, profitability and safety. Accordingly, for use in the garrisons of the State Emergency service (SES) of Ukraine, it could be the Mobile Fire Trainer ML 2000 the Polish company "Egeria group". The simulator became widespread not only in Poland - he was successfully used for training rescuers from Europe and the United States [3].

Currently, the determination of the parameters of the gas environment created by the combustion of pure propane (C_3H_8), vaseline oil and nitrogen oxide (N_2O) over a period of time remains a problematic issue in order to confirm that the parameters of the environment demand using SCBA and at the same time is conditionally safe.

Therefore it is planned to determine the conditions: which are created when combustion in such cameras, namely, the approximate temperature, the composition of combustion products, their volume during training in mobile training systems.

2 Material and Methods

The fire trainer ML 2000 was investigated. It is a mobile van, located on a semitrailer (Fig. 1), with dimensions 12×2,5×2,4 m, with a volume of 72 m^3. Taking into account that the trailer is folding and accommodates auxiliary premises (operator, smoke generator, etc.), the internal volume of the fire room itself is about 65 m^3. Figure 2, presents a scheme of the mobile training system in which the main room consists of two rooms separated by a partition with a dismantled door.

Fig. 1. General view of mobile training system «Mobile Fire Trainer ML 2000» by Egeria group (Poland).

The Figure 2 also depicts the auxiliary rooms and burners. The fire room is isolated, which excludes the penetration of smoke and heat into other premises.

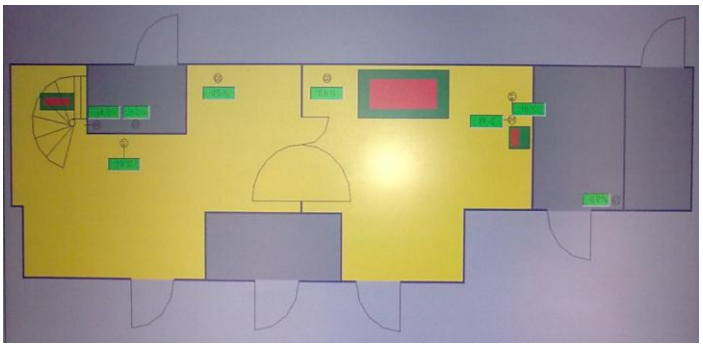

Fig. 2. Scheme of mobile training system «Mobile Fire Trainer ML 2000» by Egeria group (Poland).

The simulator ML 2000 allows training the firefighters in conditions that are as close as possible to the fire conditions. The temperature which it creates is an alternative to the real fire – 800 °C. It is provided by the combustion of pure propane (C_3H_8 – ignition temperature 504 °C) on fire burners [4]. In addition to the temperature, at the burning of propane, 3 moles of CO_2 and 4 moles of water vapour are released and the nitrogen concentration in the air increases.

$$C_3H_8 + 5(O_2+3.76N_2)=3CO_2+4H_2O+5\times3.76N_2 \quad (1)$$

3 Results

According to the research conducted on one session in a simulator with maximum conditions (with high temperature and dense smoke), lasting an average of 10 minutes, it consumes about three litres of propane.

Thus, we determine the required amount of air necessary for burning 3 litres of propane:

$$\underset{\frac{3}{22.4}}{\overset{1mole}{C_3H_8}} + 5(O_2+\underset{X}{\overset{5mole}{3.76N_2}}) = 3CO_2 + 4H_2O + 5\cdot 3.76N_2 \uparrow$$

$$X = \frac{5\cdot 3}{22.4} = 0.67 \ moles$$

$$V_a = V_0 \cdot \beta \cdot 4.76 = 71.4 \ litres$$

V_a - full theoretical volume of air; β - stoichiometric coefficient; V_0 - volume of combustible matter.

Moreover, the amount of oxygen is sufficient for human safety.

$$V_{O_2} = \frac{V_a}{4.76} = 15 \ litres$$

With regard to combustion products, they can be determined by calculating the material balance of the propane combustion process [5] at the maximum temperature created by the mobile training complex and room temperature:

$$C_3H_8 + 5(O_2+3.76N_2)=3CO_2+4H_2O+5\times3.76N_2\uparrow$$
$$M(C_3H_8)=3\times12+1\times8=44\ kg/kmol; \quad (2)$$

$$V_t = \frac{T \times P_0 \times V_0}{P \times T_0} = \frac{293(1073) \times 101.3 \times 22,4}{100 \times 273} = 24.4(89.19)\ m^3;$$

V_t - molar volume of gas from the Boyle–Mariotte law.

$$n_a = 4.76 \times \beta = 4.76 \times 5 = 23.8\ kmol; \quad (3)$$

n_a - number of kilomoles of air

$$n_{pc} = 3 + 4 + 3.76 \cdot \beta = 25.8\ kmol \cdot \quad (4)$$

n_{pc} - number of kilomoles the products of combustion.

Volume of air and products of combustion:

$$V_a^o = \frac{4.76 \times \beta \times V_t}{M} = \frac{4.76 \times 5 \times 24.4(89.19)}{44} = 13.2(48.24)\ m^3; \quad (5)$$

V_a^o - specific theoretical volume of air.

$$V_{pc}^o = \frac{n_{pc} \times V_t}{M} = \frac{25.8 \times 24.4(89.19)}{44} = 14.14(52.3)\ m^3 \cdot \quad (6)$$

V_{pc}^o - specific theoretical volume the products of combustion.

Composition of combustion products

- content CO_2

$$\omega(CO_2) = \frac{n_{CO_2} \times 100}{n_{pc}} = \frac{3 \times 100}{25.8} = 11.63\% \quad (7)$$

- content H_2O

$$\omega(H_2O) = \frac{n_{H_2O} \times 100}{n_{pc}} = \frac{4 \times 100}{25.8} = 15.5\% \quad (8)$$

- content N_2

$$\omega(N_2) = \frac{3.76 \times \alpha \times \beta \times 100}{n_{pc}} = \frac{3.76 \times 1 \times 5 \times 100}{25.8} = 72.87\% \quad (9)$$

Thus, based on the calculation of the material balance under the conditions of maximum temperature and initial as well (20 °C), when burning a kilo of propane mole, at least 14.14 m^3 of combustion products will be formed, with the following composition of CO_2 = 11.63%; H_2O = 15.5%; N_2 = 72.87%.

Therefore, the combustion of propane in a mobile training complex to obtain a high temperature will negligibly reduce the concentration of oxygen in the air and gradually increase the carbon dioxide and nitrogen content. However, this interference in the gas environment of the simulator ML-2000 is not limited.

In order to obtain smoke in the simulator burns vaseline oil and nitric oxide (N_2O). Vaseline oil - refined oil fraction, obtained after distillation of kerosene, in which there is no harmful organic substances and their compounds [6]. Colourless oily liquid, odourless and taste free. It is a mixture of kinds of paraffin and petroleum hydrocarbons, so there is no clear structural formula.

$$2N_2O \xrightarrow{170^\circ C} \underset{66\%}{2N_2} + \underset{33\%}{O_2}\uparrow \quad (10)$$

From formula 10 it is evident that during the reaction 33% of oxygen and 66% of nitrogen are formed. Nitrogen – colourless gas, without odour and taste, does not support breathing or burning. In normal conditions, nitrogen is physiologically inert, but when inhaled under pressure (compressed to 2-2 ½ kgf/cm^2), a state called nitric anaesthesia occurs similar to alcoholic intoxication [7].

As you can see, when working with the mobile complex ML 2000 together with the flame, temperature and smoke, water vapour, carbon dioxide and nitrogen are formed. All of them influence on the health of the firefighter working in SCBA.

Water vapour, penetrating in all unprotected places, will stimulate firefighters to reliably protect all parts of the body before entering the fire zone and will encourage them to prevent the penetration of gases from the environment into sub-mass space. The presence of nitrogen and carbon in the air to a large extent will not affect the body of firefighters, but inhaling them in large quantities will cause some irritation of the respiratory tract and will make "irritating effect." This is not a disadvantage, because the smoke is absolutely safe and will only force the personnel to work in PPE and SCBA with full tightness, as in the case of fire extinguishing.

Thus, the presence of high temperature, dense fog, limiting visibility, and natural fire, which strengthens psychologically, allow conducting classes with firefighters in conditions close to the real fire.

Under real conditions, corresponding loadings are created, which are provided by the training scenarios. The ML-2000 simulator has three fire burners areas which simulate several sources of fire in one room. The first one is the "Fire Stairs", which creates a fire under a metal staircase. The second one is the burner «Universal», imitates combustion in the living room, it can be simulated for combustion gas cylinder, household appliances (TV, etc.) and furniture, as shown in Figure 3.

Fig. 3. Variants of burner modeling «Universal».

The third burner is special – it's a «Flashover» that imitates the phenomenon of backdraft, it enables the supervisor to control that the training staff is ready for a sudden threat and a successful suppression (Figure 4). The entire training process is accompanied by acoustic panic simulators, explosions, a collapses of structures at a fire, etc. In general, there are more than 20 types of the Polish mobile complex [8].

Fig. 4. Training of the firefighters in the simulator with the use of the burner – «Flashover».

The mechanism of operation of each fire burner is based on the use of sensors that take into account the amount of water fed to the extinction, in accordance with the temperature. When enough water is collected, the fire automatically fades out, and in the case when the jet is not supplied accurately (with the required intensity), the fire of the flame will increase. Each of the burners areas must be extinguished and necessarily cooled, otherwise, for some time, the fire will flash again.

Taking into account the number of fire burners and the similar number of inputs and outputs, the training scenario can be diversified without repetitions. You can change the internal layout of the premises, the task of the unit (finding a victim or ballooning), the place of fire, to simulate a re-ignition and the emergence of a sudden threat. And combining

these variants, we will be able to carry out the training is not similar to one on one, which will not make possible for firefighters to get used to such classes.

You can manually monitor the course by using a remote control that allows you to adjust all processes of the mobile training complex. You can also do this by programming a scenario using a computer. However, even having determined in advance the course of conducting classes through programming, the chief has the opportunity at any time to intervene for its correction, termination or implementation of manual management. This guarantees the complete safety of the training process.

In general, the computer system automatically monitors all processes during operation. The mobile training trainer Mobile Fire Trainer ML 2000 is equipped with dozens of sensors that give their impressions to the computer, which allows the supervisor to constantly monitor the condition inside the simulator while in the operator room.

The temperature sensors located in the zone of each of the burners provide the display of temperature in the centre of the burner itself and near it, in the area where the personnel trains undergo training. In addition, the sensors are located throughout the room simulator and at different altitudes, which informs the supervisor about the temperature for firefighters at the level of the eye when they move onwards and in full height.

Given that the water for extinguishing flames in the simulator is fed into the burner area, there is a likelihood of its penetrating in the middle, which will lead to gas accumulation.

As a result, the gas will be unevenly distributed and there will be a threat of explosive concentrations. To prevent such situations, sensors are used that continuously show the concentration of propane in percentages per burner.

Data is displayed on a general circuit on a computer and can trigger an emergency ventilation system automatically.

In normal operation, indicators rarely exceed 5% of the limit, in the event that something similar happens, the operator will receive the first warning, "Signal of moderate danger" when reaching 15% concentration, then the "Medium danger signal" – 25% concentration, but the last warning, "Maximum danger signal" when reaching 35% concentration.

After the last notification, the system will automatically stop the work of the simulator and activate the emergency ventilation system, which will completely prepare ML 2000 for re-use in 30-60 seconds.

You can also stop the work of the mobile training complex by using the «STOP» button, of all there are four buttons: two are located in the fire room near the exits, which will allow you to stop the class if the condition of someone of firefighters is deteriorating, and on the control panel and in the operating room as well.

Hence, effective and diverse workouts are quite reliable and safe, since it uses the most advanced technology and advanced automated computer system.

Despite the strict training conditions, training in the ML 2000 remains absolutely safe due to its equipped with dozens of modern sensors, advanced computerized automated control system and the use of environmentally friendly substances that do not have toxic combustion products.

Conducting the classes in the Polish mobile complex will always be relevant, as the scenarios of possible training can be quite diverse and sudden, with no repetition. The number of fire burners, the number of inputs and outputs, the ability to change the layout of the premises, the re-occurrence of combustion and the sudden emergence of danger, all in a combination allows you to constantly change the tasks for the firefighters during the classes.

On the whole, this diversity will be effective if you perform tasks in a certain sequence, incrementally increasing the load and complicating the workout scenario. This will enable correctly predict and spend the resources necessary for the work of the simulator and

equally and regulated to conduct classes with all firefighters, as well as to demand clear results from them. Therefore, for the effective preparation of the firefighters on the basis of mobile training complexes, a methodology for holding classes is required.

4 Conclusions

As demonstrated by the calculations made on the example of the installation of the Mobile Fire Trainer ML 2000 by the Polish company Egeria group, in the mobile training complex, when burning propane to obtain a high temperature, the oxygen concentration in the air will remain safe – 20,16%. This will gradually increase the content of carbon dioxide, nitrogen and water vapour, as evidenced by the calculation of the material balance, since the composition of the products of combustion in the percentage ratio will be: CO_2 = 11.63%; H_2O = 15.5%; N_2 = 72.87%.

In turn, the smoke mixture obtained from the burning of vaseline and nitric oxide will contain carbon and nitrogen, which will act "irritant" in the event of penetration into the respiratory organs of firefighters without SCBA. Training in such conditions stimulates the personnel to provide reliable protection during training, ensures the development of physical, moral and psychological hardness, which will promote the high professionalism of firefighters working in SCBA.

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