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Improving the Quenching of the Undercarriage Space due to the Adhesive Properties of Gel-Forming Compositions

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Abstract. The issue of increasing the technological and technical capabilities of firefighting undercarriage space at subway stations due to more efficient, due to adhesion to the burning surfaces of gel-forming compositions is considered. It is proposed to use a special cart to deliver the gel-forming system $Na_2O{\cdot}2{,}95SiO_2 - CaCl_2$ to hard-to-reach locations of electromechanical and other equipment of electric trains. The analysis of these experiments is carried out by comparing the time and mass of spent gel-forming compositions, water, fire-extinguishing powder when extinguishing model hearths close to the real undercarriage space. It is determined that due to the adhesion of the gel to the surface of the combustible substance, it is possible to reduce the loss of extinguishing agent in comparison with water or extinguishing powder.

Introduction

In recent years, when extinguishing various fires, it is proposed to use new, inexpensive, fire-extinguishing substances such as gel-forming compounds (GFC) [1]. Indeed, modern HUSs consist mainly of two separately stored components that can be fed separately and simultaneously to the fire. One of them is a solution of gel-forming silicate of an alkali metal, the other is a solution of a substance which, interacting with silicates, forms a stable gel layer. The cost of such HUS, compared to fire extinguishing powder, which is equipped with most primary fire extinguishers, is 3 times cheaper. In addition, they have sufficiently stable adhesive properties, which allow them to reliably adhere in layers to the burning surfaces, thereby reducing many times the amount required to extinguish the extinguishing agent.

In [2] it was proved that silicate systems $Na_2O{\cdot}2{,}95SiO_2 - CaCl_2$ and $Na_2O{\cdot}2{,}95SiO_2 - K_2CO_3$ have good adhesion to various materials, higher mechanical strength than similar swellable mixtures and other gels. Moreover, gels made with calcium and magnesium gelation catalysts create strong layers on wood surfaces (subway car floor – wooden) and on metal structural elements (car and trolley constructions – metal). These layers have strong adhesion to surfaces of solid materials and retain their integrity when exposed to fire.

The gel, which creates a fire-retardant layer on the surface of the fire extinguishing object, prevents access of oxygen to the air, stopping the burning. This layer, due to its adhesive properties, is securely fixed on inclined and vertical surfaces (even on the ceiling), which, in comparison and in contrast to the use of powder fire extinguishing significantly reduces the losses associated with the deposition of the latter.

In [3], it was determined that gelling systems with ammonium gelling catalysts $((NH_4)_2SO_4{+}NH_4H_2PO_4$ + $Na_2O{\cdot}2{,}7SiO_2$ and $NH_4H_2PO_4$ + $Na_2O{\cdot}2{,}7SiO_2$ create less strong gel layers, with low adhesion to hard surfaces. When heated, they crack significantly and may crumble like powder. During thermal action, they are characterized by delamination of some fragments of the coating and their dumping, although after delamination on the surface, it does not ignite long

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With regard to the comparison of the fire-fighting capacity of GFC systems and water-based solutions, the following should be noted. Due to their adhesive properties, gel-forming systems are firmly attached to the surface of the object, which is protected during firefighting, which significantly affects the rate of their fire-fighting capacity. Indeed, when extinguishing solid combustible materials, this figure, determined by the ratio of the mass of extinguishing agent per unit area of the model hearth, in the GFC is much lower than when using water. Due to the fact that the use of GFC systems on the surface of the fire extinguishing object creates, as already mentioned, a fire-retardant layer of gel, which has a stable adhesion, which allows it to firmly attach itself to various surfaces.

It should be noted that many works of practical use of GFC in firefighting [4, 5] are based on combining the advantages of chemical and technological capabilities of HUS, which are associated with "wrapping" layers of gel burning surfaces, along with tactical and technical features of operational delivery of this new fire extinguishing warehouse to burning objects. In one recent study [6] it was possible to create a mobile fire extinguishing system with gel-forming compounds, which was installed on a cart with special wheels to overcome various obstacles (such as stairways). Tests of this installation have shown its high efficiency in extinguishing non-traditional fires, which include fires in subways, where there are obstacles in the way of firefighters and rescuers in the form of sleepers and half-sleepers in tunnels and subway stations.

To date, powder fire extinguishers of two types are mainly used at metro stations and in subway cars: in VP-5 portable cars, and in VP-50 mobile stations. Both are primary fire extinguishers [7]. Portable VP-5, located in each car, can be used by passengers in case of minor fires in the cabin. Mobile VP-50s are provided to extinguish significant fires that may occur and spread elsewhere at the station, including the electric train delivered to it. Naturally, their involvement is associated with the arrival of the train in which the fire broke out at the station, disembarkation of all passengers from cars and mandatory in all cases of fires in the subway, with the disconnection of the catenary voltage [8].

When the elements of the undercarriage equipment ignite, it is obvious that the use of car fire extinguishers VP-5 through the hatches in the floor of the car due to the limited amount of fire extinguishing powder in them (5 kg) is not effective.

In such cases, for extinguishing under the car more suitable, due to the greater amount of extinguishing powder (50 kg), can be considered station VP-50, which are located at both ends of the platform at all stations. But it takes a long time to get involved and there are some obstacles involved. Such as: moving on the platform in conditions of chaotic evacuation of passengers from cars and station, setting up to supply to the undercarriage space of sprayed fire extinguishing powder through hatches or through gaps between cars, car and platform, with strict compliance with safety rules by station workers. In such conditions, firefighting can be carried out almost only "at random" - without any monitoring of the accuracy of the powder in the fire, and this does not add confidence in the result of localization or elimination of fires in the undercarriage space of the electric train. That is, the process of extinguishing such fires depends significantly on the human factor.

A similar archaic scheme of extinguishing fires in the undercarriage space of the metro is proposed in [9]. burn under the car.

To get rid of these shortcomings in extinguishing such fires in [10] was proposed a special two-axle cart undercarriage fire extinguishing. It is proposed to solve the problem of undercarriage fire extinguishing in the subway due to the fact that two powder fire extinguishers VP-50 are placed on the frame of a two-axle cart. The cart is located on a guide track located inside the main track of subway cars between the half-sleepers in the recess of the reservoir tray. The wheelsets of the special trolley are connected by their frame to the looped cable of the traction winch, which operates on the principle of "pull-push".

The control system of the trolley movement is autonomous and is equipped with a temperature sensor and a tachometer sensor, by means of which the next station (operator) monitors the traffic mode, depending on the approach of the fire extinguisher trolley to the fire in the carriage space. The mode of opening of shut-off devices of fire extinguishers is carried out remotely by radio signals. Fire extinguishers with spent fire extinguishing powder can be quickly replaced with filled ones when the cart is returned to its location. As a result, the efficiency of extinguishing this technique is fundamentally increased.

However, in general, powder extinguishing [11] is prone to such a natural phenomenon as the deposition of powder particles on the ground (in this case - on the rail-sleeper lattice), and this reduces the volume concentration of extinguishing agent (powder) under the burning car. in this case, the combustion processes of the undercarriage equipment may not subside, as a result of which the flame may spread uncontrollably throughout the car and the train, and in a relatively short period of time (10-20 minutes) the unit of rolling stock burns out. For a comparative assessment of this undesirable phenomenon, we emphasize that the operating time of one VP-50 is 20 seconds.

Given the fact that in a fire in the subway electricity is not supplied to the catenary, it becomes possible to talk about the potential benefits of using GFC for undercarriage firefighting at subway stations. Moreover, one of the advantages of extinguishing with the use of GFC is the high fire-retardant capacity of gelling compounds, which is due to the cooling effect of the water contained in the gel, which evaporates over time. After evaporation of all water from the gel mixture, a porous layer of dried gel (xerogel) is formed, which actually eliminates the re-ignition of combustible material of the object due to the low thermal conductivity of xerogel [12].

Thus, it should be considered that the use of more effective fire extinguishing agents, in particular GFS, together with new devices for their use in subway fires is a promising task to solve the dual problem of improving fire protection measures at subway stations.

2 Main part

This paper proposes an additional direction to increase the efficiency of extinguishing different types of surfaces in the undercarriage space of subway cars, based on the integrated use of adhesive properties of GFC and special delivery of these fire extinguishing compounds under subway cars to fire-hazardous places.

The aim of the work is to improve the efficiency of firefighting of various equipment in the undercarriage space of cars at subway stations due to the adhesive properties of gel-forming compositions.

Materials. During the research, the analysis of information on fires and fires in the subways of Ukraine and the world in recent years [13]. In our workit was testified that the wooden floor of cars, traction electric motors (TED), power and switching cables made of rubber-like hydrocarbons and polymer materials, traction gearboxes filled with fire-hazardous lubricants, etc. are considered vulnerable from the point of view of fire safety. Their fire load, distributed on the floor relatively evenly and ranges from 45-50 kg / m2, depending on the type of car. Be it: model 81-714 (717), or model 81-718 (719), operated in the subways of Ukraine (Fig. 1 and Fig. 3).

Moreover, the carriage space is virtually inaccessible location of the specified fire, load.

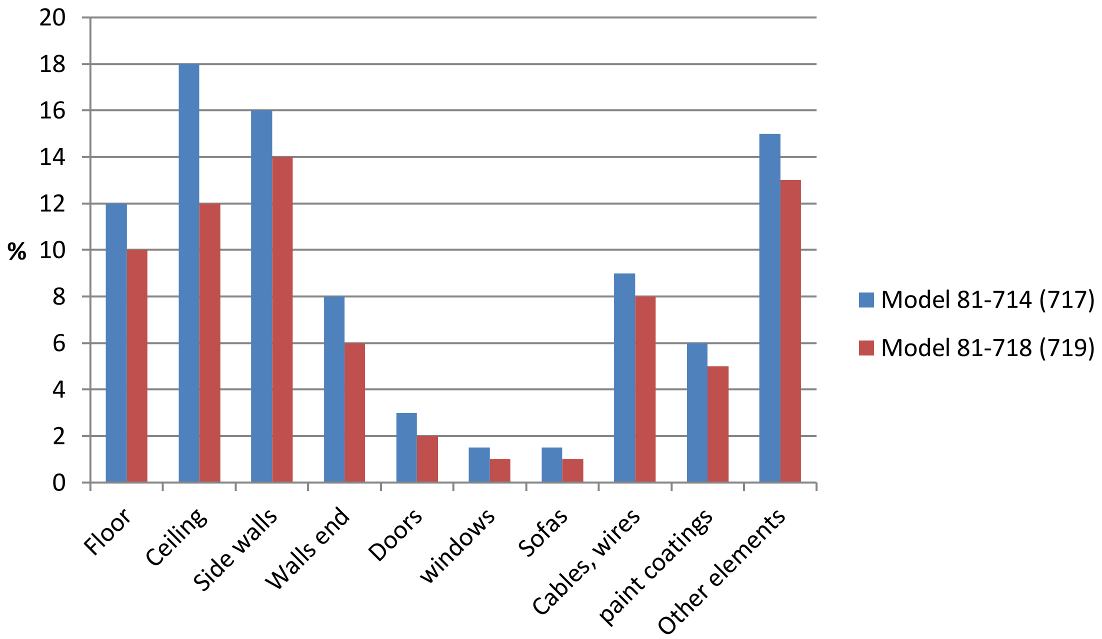


Fig. 1. Percentage of ways of spreading fires from relevant sources

In addition, it should be noted that the main part of the materials and equipment of cars contributes to the rapid spread of flames and the spread of leakage of toxic gases, which in case of fire poses a risk of poisoning by combustion products (Fig. 2). All this causes significant difficulties for firefighters.

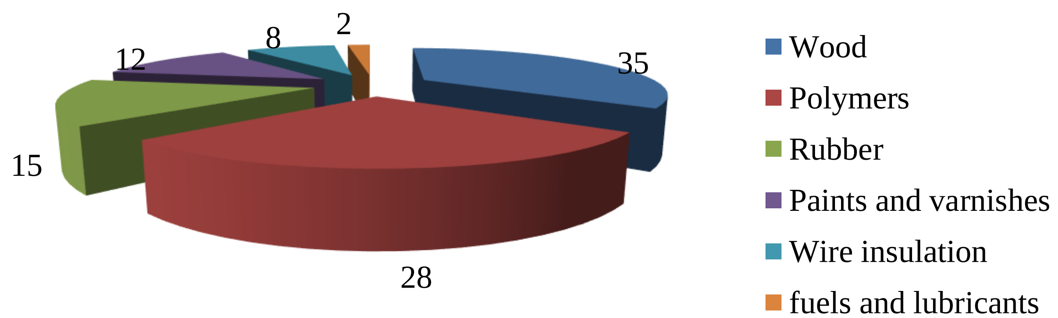


Fig. 2. Percentage of fire-hazardous elements of subway car equipment

It is known that the fire hazard of the subway is associated with the mandatory presence of three components of the combustion process, namely: combustible substances, sources of ignition and oxygen. The most characteristic of the subway are sources of ignition of electrical origin, as the entire subway is permeated with electrical communications with a voltage of 12 V to 10 kV. Also typical is the use of combustible materials in rolling stock, office space and the presence of oxygen in the air, which is forcibly supplied to subway buildings. However, given that oxygen and air move along tunnels, stations and cars, in terms of fire hazard, almost all equipment of subway cars should be considered as a specific fire load, which is not always available.

In particular, the space under the car is a very vulnerable place for uncontrolled fires and their spread (Fig. 3). Since the rate of air flow with oxygen is relatively high and the most probable sources of ignition are concentrated here (short circuits, technological overheating during braking, etc.).

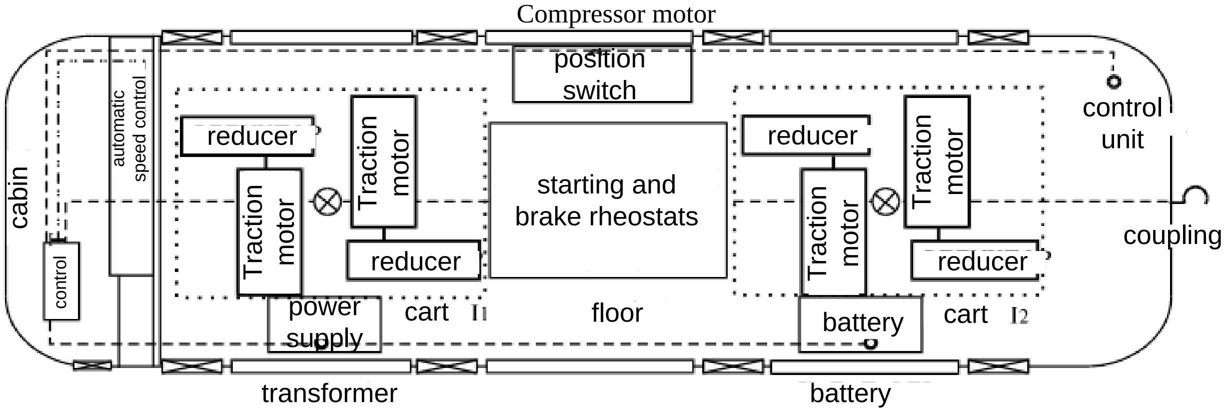


Fig. 3. Scheme of location of fire-hazardous places under the car space of the subway car.

Tests. Knowing the shortcomings of the use of fire extinguishing powder in extinguishing under the car and taking into account the need to supply fire extinguishing agent (BP) from the bottom up on sloping surfaces in the undercarriage space, the effectiveness of extinguishing such fires was studied. To increase the efficiency of extinguishing used HUS, which in different conditions have a strong adhesion to the surfaces of fire extinguishing, thereby minimizing the irrational loss of explosives.

Delivery of GFC to the undercarriage space is offered to carry out by means of the special cart (fig. 4). Such a trolley contains two cylinders placed on the frame of the narrow gauge with GFC components attached to the frame by clamps with locks, and has two wheel pairs that together with the frame create a movable trolley. The first and second wheel pairs, a special cart, connected by a cable to a drum winch with a corresponding drive, operating on the principle of "pull-push". The cart itself is mounted on narrow tracks, in the middle of the main track of subway cars. Each cylinder is filled under pressure with one GFC component and connected via a shut-off device to a special nozzle that mixes and sprays the GFC components on the burning elements of the undercarriage equipment. The trolley is pulled by the winch over the entire area of the fire as many times as needed to stop the burning under the car.

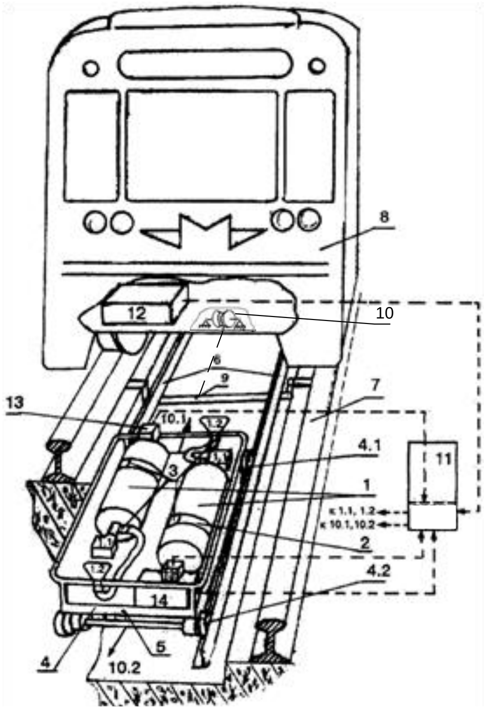
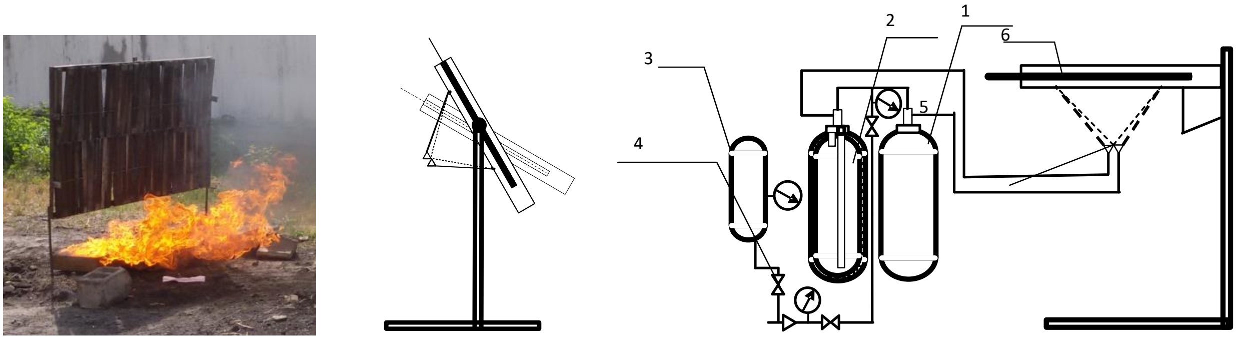


Fig. 5. The device of undercarriage extinguishing: 1 - cylinders with GFC components; 2 - fastening clamps; 3 - fastening locks; 4 - cart; 4.1, 4.2 - first and second wheel pairs; 5 - coupling; 6 - narrow gauge road; 7 - main track; 8 - subway car; 9 - sleeper; 10. - traction winch with a cable "pull-push", 11 - control system of the trolley; 12 - car movement control system, 13 - temperature sensor; 14 - tachometer

To more accurately determine the benefits of GFC to the most common extinguishing agents used in extinguishing fires under a subway car, in our work were conducted close to reality comparative experiments to determine the effectiveness of extinguishing model fires. To implement practical experiments, a fragment of the floor of the car was made, which in its fire load coincides with the model hearth 1A (Fig. 6).

Fig. 6. Imitation of the car floor, which in its fire load is close to the model hearth 1A.

Research of efficiency of extinguishing of undercarriage space. The supply of GFC components to model hearths was carried out by a mobile fire extinguishing system with gel-forming compounds, which can overcome various obstacles in its path [6]. To bring the conditions of the experiment as close as possible to the actual extinguishing of the undercarriage space, a special stand was made (Fig. 7), which allowed to change the position of the model hearth in space to the position of the conditional ceiling-floor. Thanks to a special stand, the extinguishing agent was supplied to the model hearth located at a variable angle α (Fig. 7, b), up to the bottom-up supply to the horizontally located surface (Fig. 7, c).



a) b) c)

Fig. 7. The scheme of the bench installation for an estimation of efficiency of extinguishing of model hearths: a) the hearth is located vertically; b) the hearth is located at an angle of 30 ° and 60 °; c) the hearth is located horizontally at an angle of 90 °; 1 - container with an aqueous solution of the gelling agent; 2- container with an aqueous solution of gelation catalyst; 3 compressor; 4- valve; 5-spray; 6- model hearth.

The procedure for lighting the model hearth had the following sequence. A model hearth was placed on the stand, under which a pallet was inserted, in which 1 liter of gasoline was poured over a layer of water (Fig. 7, a). Gasoline caught fire. After complete burnout (in 3 minutes) the pallet was removed. The free burning time was chosen equal to 1 minute The total ignition time of the model cell was 4 minutes, after which the supply of extinguishing agents began. Extinguishing efficiency was characterized by the period of time from the beginning of the supply of the solution to the cessation of combustion. The result was considered positive if extinguishing lasted up to 40 s and for 600 s after the end of extinguishing, no flame was observed (Fig. 8). Another, no less important criterion of extinguishing efficiency was the mass of extinguishing agent extinguished, which was determined by weighing the installation before and after extinguishing.

From physical experiments (Fig. 8) it is clear that the adhesion of the gel layers actively prevents the extra cost of extinguishing the extinguishing agent GFS, due to runoff in contrast to water. Also, the adhesion of the gel to the surface is resistant to intense air flows of the subway, preventing the demolition of fire extinguishing powder particles by air flows. Thus, the consumption of GFC due to the stable adhesion of the gel layer to the burning surface is many times lower compared to other fire extinguishing substances that can be used in extinguishing the undercarriage space at subway stations.

Fig. 8 Adhesion of the gel layer on the surface of the model hearth made of wood

For statistical confirmation of the recognition of the best way to extinguish fires of any elements of undercarriage equipment, the created installation of Fig. 7, comparative experiments in the total volume of n = 180 were carried out on the average of 20 tests for each of the 3 types of explosives, determining the average values of time t of fire extinguishing by these extinguishing agents, at three specified angles of their supply αo (Table 1).

Table 1. Comparative data to assess the effectiveness of extinguishing at different angles of the model hearth with different explosives: GFS, water, fire extinguishing powder.

№	The angle α^o of the model hearth	GUS		water		fire extinguishing powder	
		Q, кг	t, c	Q, кг	t, c	Q, г	t, c
1.	30°	3	40	8,8	94,4	4,4	48
2.	30°	3,1	42	9	95	4,5	49
3.	30°	3	38	8,7	93	4,3	47
4.	60°	3,3	43	11,5	101	5,5	61
5.	60°	3,2	44	11,3	100	5,4	59
6.	60°	3,3	44	11,7	105	5,6	63
7.	90°	3,5	45	12,8	107	6,5	55
8.	90°	3,7	47	13	109	6,6	56
9.	90°	3,6	46	13,1	110	6,7	58

Note: Q - the cost of extinguishing agent; t– extinguishing time of the model hearth

Solving this problem of finding the dependences of the average time t of quenching on the angle of relative inclination of the BP supply device, we apply the known method of statistical analysis - regression analysis, which approximately approximates the dependences under study. The results are presented in the form of a graphical interpretation (Figs. 9, 10, 11).

Blue. (Fig. 9,10,11) implementation of the simplest linear regression, the analytical form of which will be:

for GFC solution – $t = 40{,}30 + 0{,}05444\alpha$;

for water – $t = 86{,}80 + 0{,}2544\,\alpha$;

for fire extinguishing powder: $t = 46{,}27 + 0{,}1422\,\alpha$.

Red colour. (Fig. 9, 10, 11) this is an approximation where the original data is attached to a second-order statistical polynomial.

for GFC solution we have: $t = -0{,}0003571\ \alpha^2+0{,}09730\ \alpha +39{,}23$;

for water quenching the dependence has the form: $t = -0{,}001786\ \alpha^2+0{,}4687\ \alpha +81{,}44$;

for fire extinguishing powder $t = -0{,}0075\ \alpha^2+1{,}042\ \alpha +23{,}77$.

Green. Regressions in the form of a polynomial of the third degree with the construction of their graphs and real points of their curves:

for GFC solution, we have: $t = 0{,}00006162\ \alpha^3 - 0{,}01125\ \alpha^2+0{,}6846\ \alpha+29{,}78$.

for water extinguishing: $t = 0{,}00001957\ \alpha^3 - 0{,}005245\ \alpha^2+0{,}6552\ \alpha+78{,}44$.

for fire extinguishing powder: $t = 0{,}00001614\ \alpha^3 - 0{,}004647\ \alpha^2+0{,}8884\ \alpha+26{,}2$.

In fig. 9,10,11 circles marked the average values of time t and showed that the best time for extinguishing fires is achieved by a solution of GFC at the angle of extinguishing $\alpha = 30^o$.

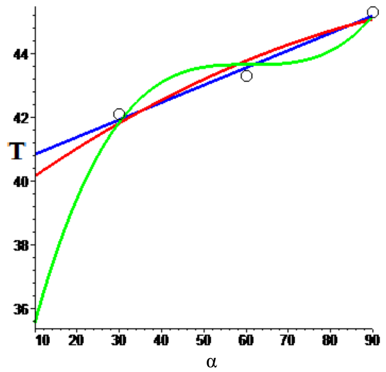


Fig. 9. Regression dependence of the angle of inclination on the average time t of quenching by GFC solution

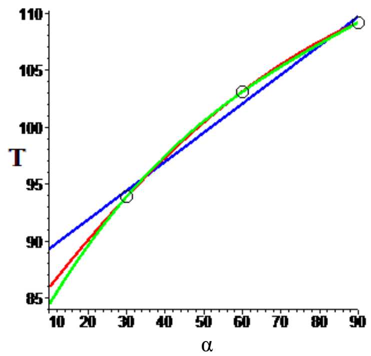


Fig. 10. Regression dependence of the angle of inclination on the average time t of quenching with water

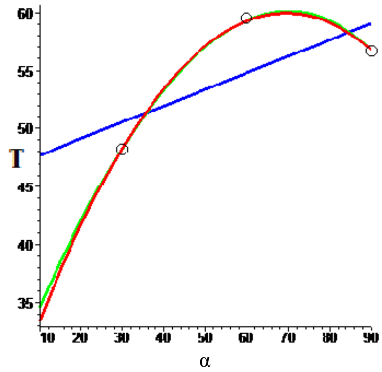


Fig. 11. Regression dependence of the angle of inclination on the average time t of powder quenching

Note: Figures 9, 10, 11 are other regressions, but for the same data on the slope of the BP supply device for quenching ($\alpha = 30^o$, $\alpha = 60^o$ and $\alpha o = 90^o$).

It is easy to notice that only for the second degree polynomial the points of the initial data fit exactly on the polynomial curve, because in this case (3 points) the regression turns into a polynomial approximation.

From the given data it is seen that the possibilities of using GFC in extinguishing the elements in the undercarriage space are many times superior in their fire-fighting ability to water and allow to extinguish the fire 2.5 times faster than water. Also, fire extinguishing powder has a fire extinguishing capacity lower than GFS, because it is spent 1.5 times more to extinguish the model and the extinguishing time is longer. In addition, fire extinguishing powder is three times more expensive and requires refueling at specialized enterprises, unlike GFS.

When conducting comparative experiments on extinguishing the model hearth, it was determined that changing the angle of the burning surface significantly affects the efficiency of extinguishing with water and fire extinguishing powder. This leads to additional irrational losses of extinguishing agent due to runoff and wear by air currents. However, the effectiveness of GFC extinguishing due to stable adhesion of the gel to the surface at different angles of inclination, remains stable, which further confirms the feasibility of their use in firefighting undercarriage space.

4 Conclusion.

1. The problem of increasing the technological and technical capabilities of firefighting in the undercarriage space of electric trains at subway stations is formulated.

2. To improve the quenching of the undercarriage space, it is proposed to use new, more effective, due to adhesion to burning surfaces gel-forming compositions. In order to ensure the supply of fire-extinguishing substances in hard-to-reach places under subway cars, it is proposed to use a special cart that moves inside the main track of the subway in the recess of the reservoir tray.

3. Comparative experimental studies on the advantages of GFC in relation to other fire extinguishing substances in extinguishing fires in the undercarriage space of subway cars. It is confirmed that the main advantage of the gel is the adhesion to surfaces with different inclination, which takes place in the undercarriage space. It is determined that due to the adhesion of the gel to the surface of the combustible substance, it is possible to reduce the loss of extinguishing agent 3 times compared to water and 1.5 times compared to extinguishing powder.

4. It is determined that when changing the angle of the fire extinguishing object, the efficiency of extinguishing with gel-forming compositions, as a result of stable adhesion of the gel to the surface, is not a change. However, when extinguishing with water or fire extinguishing powder with increasing the angle of inclination of the surface α to 90o, the efficiency of their fire extinguishing is reduced by 48 and 53%.

5. It is established that due to the synthesis of adhesive properties of GFC and special trolley of operative delivery of their components to burning elements of subcarriage equipment of subway cars positive results of increase of efficiency of fire protection against fires in subcarriage space of cars at subway stations are received.

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