

# PRODUCTION AND PERFORMANCE EVALUATION OF NOBLE FIRE EXTINGUISHING FOAM SUSPENSIONS USING LOCALLY AVAILABLE AND ENVIRONMENTALLY FRIENDLY NATURAL MINERAL RAW MATERIALS

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**Abstract:** The main goal of this research is the fabrication of halogen free, environmentally friendly fire-extinguishing powders using local mineral raw materials and the development of technological processes for producing highly efficient fire-extinguishing foam-suspensions on the basis of the produced powders. Fire-extinguishing powders are made by mechanical treatment and mixing of raw materials: zeolite, clay shale, perlite and ammophos. The process does not need introduction of expensive, halogen-containing, hydrophobizators and ensures the cost-effective production of fire-extinguishing powders. The obtained fire-extinguishing powders are characterized by high performance properties, high fire-extinguishing capacity and coefficient of atomic oxygen recombination. Thus, they are characterized both by homogeneous and heterogeneous inhibition of combustion processes. The efficiency of the produced powders is not inferior to that of standard powders of common production. In addition, in contrast to their traditional analogs they are halogen free, environmentally friendly and cheaper (1.2-2 times cheaper). The obtained powders, unlike the ones of conventional production, have good compatibility with water and foam. Our foam-suspensions are prepared just by mechanical mixing of fire-extinguishing powders with water and surface-active substances – foamers. The process does not require chemical treatment of materials. Thus, the developed technology is simple and cost-effective. The foam-suspensions produced on the basis of the obtained powders have higher heat capacity, permeability, wetting effect like water and foam and unlike them, they allow for homogeneous as well as heterogeneous inhibition of the burning process. Thus, the so produced foam-suspensions will have higher extinguishing effect than water, foams or powders, taken separately. Based on the above, it can be suggested that the produced powders can be used for extinguishing all types of fires, including large-scale ones in a combination with water and foams.

**Keywords:** Environmentally-friendly; Highly efficient; Fire extinguishing powder; Foam-suspension

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## 1. Introduction

Recently fires have progressively increased in a number and scales. The economic losses caused by fires are often catastrophic. They comprise several tens of billions dollars annually. Traditionally, CO<sub>2</sub>, water and foam are used for fire-fighting. But it should be mentioned that water is characterized by: high consumption (50l per 1 kg burning material), high electric conductivity, insufficient wetting capacity, and low adhesion to the object at extinguishing. Therefore, different mineral materials and surface-active substances - foamers - are added to water to reduce water surface tension,

increasing thus, permeability and wettability and decreasing consumption. Chemical foams are produced as a result of the action of sodium carbonates, bicarbonates, halogenides and nitrates with acids in the presence of foamers. Their efficiency depends on the temperature and concentration of mineral salts and foaming agents. Air-mechanical foam is produced by mixing a foam concentrate with water and air. Its action is conditioned by the thermo-insulation and cooling effect of the burning material. It is much more economical than the chemical one [1-5]. Unfortunately, the use of foams for extinguishing

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large-scale fires is associated with much consumption of water, mineral salts and surface-active substances; at the same time, foams are not universal and ecologically safe.

The mentioned traditional methods of fire extinguishing are rather expensive and low effective. Particularly frequent are the cases of poisoning and suffocation caused by the toxic gases produced by burning materials. Therefore, the world faces the urgent problem of fire localization and liquidation, as well as the development of preventive measures to ensure suppression of the burning material in the combustion zone and decrease in the toxic gases release during thermal destruction. The most urgent of these measures is the use of effective fire extinguishing substances. The best fire-extinguishers are powder fire extinguishers, which are characterized by high effectiveness and universality. They are most widely used in the cases when the use of traditional fire-extinguishing agents is not practical. Commercially produced fire-extinguishing powders mainly represent fine dispersed mineral salts modified with different halogen-containing, water-repellent hydrophobic agent of organic origin. Therefore, most of them are halogen-containing and do not comply with modern requirements, particularly in the view of universal, environmentally friendly and effective usage [6, 7].

Therefore, elaboration of non-halogen, non-toxic, and environmentally friendly fire-extinguishing agents is the most urgent global problem.

It should also be mentioned that fire-extinguishing powders are characterized by less heat capacity, low permeability and wetting effect as compared to water and foams; that is why upon fighting conflagrations, they cannot entirely solve the problem of re-ignition caused by inflammation of flickering focuses in open space. Based on the above, it can be said that for smothering conflagrations, particularly forest fires, the use of only fire-extinguishing powders is less effective [6, 8].

The main goal of this research is the fabrication of halogen free, environmentally friendly fire-

extinguishing powders using local mineral raw materials and the development of technological processes for producing highly efficient fire-extinguishing foam-suspensions on the basis of the produced powders.

Said fire-extinguishing powders are produced by mechanical treatment and mixing of raw materials. They do not need additional chemical treatment and introduction of expensive, halogen-containing, water-repellent hydrophobic agents. It ensures cost-effective production of powders against imported analogs. The raw materials - zeolite, clay shale and perlite are chosen because of their high-performance properties and with consideration of the factors facilitating reduction of the burning process. This is enabled by chemical and thermogravimetric analysis of the material. The mineralogical composition of utilized materials show that they are of silicate origin and contain alkali and alkaline-earth metal carbonates, bicarbonates, silicates, hydroxides, and water of crystallization. On the basis of a thermogravimetric analysis (TGA) it is stated that incombustible gases, water steam and metal oxides emitted upon their destruction promote inhibition of the burning processes in the combustion zone and formation of a swelled layer in the surface zone. This, in turn, means that the powders composed of such raw materials are, like efficient flame retardants, characterized by high inhibition properties. To raise the powder efficiency, optimal dispersity (up to 250  $\mu\text{m}$ ) was selected to ensure that the caking capacity be minimal, the powder feed be convenient (direct feeding of high-disperse powder into the ignition place creates many problems), the performance properties be satisfactory, and both the homogeneous and heterogeneous action of the burning process occurred [9-13].

For rigorous estimation of fire-extinguishing ability of extinguishing agents (compound fire extinguishing powders and foam-suspensions) both effects - heterogeneous and homogeneous inhibition of burning products are taken into consideration. Heterogeneous inhibition implies heterogeneous recombination of active centers (atomic oxygen and hydrogen), on the surface of

solid particles of the powder. Oxygen atom is one of the leading active centers of burning reactions. So, for the complex evaluation of extinguishing effect the special characteristics were selected: [12, 13]

- Reciprocal value of the extinguishing “surface” concentration -  $1/C_n \cdot S$ ;  
“surface” concentration can be determined by product of mass concentration ( $C_n$ ) on powder specific surface area ( $S$ ).
- Coefficient of atomic oxygen recombination -  $\gamma_0$ .

It is also stated that zeolites in composite powders are functioning as efficient hydrophobizers and zeolite-containing composite powders do not need introduction of any water-repellent hydrophobizing agents [11, 13]. Therefore, it can be assumed that the adding of various raw materials of high inhibitory properties to zeolite-containing composite powders will considerably increase the fire-extinguishing capacity rather than cause significant changes of the performance properties.

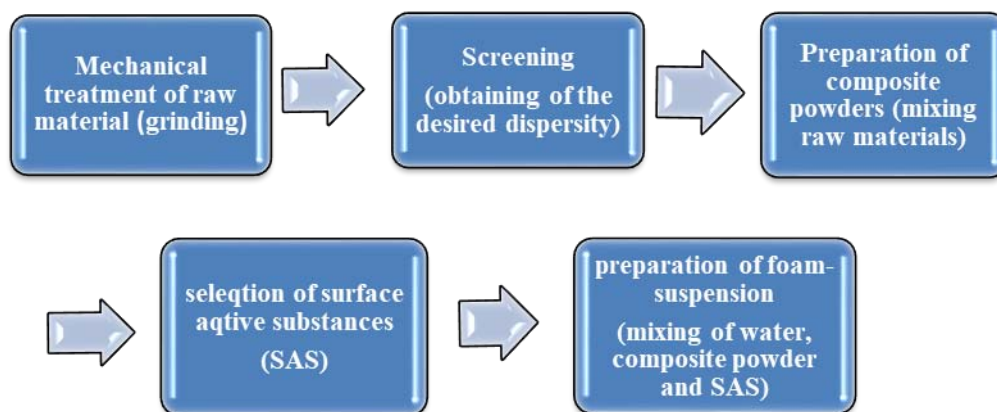
## 2. Materials and Method

The technological processes for production of foam-suspensions differ from the conventional

technologies for production of fire-extinguishing agents (Fig. 1).

Foam-suspensions are prepared just by mechanical mixing of produced powders, water and surface-active substances – foamers. The process does not require chemical treatment of materials. Thus, the developed technological processes are simple and cost-effective.

The fire-extinguishing powders are prepared using only mechanical treatment (grinding, screening - selection of dispersity - up to 250  $\mu\text{m}$  and drying at 70-100 $^{\circ}\text{C}$ ) and mixing of domestic, local mineral raw materials: zeolite, perlite, clay-shale and ammophos. They do not need introduction of expensive, halogen-containing hydrophobic additives and ensure a cost-effective production of powders [13, 14]. The obtained fire-extinguishing powders, unlike the conventionally produced powders, have good compatibility with water and foam. The powder easily mixes with water. Powder particles are evenly distributed and do not consolidate in water. As a result, highly stable powder-suspensions are obtained. The addition of foamers into the suspensions causes powder flotation, enabling the spraying of the powder together with water and foam.



**Figure 1:** Technological process for production of fire extinguishing foam-suspensions.

### 2.1. Performance properties

Performance properties (powder dispersity, tendency to humidity, caking capacity, storage duration, stability of powder suspension and foam

state) of obtained fire-extinguishing powders and foam-suspensions are determined by the following standard laboratory methods: [15,16]

- powder dispersity,  $x$  (%) - granulometric composition, mass concentration of powder remains left on the sieve

$$x = (m_1/m) \times 100$$

where:  $m_1$  - mass of powder remains on the sieve, kg;

$m$  - total mass of remains, kg;

- tendency to humidity,  $W$  (%) - the ratio of moist absorbed with powder to powder mass

$$W = (m_1 - m)/m \times 100$$

where:  $m_1$  - mass of powder remains after moistening, kg;

$m$  - total mass of remains, kg;

- caking capacity,  $C$  (%) - caked mass ratio to powder mass

$$C = (m_c/m) \times 100$$

where:  $m_c$  - mass of formed cakes, kg;

$m$  - powder mass, kg.

- storage duration – the duration of powder keeping under conditions established by normative documents, during which the powder performance properties are preserved;
- powder suspension stability - the suspension stability depends on the powder dispersity and suspension viscosity, which in turn depends on the volumetric concentration of the powder. The viscosity of the suspension is determined by a capillary viscometer. Method require the ratio of time between the capillary tube to suspension and water flows and calculated by the formula:

$$\mu_s = \mu_0 \frac{\Delta_s t_s}{\Delta_0 t_0}$$

where:  $\mu_0 = 0.001$  - water viscosity, g/cm.sec;

$\Delta_s, \Delta_0$  - density of suspension and water, g/cm<sup>3</sup>;

$t_s, t_0$  - suspension and water flow, sec.

- foam state, time when 50% of foam volume is deteriorated or time when 50% of liquid phase is separated.

The results of an experimental study of performance properties of fire-extinguishing powders and foam-suspensions are given in Table 1.

An analysis of the obtained results proved that addition of a small amount of ammophos to the zeolite-containing composite powders changes the performance properties insignificantly. Thus, composite powders (zeolite - 34%, perlites - 33.3%), clay shales - 20%, ammophos - 12.7%) are characterized by high performance properties and they are not inferior to the performance properties of the composite powders of zeolite, perlites and clay shales. Their storage duration are more than two years. Such powders have good compatibility with water and foams. They easily mix with water. Powder particles are evenly distributed in water and their consolidation does not take place. Thus, the received powder-suspensions are characterized by high stability. The stability of suspension determines the powder dispersity and suspension viscosity, which in turn depends on the powder volumetric concentration. Based on the above, the following values were selected: powder dispersion - less than 250  $\mu\text{m}$ , their volumetric concentrations - 20-25%, and suspension viscosity - 0.015-0.018 Poise (g/(cm·s)). At the same time, it should be noted, that zeolites as hydrophobizators are characterized by high adsorption properties of metal ions and gases. Zeolite cause gas bubbles adsorption in the liquid/gas interface; forming armor for bubbles, which reduces the internal gas transfer and enhances foam stability [17, 18]. Therefore, foam-suspensions produced on the basis of the obtained composite powders (zeolites, perlites, clay-shales and ammophos) are characterized by high stability, which is determined by suspensions stability (suspension viscosity - 0.015-0.018 g/cm.sec) and by foam state (30-40 sec).

Table 1: Performance properties.

| # | Materials   | Powder dispersity, S (mm) | Tendency to humidity, W% | Caking capacity, C% | Suspension viscosity, P (g/cm.sec) | Foam state, (sec) |
|---|---|---------------------------|--------------------------|---------------------|------------------------------------|-------------------|
| 1 | Zeolite (34%) + Clay shale (33.3%) + Perlite (33.3%)                    | # 0.2-0.25                | 0.14                     | 0.01                | -                                  | -                 |
| 2 | Zeolite (34%) + Clay shale (25.0%) + Perlite (33.3%) + Ammophos (7.7%)  | # 0.2-0.25                | 0.16                     | 0.013               | -                                  | -                 |
| 3 | Zeolite (34%) + Clay shale (20.0%) + Perlite (33.3%) + Ammophos (12.7%) | # 0.2-0.25                | 0.20                     | 0.015               | -                                  | -                 |
| 4 | Zeolite (34%) + Clay shale (16%) + Perlite (33.3%) + Ammophos (16.7%)   | # 0.2-0.25                | 0.40                     | 0.03                | -                                  | -                 |
| 5 | Powder-suspension powder (20%) + water (80%)                            | # 0.2-0.25                | -                        | -                   | 0.015                              | -                 |
| 6 | Powder-suspension powder (25%) + water (75%)                            | # 0.2-0.25                | -                        | -                   | 0.018                              | -                 |
| 7 | Powder-suspension powder (30%) + water (70%)                            | # 0.2-0.25                | -                        | -                   | 0.025                              | -                 |
| 8 | Foam-suspension (foamer 0.5%)   | # 0.2-0.25                | -                        | -                   | -                                  | 30-40             |

## 2.2. Fire- extinguishing ability

In order to evaluate the fire- extinguishing ability of powders and foam-suspensions the “polygon testing” methods are used, which consider extinguishing of different class standard fires with the help of fire- extinguishing constructions and enables to determine: minimum quantity of powders and of foam-suspensions - minimum consumption per unit area (G); minimum mass concentration of extinguishing (Cn) and time of fire- extinguishing ( $\tau$ ) [13, 14].

Table 2: Fire extinguishing ability

| Materials                                 | Class of fire | Time of fire extinguishing, $\tau$ (sec) | Minimum consumption per unit area, G (kg/m <sup>2</sup> ) | Minimum mass concentration, Cn (kg/m <sup>3</sup> ) | Powder special surface area, S (sm <sup>2</sup> /kg) | 1/Cn · S               | Coefficient of atomic oxygen recombination $\gamma_0$ |
|---|---------------|--|---|---|--|------------------------|---|
| Zeolite + Clay shale + Perlite            | A             | 11                                       | 1.8   | 3.6   | 1.9×10 <sup>6</sup>                                  | 0.146×10 <sup>-6</sup> | 3.3×10 <sup>-3</sup>                                  |
|   | B             | 8  |   | 2.0   |  |                        |   |
| Zeolite + Clay shale + Perlite + ammophos | A             | 9  | 1.6   | 2.8   | 3.9×10 <sup>6</sup>                                  | 0.1×10 <sup>-6</sup>   | 2.6×10 <sup>-3</sup>                                  |
|   | B             | 7  |   | 1.6   |  |                        |   |
| Foam suspension                           | A             | 5  | 1.1   | 1.5   | -  | -                      | -   |
|   | B             | 6  | 0.9   | 1.3   |  |                        |   |

Coefficient of atomic oxygen recombination -  $\gamma_0$  is determined by the Electro Paramagnetic Resonance (EPR) methods. The fire-extinguishing ability of powders and foam-suspensions based on the obtained powders are determined for the A (wood) and B (oil) class standard fires. The results of an experimental study of the fire-extinguishing ability of powders and foam-suspensions are given in table 2 below.

The study results show that the addition of zeolite-containing composite powders (zeolites, perlites and clay-shales) to ammophos considerably improves the fire-extinguishing ability.

The fire-extinguishing ability of foam-suspensions produced on the basis of the obtained powders (zeolites, perlites, clay-shales and ammophos) is higher than that of the obtained powders.

### 3. Results and Discussion

The produced fire-extinguishing powders are characterized by high performance properties, high fire-extinguishing ability and recombination coefficient of atomic oxygen. Thus, they are characterized by both the homogeneous and heterogeneous inhibition of combustion processes. The efficiency of the produced powders is not inferior to that of standard conventionally produced powders, but unlike them they are halogen-free, environmentally friendly and universal. The preliminary researches showed, that the price of powders of our preparation, including production and delivery, is in range 0.4-0.5 \$ per kg, while the price of imported powders is 0.7-1\$ per kg including transportation expenses. According to above said, the price of powders obtained by us will be about 1.5-2 times lower than existing prices on Georgian market.

The technological processes for production of obtained powders and foam-suspensions differ from the conventional technologies for production of fire-extinguishing agents. Foam-suspensions are prepared just by mechanical mixing of obtained fire-extinguishing powders with water and foamers. Such powders are hydrophilic substances, they generate sustainably suspension with water (their volumetric concentrations - 20-25%, and suspension viscosity – 0.015-0.018 Poise (g/(cm·s)) and the additional introduction of foamers into powder suspensions causes powder flotation. Thus, the technological processes for production of obtained foam-suspensions not associated with significant production costs, they are simple and cost-effective.

Ammophos is a water-soluble heterogenic inhibitor. In the case of production of foam-suspensions based on the produced composite

powders modified with ammophos, an increase in the water inhibition ability is expected, i.e., the inhibition effect of chemical reactions going on in the flame zone increases. Also increased is the diluting effect of burning gases and water heat capacity. Hence, ammophos significantly raises fire extinguishing capacity of foam-suspensions.

Based on all the above, it can be suggested, that foam-suspensions, produced on the basis of the obtained powders, have higher cooling effect, permeability (high dispersion of sprayed water) wetting effect like water and foam and unlike them they make both the homogeneous and heterogeneous inhibition of the burning process. Thus, the so produced foam-suspensions will have a higher extinguishing effect than water, foams or powders taken separately.

As is generally known, zeolites and ammophos represent combined fertilizers, which decreases the acidity of soil, regulates interchange of P, K and N - ions in the soil, cultivates microorganisms and promotes their growth, which in turn are indicators of soil productivity [18]. Proceeding from the above said, we can predict, that the obtained composite powders and foam-suspensions not only effectively extinguish fires, but they can also regenerate damaged soil.

From the all above-mentioned one can suggest that the use of received powders is possible at extinguishing of all types of fires, as well as, in complex with water and foams for extinguishing of large-scale fires – forest fires and does not need additional antiseptic measures.

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