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Review Article

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Evaluation of Noble Environmentally Friendly and High Efficient Fire-Extinguishing Means

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Abstract

Reviewing the history of the development of preventing measures, to ensure suppression of fire clearly reveals, that the most urgent of these measures is the use of environmentally friendly, highly efficiency fire extinguishing means. The best fire-extinguishing means are fire-extinguishing powders, which are characterized by high effectiveness and universality. Fire- extinguishing powders of serial production represents the fine dispersed mineral salts with different additives, which decrease tendency of consolidation and caking of powder. In serial production powders halogen containing, organic hydrophobizators are mainly used as such additives. Thus, most of them are halogen containing and do not satisfy the contemporary demands, in the first place with the view of effective, non-toxic and universal use. It also should be mentioned, that fire- extinguishing powders are characterized with less heat capacity, low permeability and wetting effect compared to water and foams, that's why at extinguishing large scale fires, particularly - forest fires, use of just fire- extinguishing powders is less effective.

This article discusses the elaboration of non-halogen, environmentally friendly, high-efficient, universal fire-extinguishing powders on the basis of local mineral raw materials of silicate origin and production of highly effective foam-suspensions based on such powders, the use of which will have higher extinguishing ability than water, foams or powders taken separately. The received fire-extinguishing powders will be used at extinguishing of all classes of fires, as well as, in complex with water and foams for extinguishing of large scale fires – forest fires.

Keywords: Environmentally-Friendly, Highly Efficient, Fire - Extinguishing Powder, Foam-Suspension

Introduction

Fires are unsolved problems of world civilization. Fires impact people, property and the environment in all countries around the world. In some cases, the resulting losses are extraordinary, causing hundreds of deaths, widespread damage to property and contents and significant impacts on the environment. More often, fires may cause a single casualty or affect a single home, though the effects are still highly significant to those affected and collectively are substantia we can hear about large scale forest fires in the media from several areas of the European Union almost every year. A large forest fire causes a serious impact on the environment, determining its future for decades. Prevention of forest fires is one of today's most important tasks as well as appropriate preparedness for effective fighting against them. To do so, it is vital to have detailed knowledge on the characteristics of different forest types and their environment, their ecosystems and technical information on the properties of forest fires and their effects on the different elements of the environment and lessons learned from previous cases. Based on gathered information of past events authors have provided a complete system of forest fire categories by their size, type, risks and consequences. A large forest fire causes a serious impact on the environment, determining its future for decades. Recently fires have progressively increased in a number and scales. The economic losses caused by fires are often catastrophic. They comprise several tens of billion dollars annually. No less dangerous are the cases of population chocking and poisoning by fire, which is caused, mainly, by combustion products as well as by toxicity of using preventing measures. Unfortunately, the statistics confirms, that traditional preventing measures, for the present, are sufficiently expensive, not universal and less efficient. Therefore, before the whole world sharply arises a problem of fire localization, liquidation and elaboration of such preventing measures, which will provide inhibition of materials burning in ignition zone and decreases of toxic gases evolution during thermal destruction. Among these measures, the most topical is the use of environmentally friendly, highly effective fire-extinguishing means [1-5].

At the same time, it should be noted, that not all fires are the same. There are different classifications of fires differentiated by the type of material that is burning. In general terms, there are five primary fire types:

Class A fires - fires in ordinary combustibles such as wood**,** paper, cloth, -rubber, and many plastics;

Class B fires - fires in flammable liquids such as gasoline, petroleum greases, oils, oil-based paints;

Class C fires - fires involving energized electrical equipment**;**

Class K fires are fires in cooking oils and greases such as animal and vegetable fats**.**

Some types of fire extinguishing agents can be used on more than one class of fire. Others have warnings where it would be dangerous for the operator to use on a particular fire extinguishing agent [4, 5].

The Types of Fire-Extinguishing Means and Their Disadvantages

Traditionally CO_2, water, foam, dry chemical and halon are used for fire- extinguishing. But it should be mentioned that water is characterized with: high consumption (50 l per 1 kg burning material), high freezing, electric. conductivity, corrosion activity and density (org. Water surface), insufficient wetting capacity and low adhesion to the object at extinguishing. Therefore, different mineral materials and surface active substances are added to water, which reduce water surface tension, thus increasing permeability and wettability and decreasing the consumption. According to their composition surface active substances are:

- synthetic (hydrocarbonic): alkyl aryl sulphonates, secondary alkyl sulphonates, natrium sulphonic acids with ethanol and ethylene glycol additives;
- fluorine synthetic – fluorinated hydrocarbones;
- albiminous.

Foams can be chemical and air mechanical. 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. It is safe for people, is electrically neutral and does not cause metal corrosion. Therefore, at the priority is given to airmechanical foams. Unfortunately, the use of foams for extinguishing of large-scale fires is associated with much consumption of water, mineral salts and surface-active substances; at the same time, foams are not universal, ecologically safe and they cannot be used at extinguishing of all types of fires [6-8].

The carbon dioxide (CO_2) extinguisher was invented (at least in the US) by the Walter Kidde Company in 1924. CO_2 is still popular today as it is an ozone-friendly clean agent and is used heavily in film and television production to extinguish burning stuntmen. Carbon dioxide extinguishes fire mainly by displacing oxygen and also be removing the heat with a very cold discharge. Carbon dioxide can be used on B & C Class fires. They are usually ineffective on A Class fires [6, 9].

Dry Chemical extinguishing agents have been used since the early 1900's. Dry Chemical fire-extinguishers work by chemical reaction with the fire causing the destruction of dry chemical particles, chemically inhibiting combustion and expelling the oxygen thereby smothering the flames. It is used very small free-flowing particles of sodium bicarbonate, potassium bicarbonate, potassium chloride, mono-ammonium phosphate, or other such Dry chemicals mixed with anti-caking agents and moisture absorbers. Dry Chemical agents used for extinguishing of A, B and C class fires. Theoretically, the smaller the particle size, the more effective the chemical will be as an extinguishing agent. Dry Chemicals front and produces CO2. It is generally recognized that while CO2 is formed during the extinguishment can be found with particle sizes ranging from 10 to 75 microns. The relationship of particle size to extinguishing effectiveness implies that the surface area of Dry Chemical agents plays a key role in extinguishing a fire. Some "smothering" action occurs when Dry Chemical is decomposed in a flame process, however, the quantity of CO2 being generated is as small as to be insignificant in comparison with other factors, such as caking capacity and moisture absorbes of Dry Chemical [10, 11].

Halogenated agents have been used for fire fighting since the early 1900's. Of the ten halogenated agents that have been used two have been the most common since the early 1970's - halon 1211 and halon 1301. Both 1211 and 1301 specifically, are identified as ozone-depleting agents, they work by inhibiting the chain reaction of the fire, and in the case of Halon 1211, cooling class A fuels as well. Halon is still in use today, but is falling out of favor for many uses due to its environmental impact. Halogenated agents as used in hand portable extinguishers were never as effective as more common agents on typical class B and class A fires. Europe, and Australia have severely restricted its use, since the Montreal Protocol of 1987. Less severe restrictions have been implemented in the United States, the Middle East, and Asia [12, 13].

From the all above-mentioned one can suggest, the mentioned traditional methods of fire- extinguishing are yet expensive, not universal, neither eco-safe and low effective. Particularly frequent are the cases of poisoning and suffocation caused by the airs isolated at fires. In the zones of wood fires the concentration of toxic matter in air many times exceeds the admitted one. According to statistics damage caused by fire decreases from 80% to 40% but suffocation and poison by released toxic airs is raising from 20% to 60% [3, 4, 8].

Therefore, the world faces the urgent problem is 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 means. The best fire-extinguishers are powder fire extinguishers, which are characterized by high effectiveness and universality. During the storage fire-extinguishing powders don't characterized by abrasive action, they are chemically inert. Act of powder extinguishers 50-60 times faster than gas fire-extinguishers, they operate in such low temperatures, when the use of halones, CO2, water and foams is impossible. In contrast with halones and CO2, they are non-toxic and do not require an object hermiticity. Powder extinguishers are used to extinguish fires in underground as well as in over ground buildings, manufacturing buildings, cinemas, libraries, garages, shopping centers, etc. [6, 12, 14].

At present, in comparison with all fire-extinguish means, the production of fire-extinguish powders occupies 80% in Europe and 60% in Russia. Approximately 130 various foreign firms and factories are involved in the production and supply of such powders. Imported powders of in-series production slightly differ from one another and were not changed principally over last 30 - 40 years [6, 12].

At present powder and foamy fire extinguishing substances are produced by a number of companies and enterprises. Brief information concerning leading companies and organizations producing fire-extinguishing foams and powders is given in Table 1.

Table 1

№	Producer countries	Producer firms	Type of extinguishers
Foam fire extinguishers of serial production			
1	Russia: 1) Moscow	Ltd "Lessnab"	ПО-НСВ PYROCOM TS ECO
	2) Ivanovo	Ltd "Ivkhimprom"	Fairex
	3) Tula	Ltd "Ural PozhTechnica"	ПО – 6 СП ПО – 6 СПМ
2	Germany	Expyrol	A 3F/A
3	France	Group Leader S.A.	AFFF
4	Japan	Yon Corporation	
5	USA	Minnesota Manufacturing Mining	
Powder fire extinguishers of serial production			
1	Russia: 1) Moscow region Reutovo City	LTD "Kalancha" and DA "Graviton"	Phoenix ABC – 70 Wexon ABC – «BIZONE»
	2) Moscow	EPOTOS	Buran– 0.5; Buran – 2.5 Buran – 8
	3) Kostroma region Buy City	ZAO "Ekokhimmash"	
2	Belorus Minsk	ZAO "Istochnik Plus"	Magnust-2 Magnust-6
3	Ukraine, Kyiv	Pozhtehnika, Kievskoe speczializirovannoe predpriyatie	ВП-1(3), ВП-2(3), ВП-3(3), ВП-4(3), ВП-5(3), ВП-6(3),
4.	Spain Navarra	EXTINTORES MONCAYO - EXMON	E001, E002, E006-P, E002-LX
5	United Kingdom Rotherdam	Jewel Fire Products Ltd	P1FJ, P2FJ, P4FJ
6	United States of America	International Paper ANSUL PASTOR	Sentri 5(2.04) OPR-1, OPR(3), OPR(6)
7	Canada	Firehouse International Inc.	2 PK V/B, 2,5 PK V/B, 5 PK V/B, 10 PK TALL, 10 PK SHORT
8	Turkey	Alarm Wangen Sondurme limited	
9	China	Shaoxing Newidea Fire Protection Co., Ltd	SS10P, SS20P, SS30P, SS450P
		Jiangsu Huayan Marine Equipment Co., Ltd	MFZL5, MFZL6, MRZL8, MFZL9

The basis of such powders, mainly, is follows mineral salts: alkaline metal chlorides, sodium and potassium sulfates and carbonates, ammonium phosphates, sodium and potassium chlorides.

- Alkaline metal chlorides are characterized by high fire-extinguish ability but they are hygroscopic and exhibit a high degree of consolidation and caking. Sulfates are characterized by good operating properties but have low fire-extinguish ability.
- Phosphates and carbonates exhibit high fire-extinguish ability, but are characterized by low performance properties.

Therefore, the use of such salts is recommended together with such additives, as coal, ammonia carbonate, silicates (Fluorine silicat and chlorosilane), oxides of transition metals and hydrophobizators.

From the all above-mentioned one can suggest, that fire-extinguishing powders of serial production represents the fine dispersed mineral salts with different additives, which improve the performance properties of salts, in particular, tendency of consolidation and caking. Thus, the extinguishing powders represent the complicated heterogeneous systems and the chemical composition of powders determines the extinguishing as well as high performance properties. In order to improve performance properties, mainly to decrease the caking capacity, water absorption additives are used for hydrophobization of powders. As an additives halogen containing, organic origin hydrophobizators are mainly used. Thus, most of them are halogen containing and do not satisfy the contemporary demands, in the first place with the view of effective, non-toxic and universal use. In this case, it is unambiguously stated that when halogen gets into atmosphere it causes the disturbance of ozone layer. Therefore, at present one of the most important problem is the elaboration of non-halogen, non-toxic, environmentally friendly fire- extinguishing powders [6, 14, 15].

As the literary analysis shows, fire-extinguishing ability, every so often, mutually contradictory. Improving of one of them cause's deterioration of another. Hence, enhancement of fire-extinguishing ability of materials requires the optimization complex characteristics of fire-extinguishing materials, which are not studied completely yet. It also should be mentioned, that fire-extinguishing powders are characterized with less heat capacity, low permeability and wetting effect compared to water and foams, that's why at extinguishing large scale fires they cannot wholly solve the problem of new ignition caused with inflammation of flickering focuses in open space. With consideration of the above said it follows, that for extinguishing of large scale fires, particularly - forest fires, use of just fire- extinguishing powders is less effective [4, 16].

Fabrication of New Types Halogen Free, Environmentally Friendly Fire-Extinguishing Powders and Foam-Suspensions

The main goal of our researches is the fabrication of halogen free, environmentally friendly fire-extinguishing powders using local mineral raw materials, which will have a good compatibility with water and foam and the development of technological processes for producing highly efficient fire-extinguishing foam-suspensions on the basis of the produced powders, the use of which will have higher cooling effect and permeability compared to powders, while differing from water and foam they will make homogenic, as well as, heterogenic inhibition of burning process.

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.

Raw materials –zeolite, clay shale, perlite, dolomite, barite-calcite and ammophos are chosen according their high performance properties and due to the factors indicating the reduction of burning processes. Their chemical and thermo-gravimetric analysis allows this possibility. The mineralogical composition of utilized materials show that they are of silicate origin and contain alkali and alkaline-earth metal carbonates, bicarbonates, oxalates, also Fe, Al and alkali metal hydroxides and crystallization water. Therefore, at high temperatures they are characterized with emission of incombustible gases, water steam and metal oxides. Thus, separated incombustible gases and water steam in flame zone act as phlegmatizers while in surface zone they cause the formation of risen layer. The risen layer, metal oxides protective film and coke layer create the "fire-limiting" effect. This is indicating to the fact that the composite powders of such raw materials are, like efficient, flame retardants and characterized by high inhibition properties [17, 18].

The effectiveness of powder depends on their inhibition properties and on their performance characteristics as well. The most important performance characteristics are: tendency to consolidation and caking, moisture adsorption, dispersity, powder flow and storage duration. The least desirable performance property is tendency to consolidation and caking, which complicates and conclusively cancels the fire-extinguishing ability of the powder. It also should be mentioned, that performance properties of powder depend on their dispersity. Caking capacity of high-dispersive powders sharply increases with increasing dispersity, while the caking capacity of lower-dispersive powders insignificantly changes with changing dispersity, and when powder dispersity is within - 200–250μm the caking capacity drops to zero. Therefore, for the increase of efficiency of powder, optimal dispersity (up to 250 μ) we selected in such way, that caking capacity be minimal, powder feed must be convenient (high-disperse powder direct feeding into ignition place creates many problems) and a homogeneous action of combustion products on the flame as well as a heterogeneous inhibition of combustion process must take place [15, 18].

On the basis of the experimental results of performance factors of raw materials it is stated, that zeolite in composite powders play the role of efficient hydrophobizing agents. Therefore, we can summarize, that adding of various raw materials (ammophos , dolomites, diatomites, calcites, etc.), which are hygroscopic, but characterized by high inhibition properties, to zeolite containing composite powders will not cause significant changes of performance characteristics, but will considerably increase fire extinguishing capacity. It allows to create a wide range of zeolite-containing fire-extinguishing powders on the basis of local mineral raw materials. Thus, zeolite-containing composite powders are characterized with higher performance properties and do not require the addition of any expensive hydrofobizazing additives. Therefore, fire-extinguishing powders we prepared using only mechanical treatment (grinding, screening up to 250 μm dispersity, drying at 700-100^{0}C) and mixing of raw materials. It does not require any additional chemical processing and modification with expensive halogen containing hydrofobizing additives. It simplifies the technological process of production and ensures cost-effective production of powders against imported analogs [16, 18].

For the increase of efficiency of powder, optimal dispersity (up to 250 μ) we selected in such way, that caking capacity be minimal, powder feed must be convenient (high-disperse powder direct feeding into ignition place creates many problems) and a homogeneous action of combustion products on the flame as well as a heterogeneous inhibition of combustion process (which means heterogeneous removal of reaction active centers on the surface of solid particles of the powder) must take place. But it is known, that if powder particles dimensions exceed 50 mcm than, such particles have no time to be heated to ignition temperature, therefore homogeneous mechanism of extinguishing is less effective and heterogeneous mechanism has leading role. So, for the complex evaluation of extinguishing effect it is necessary to take account of the both effect.

So, for the complex evaluation of extinguishing effect the following characteristics have been selected:

- Reciprocal value of extinguish "surface" concentrate - 1/ Cn•S;
- Coefficient of atomic oxygen recombination - (γ_0).

In order define - γ_0 are used Electro Paramagnetic Resonance (EPR) methods.

In order to determine fire- extinguishing ability are used polygon methods, which consider extinguishing of different class standard fires with the help of fire- extinguishing constructions and enable to determine: minimum mass consumption of powder (G); minimum mass concentration of extinguish (C_n); extinguish time (τ); material supply intensity (I) and extinguishing "surface" concentration (Cn•S)

On the basis of the experimental results it is stated, that composite fire-extinguishing powders based on zeolites, perlites, clay shales, dolomites, barite-calcites and ammophos are characterized by the 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, universal and far cheaper than imported analogues. 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 [19, 20].

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. Therefore, foam-suspensions are prepared just by mechanical mixing of composite fire-extinguishing powders with water and foamers. Thus, the technology for production of obtained fire-extinguishing powders and foam-suspensions significantly differs from the conventional technologies. It is simple and is not associated with significant economic costs. At the same time, it should be noted, that ammophos is water-soluble heterogenic inhibitor. In case of production of foam-suspension based on the produced composite powders modified with the 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) and 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. 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 [16, 20].

From the all above-mentioned one can suggest, that the fire-extinguishing powders of our preparation may be effectively used for extinguishing of all classes of fires in underground and aboveground objects, within large temperature range, as well as at such low temperatures when CO_2, water and foam cannot be used and in complex with water and foams for extinguishing of large scale fires – forest fires.

Conclusions

- Fire-extinguishing powders are prepared by mechanical treatment (grinding, screening - selection of dispersity - up to 250 μm and drying at 70-100^{0}C) and mixing of raw materials: zeolite, perlite, clay-shale, dolomite, barite-calcite and ammophos, which does not require the modification with expensive halogeninclusive hydrofobizing additives. On the one hand it simplifies technological process of production of powder and on the other hand decreases prices of powder.

- Such powders are characterized by the high-performance properties as well as a high fire- extinguishing effect. Thus, the efficiency of the produced powders is not worse than of standard powders of common production, but unlike them they are halogen-free, environmentally friendly, and universal and about 1.5-2 times lower than existing prices on Georgian market.

- Received powders are characterized of good compatibility with water and foams. Thus, foam-suspensions elaborated on the basis of the such powders, have higher cooling effect and permeability compared to powders, while differing from water and foam they make homogeneous, as well as, heterogeneous inhibition of burning process. Therefore, they have higher extinguishing effect than water, foams or powders taken separately.

- From the all above-mentioned one can suggest, that the fire-extinguishing powders of our preparation may be effectively used for extinguishing of all classes of fires in underground and aboveground objects, within large temperature range, as well as at such low temperatures when CO_2, water and foam cannot be used and in complex with water and foams for extinguishing of large scale fires – forest fires.

References

1. James Milko, The Effect of fires on People, Property and Environment. Physical Science and Engineering.
2. László Földi, Rajmund Kuti (2016) Characteristics of Forest Fires and their Impact on the Environment. AARMS 15: 5-17.
3. Forest Fires. Environmental Literacy Council. Web Site, Washington.
4. Potapova T (2003) «Forest Fires» Info Pravo – Recommendations for detection and extinguishing of forest fires (УТВ). V Mire Nauki, №3.
5. Portable Fire extinguishers. https://www.femalifesafety.org/types-of-extinguishers.html
6. Schreiberg G, Porret P (1985) Fire-extinguishing Means, M.
7. Peng Wang (2015) Application of green surfactants developing environment friendly foam extinguishing agent. Fire Technology 51: 503-511.
8. Yi Lu, Tao Wang, Min Pang, Zhao-jun Tian (2018) Preparation and high temperature resistance of a novel aqueous foam for fire extinguishing. Procedia Engineering 211: 514-520.
9. Fire Extinguishing Agents https://www.skybrary.aero/index.php/Fire_Extinguishing_Agents.
10. J Craig Voelkert (2009) Fire and fire-extinguishment. A BRIEF GUIDE TO FIRE CHEMISTRY AND EXTINGUISHMENT THEORY FOR FIRE EQUIPMENT SERVICE TECHNICIANS. https://www.amerex-fire.com/upl/downloads/educational-documents/fire-and-fire-extinguishment-99cd88b2.pdf
11. Dry Chemical Fire Extinguishers. http://www.businessdictionary.com/definition/dry-chemical-fire-extinguisher.html
12. Takahashi F, Linteris G, Katta V (2005) Physical and chemical aspects of cup-burner flame extinguishment. Halon Options Technical Working Conference, 15th Proceedings, Albuquerque, NM, pp 1-10. .
13. "Halon Disposal"(2006) *Ozone Protection*. Australian Government Department of the Environment and Heritage (Australia).
14. Fire extinguishing powders (2000) Nauka v Sibiri. Weekly Newspaper.
15. Gurchumelia L, Bezarashvili G, Chikhradze M, Chudakova O (2009) Investigation of performance properties of novel composite fire-extinguishing powders based on mineral raw materials. Materials Characterisation. Wit Press publishes leading books in Science and Technology, New Forest, UK 64: 337-347.
16. Gurchumelia L, Tsarakhov M, Bejanov F, Tkemaladze L, Chudakova O (2017) New types, halogen less, eco-safe fire-extinguishing powders and foam-suspensions. International conference "Ecology and Safety" Proceedings. Bulgaria, Elenite 2017: 78-84.
17. Gurchumelia L, Baliashvili G, Bejanov F and Sarjveldze N (2008) Development of Novel Composite Fire-extinguishing Powders on the Basis of Mineral Raw Materials. Modelling, monitoring and management of Forest Fires. Wit Press publishes leading books in Science and Technology, Toledo, Spain 2008: 61-67.
18. Gurchumelia L, Khutsishvili Z, Nadareishvili L (2015) Elaboration of new types, halogen less, eco-safe fire-extinguishing powders and evaluation of their efficiency. BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES 9: 65-70.
19. Gurchumelia L, Tsarakhov M, Tkemaladze S, Tkemaladze L, Bezarashvili G (2018) Development of Novel Environmentally Safe and Highly Efficient Fire-Extinguishing powders Based on Local Mineral Raw Materials. Safety and Security Engineering. VII, WIT Transactions on the Built Environment 174: 131-140.
20. Gurchumelia L, Tsarakhov M, Machaladze T, Tkemaladze S, Bejanov F, Chudakova O (2018) Elaboration of new types of environmentally safe fire-extinguishing powders and establishment of the conditions of extinguish optimum and effective use of such powders. Modern Chemistry & Applications 6: 2329-6798.