

Possibilities of Using Potassium Carbonate and Bicarbonate as Inhibitors in the Composition of Aqueous Fire-Extinguishing Substances

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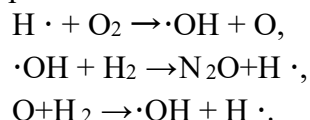
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Abstract. The paper presents research of the possibility of using potassium carbonate and bicarbonate as inhibitors in the compositions of aqueous fire-extinguishing substances for the elimination of fires associated with the burning of solid and liquid combustible materials. It has been shown theoretically and experimentally that both potassium carbonate and bicarbonate are highly effective in inhibition of chain reactions in the gas phase of flame combustion. Recommendations on the selection of the inhibitory component when creating compositions of aqueous fire extinguishing substances are given.

1 Introduction

The methodological basis for the development of compositions of new effective substances for fire protection and fire extinguishing is the acquisition of new and in-depth knowledge about the conditions for the implementation of a complex of fire protection and fire extinguishing factors of the influence of these substances (cooling, inhibition, phlegmatization, isolation) on the processes of ignition, the spread of flame over the surface and the cessation of burning of various materials [1, 2]. Therefore, the research of the possibility of introducing inhibiting components into the composition of aqueous fire extinguishing substances (AFEA) should be considered as a mandatory stage of relevant research.

Modern science considers the process of burning hydrocarbons as a complex of chemical chain reactions. The theory of chain reactions was created by the scientific works of M. Semenov and R. Hinshelwood [3, 4]. According to this works, the combustion process should be attributed to chain reactions with branched chains. Processes with branched chains differ from unbranched is that in them a single reaction of one free radical lead to the formation of more than one new free radical. One of them continues the original chain, and the other(s) start a new one(s). An example of this type of process can be the oxidation of hydrogen, which under certain conditions proceeds as follows:



The radicals that are formed in the first two reactions ensure the development of an unbranched chain, and the oxygen atom, which has two free valences, in the third reaction forms two additional radicals that start branching. Thus, a large number of free radicals are formed. The "propagation" of radicals leads to an avalanche-like flow of the process. However, even in these processes, chains are broken. Only in that case, when the rate of branching exceeds the rate of interruption, the speed of the process rapidly increases. The rate of branching of the chain is determined by the number of encounters of reactive particles with molecules of the original substance, that is, it is proportional to the concentration of the substance and the volume of combustion. The radical theory of combustion inhibition is based on the removal of active centers (atoms and/or radicals) responsible for the

development of the combustion process from the reaction zone and their binding to hydrocarbon molecules (or radicals formed from them).

It is known that OH-radicals are active centers of combustion responsible for the branching of chain reactions. Therefore, the inhibition should be aimed at reducing their number in the combustion center, which under certain conditions will ensure disruption of the chemical reactions of combustion. There is a well-known method of evaluating the inhibitory property, which is based on the registration of changes in the intensity of radiation of excited hydroxyls when inhibitors in any state of aggregation are introduced into the flame of liquid and gaseous combustible substances [5]. Using the installation, the scheme of which is shown in Fig. 1, the inhibitory properties of finely atomized aqueous solutions of inorganic potassium salts were investigated by the method of optical electroscopy based on the decrease in the intensity of the OH-radical radiation of the n-heptane flame during the introduction into the burner of finely atomized aqueous solutions of inorganic potassium salts [6, 7].

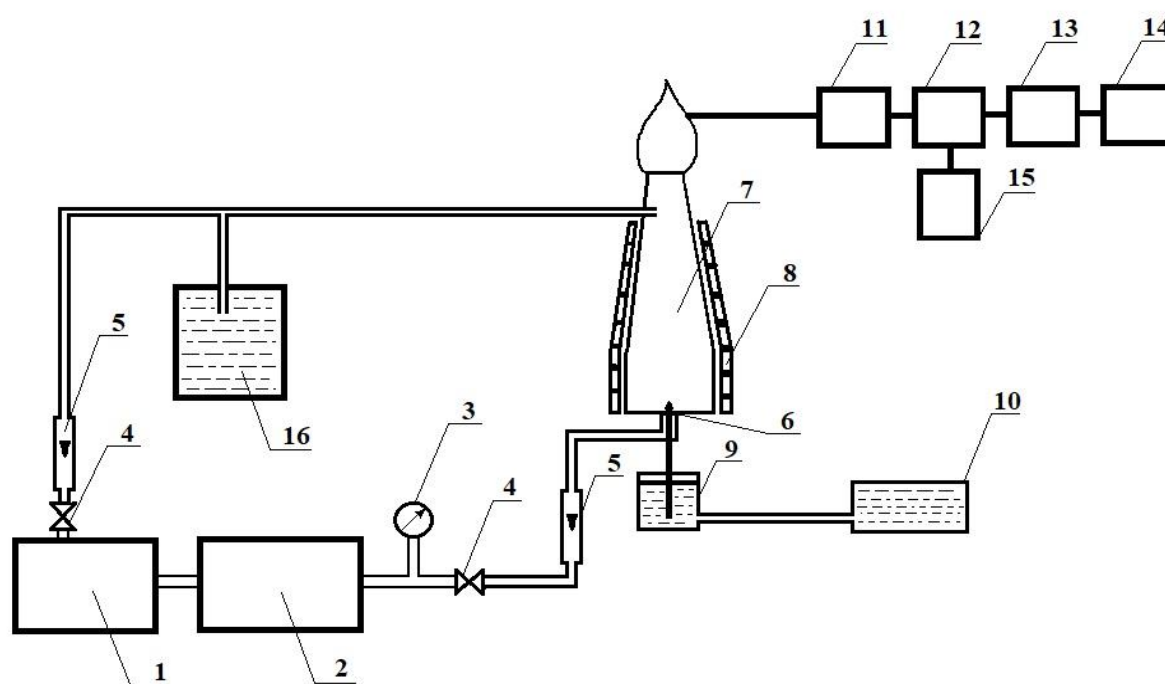


Fig. 1. Schematic representation of the installation for detecting the inhibitory capacity of water fire extinguishing substances: 1 – compressor; 2 – receiver; 3 – manometer; 4 – valves; 5 – rotameters; 6 – pneumatic sprayer; 7 – atomizer; 8 – heater; 9 – container with n-heptane; 10 – overflow device; 11 – spectrometer; 12 – photomultiplier; 13 – amplifier; 14 – registrar; 15 – power supply unit; 16 – container with fire extinguishing agent

The relevant results of aqueous solutions of potassium carbonate and bicarbonate by the specified method research are shown in Fig. 2. The figure shows some advantage in the inhibitory capacity of potassium carbonate compared to potassium bicarbonate (by 5 % at a 20 % salt concentration in the solution), which is most likely to be explained by the increased number of potassium ions at the same mass fraction of salt in the solution.

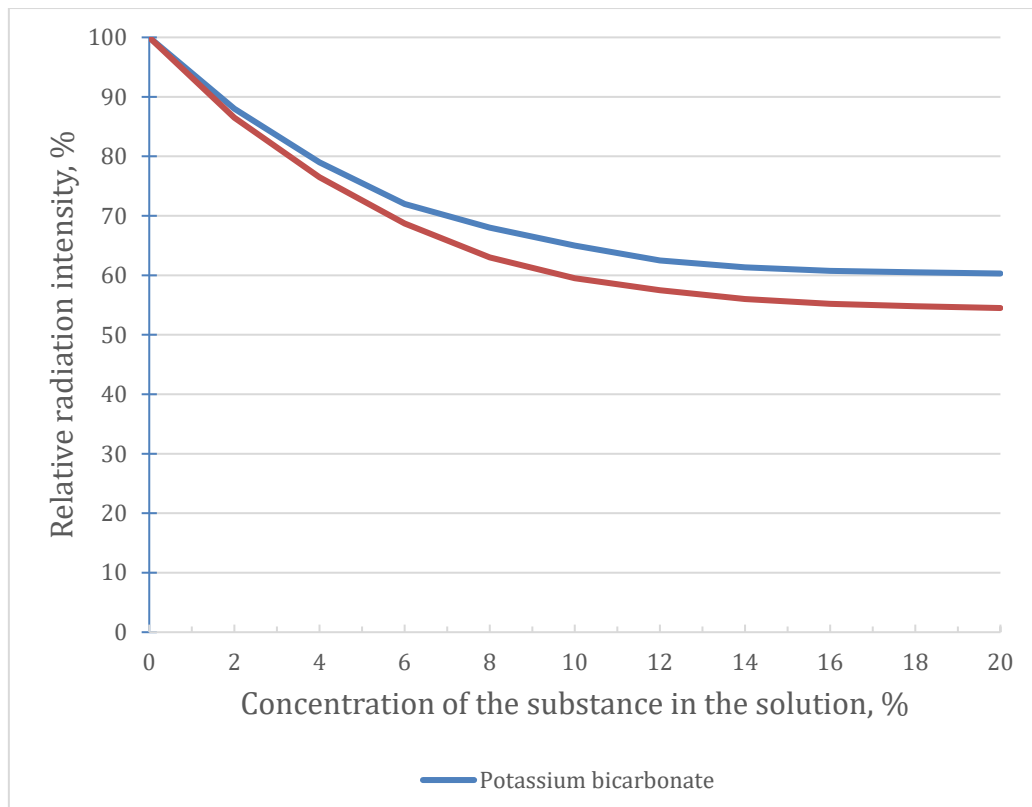


Fig. 2. Dependence of the change in the intensity of OH radical emission of n-heptane flame on the concentration in an aqueous solution of potassium carbonate and bicarbonate

If you are guided only by the data obtained as a result of the above experiment, while choosing an inhibitory component for the composition of an aqueous fire-extinguishing agent, it is possible to make a mistake, since the impact of the introduction of this component on the implementation of other fire-extinguishing factors should also be evaluated. For example, the size and mass of the droplets should be estimated, which will be provided in the process of supplying the extinguishing agent for extinguishing and the related effective area of cooling, insulation, etc.

2 Main Part

The purpose of this work is to substantiate the possibility of using potassium carbonate and bicarbonate as inhibitors in the compositions of aqueous fire-extinguishing substances for extinguishing flammable liquids (class B fires).

To evaluate the effect of the inhibitory component in combination with the entire complex of fire-extinguishing factors for water-based fire-extinguishing substances, the method for determining the critical intensity of supplying the water-based fire-extinguishing substance for extinguishing the flame of a combustible liquid is more suitable [8]. The installation scheme is presented in Fig. 3.

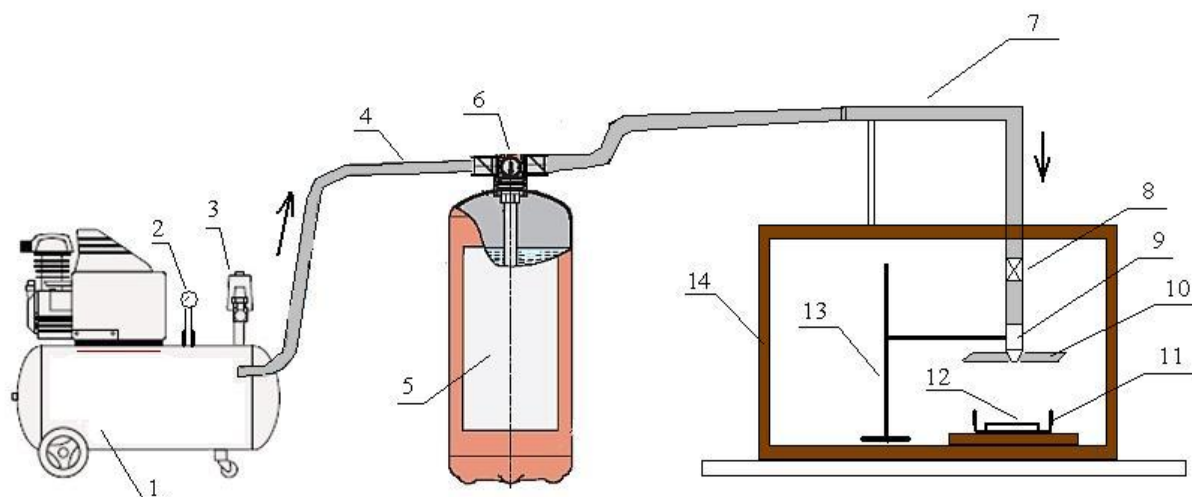


Fig. 3. Schematic representation of the stand for determining the critical intensity of supply of water fire extinguishing substances during extinguishing class B fires, where: 1 – compressor; 2 – manometer; 3 – safety valve; 4 – working gas supply pipeline; 5 – capacity for fire extinguisher based fire extinguisher; 6 – filling nozzle with shut-off fittings; 7 – pipeline for supplying hot water to the irrigator; 8 – shut-off valve; 9 – adapter with a spray nozzle; 10 – protective screen; 11 – pallet; 12 – tray; 13 – tripod; 14 – fume cupboard for experiment

About research methodology. A container based on a water fire extinguisher was filled with a water fire extinguishing agent in the amount of 4 liters, weighed and the data were entered into the protocol.

With the help of a compressor, an excess pressure of 0.8 MPa is created in the tank, the value of which is controlled by a manometer. The valve is closed. Metal trays with an inner diameter of (100 ± 1) mm to (200 ± 1) mm and a height of 25 mm with a wall thickness of 2.5 mm and a metal tray with a side height of 50 mm are placed in the extinguishing chamber. The deco is installed in a pallet installed on a flat horizontal surface. Distilled water is poured into the pan, and then fuel, in the volume indicated in table 1. The fuel in the pan is set on fire. After (30 ± 5) sec of free burning, open the shut-off valve and begin to supply finely atomized fire-extinguishing powder to the surface of the burning liquid for no more than 30 sec until extinguishing is achieved. If the fire is successfully extinguished, the size of the deck is increased and the experiment is repeated with the amount of water and fuel set in Table 1. Thus, the maximum size of the deck, which was reliably extinguished by the investigated fire extinguishing substance in three consecutive experiments, is determined.

A spray nozzle was used with a fire extinguishing agent supply intensity of 1.0–2.5 ml/sec with a jet with an opening angle of 45° at a pressure of 0.5 MPa, which is set at a height of 0.2 m from the surface of the combustible liquid mirror. "Nefras S-2-80/120" was used as a combustible liquid.

Experiments begin with a fire source with a diameter of 0.1 m. In the case of its successful extinguishing, they gradually move to fire foci with diameters of 0.12 m, 0.14 m, 0.16 m, 0.18 m, 0.2 m. If a negative result is obtained for the above-mentioned source, they move to smaller foci with diameters of 0.11 m, 0.13 m, 0.15 m, 0.17 m, 0.19 m, respectively. After the extinguishing of the model fire is completed, the shut-off valve is closed and data on the extinguishing results are entered into the protocol.

The consumption of the fire extinguishing agent is determined by the weighing method, by collecting the finely atomized solution in a pre-weighed vessel during the specified period of time in three parallel experiments.

Extinguishing agent consumption per unit of time R (cm^3/sec), determined by the formula:

$$R = \frac{m_1 - m_0}{\tau \times \rho}; \quad (1)$$

where m_0 – mass of the vessel for collecting sprayed fire extinguishing substance, g;

m_1 – the mass of the container for collecting the sprayed extinguishing agent with the collected substance, g;

t – fire extinguishing agent collection time, sec;

r – density of the investigated fire extinguishing substance, g/cm³.

The result of determining the rate of fire extinguishing agent consumption is taken as the arithmetic average of three test results. The maximum deviation of the determination results obtained by one operator under the same conditions from the average arithmetic value should not exceed 5 %.

In Fig. 4 presents a photo of a working moment in the process of conducting research.



Fig. 4. Photo of a working moment in the process of conducting research

Determination of the density of the investigated fire extinguishing substance consists in visual reading of the scale mark of a graduated hydrometer immersed in a cylinder with the investigated fire extinguishing substance. The result of the research is taken as the arithmetic mean of two parallel determinations, the difference between which should not exceed 0.001 g/cm³.

The critical sample feeding intensity at which quenching is achieved is calculated:

$$I_{kr} = \frac{R \times 10^{-3}}{S_{max}}, \quad (2)$$

where S_{max} – the area of the largest deck, which was repaid under the conditions of research, m².

The indicator of the relative fire-extinguishing efficiency of a fire-extinguishing substance is determined by the formula:

$$K = \frac{I_{krH_2O}}{I_{krAFEA}}, \quad (3)$$

where I_{krH_2O} – critical intensity of water supply, l×s⁻¹×m⁻²;

I_{krAFEA} – critical intensity of water fire extinguishing agent supply, l×s⁻¹×m⁻².

Table 1. Characteristics of class B fires

Diameter of the deck of the model hearth, [m]	Area of the combustion surface of the model hearth, [cm ²]	The volume of fuel in model hearths, [cm ³]
0.10	78.5	39.3
0.11	94.9	47.5
0.12	113.0	56.5
0.13	132.7	66.3
0.14	153.9	76.9
0.15	176.6	88.3
0.16	209.6	100.5
0.17	226.9	113.4
0.18	254.3	127.2
0.19	283.4	141.7
0.20	314.0	157.0

The obtained average values of the parameters determined as a result of experimental research are shown in Table 2. The table is filled in for 2.5 % (wt.) solutions of potassium carbonate and bicarbonate.

Table 2. Results of research on the relative fire-extinguishing efficiency of water-based extinguishing agents for extinguishing class B fires with fine-sprayed jets.

Researched substance	Density of the researched substance, [g/cm ³]	The mass of the vessel for collecting the sprayed extinguishing agent (m_0), [g]	The mass of the container for collecting the sprayed fire extinguishing substance with the collected substance (m_1), [g]	Fire extinguishing agent collection time (t), [sec]	Consumption of fire extinguishing agent (R), [cm ³ /sec]	Deck area (S), [cm ²]	Quenching result
Distilled water	1.000	3.05	35.90	30	1.080	94.9	repaid
Potassium carbonate solution	1.019	3.05	38.15	30	1.148	226.9	repaid
Potassium bicarbonate solution	1.014	3.05	39.17	30	1.187	254.3	repaid

The calculated index of relative fire-extinguishing efficiency K for potassium carbonate solution is 2.25, and for potassium bicarbonate – 2.44.

3 Conclusion

1. The calculated value of the relative fire-extinguishing efficiency indicator according to the method of determining the critical intensity of the supply of an aqueous fire-extinguishing agent for extinguishing the flame of a combustible liquid indicates the prospects of using potassium carbonate and bicarbonate as inhibitory components in the compositions of aqueous fire-extinguishing agents.

2. While choosing between potassium carbonate and bicarbonate as an inhibitor in developing the composition of an aqueous fire-extinguishing substance, one should be guided by test data that ensure the implementation of the inhibitory effect in combination with other fire-stopping factors (cooling,

phlegmatization/dilution and isolation), and operating conditions (the temperature range of using an aqueous fire-extinguishing substance, limitations of the permissible pH level, etc.).

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