Influence of total head of foam on optimum intensity and minimum particular expense solution size of foamer

Evgeniy Degaev, Alena Suvorova and Alexandra Suhova

Moscow State University of Civil Engineering, Yaroslavskoe shosse 26, Moscow, 129337, Russia
E-mail: degaev@inbox.ru

Abstract. The issues addressed included questions and prospects for use of the hydrocarbonic and fluorinated film-forming foamers for fire suppression of emergency passages and the fires of oil products in tanks at supply of foam from long distance. The results of the experiment show that hydrocarbonic foams with increase in falling height cause strong decrease in efficiency of fire suppression. The blow of foam about a surface conducts to partial immersions in oil product that leads to foam pollution by fuel. It is shown that using hydrocarbonic foamers with growth of total head from 5 to 15 cm a particular expense size and optimum intensity 2 times increase. While the fluorinated foams show increase inefficiency of fire suppression by increase in total head which is explained by superficial activity - aqueous solutions of film-forming foamers have positive value of spreading coefficient. The higher the drainage is, the stronger the foam and hydrocarbon surface hit that leads to the accelerated release of solution from foamy films more strongly and promotes fast foam spreading. Experiments confirm expert's opinion about low efficiency of the foams, received their hydrocarbonic foamers when giving with compact streams on long distance. Therefore, replacing of fluorinated film-forming foamers with hydrocarbonic ones, which decay after application well, is premature.

1. Introduction
The capital construction objects of production and storage facilities have increased fire safety, especially if these objects are related to the oil industry. Foam is traditionally used for fire protection of tank farms. Reasons to use firefighting foam include:
• fire prevention – application of a foam blanket on an unignited spill;
• vapour suppression – prevention of vapours from finding an ignition source;
• odour control – suppression of hazardous or noxious vapours;
• personnel exposure – protection of fire and/or rescue personnel during emergency operations;
• asset protection – pre and post security of the hazard until securement or removal is conducted.

Firefighting foam is a foam used for fire suppression. Its role is to cool the fire and to coat the fuel, preventing its contact with oxygen, resulting in suppression of the combustion. Fire-fighting foam was invented by the Russian engineer and chemist Aleksandr Loran in 1902.

The original foam was a mixture of two powders and water produced in a foam generator. It was called chemical foam because of the chemical action to create it. In general, the powders used were
sodium bicarbonate and aluminium sulfate, with small amounts of saponin or liquorice added to stabilise the bubbles.

The use of low-expansion foam to extinguish fires at tank farms, at storage and production facilities, as well as in case of emergency spill and abnormal fires of petroleum products is due to the possibility of foam supply from a long distance. Strong heat flow from torch-like flame does not allow approaching for the supply of foam of medium and high expansion.

Aqueous film-forming foams (AFFFs) are among the most popular fire-fighting foams used in liquid fuel fires because of their film forming and fast knock down property.

AFFFs are synthetically formed by combining fluorine-free hydrocarbon foaming agents with highly fluorinated surfactants. When mixed with water, the resulting solution achieves the optimum surface and interfacial tension characteristics needed to produce an aqueous film. One key ingredient of AFFFs, the fluorocarbon surfactant i.e. perfluorooctane sulfonate (PFOS) which is used to reduce surface tension and positive spreading coefficient.

In the foam industry, concentrates are typically referred to as “3 %” or “6 %” concentrate, depending on the mixture rate with water (a fire fighting foam solution made from “3 %” concentrate will consist of 97 parts water to 3 parts AFFF concentrate). AFFF concentrates contain about 60-90% water and have a fluorine content of about 0.3-1.8% [1,2].

In connection with environmental requirements, the use of foamers containing fluorinated stabilizers to extinguish fires can be limited. It is a question of using hydrocarbon foamers instead of aqueous film forming ones, which are not up to fire extinguishing efficiency, but to a lesser degree pollute the environment.

The purpose of this work is to experiment with the tank model on extinguishing the flame of petroleum products from a different height of the foam drop: from the foam pure to the surface of the burning liquid. The names and brand of foamers will be given in a generalized form to avoid reproaches from the suppliers of foamers. The names of foamers will be given as fluorine film forming foamer and hydrocarbon foamer. The foam obtained from the working solutions of both foamers corresponded to expansion of 7.0 ± 0.5.

2. Materials and Methods
The tests were carried out on bedstead described in GOST R 53280.2-2010. The dependence of the specific consumption and extinction time on the foam application rate was determined. The distance of the drainpipe from the burning hydrocarbon surface was changed vertically: from 5 to 15 cm. The foam was applied directly to the burning surface. N-heptane was used as a flammable liquid that allowed obtaining reproducible results [1-4].

Preliminary measurement of interracial tension of the working solutions at the heptane junction was carried out to confirm the nature of the foamer. The ring method was used to measure the interracial tension of foamer solutions. These tests confirmed the nature of foamers’ surfactant base. The spreading on heptane coefficient for film-forming foamers should be greater than zero, and the interracial tension should be lower than for heptane - 17 mN/m. Solutions of hydrocarbon SAS have interracial tension around 30 mN/m that is noticeably higher than that of heptane [5-8].

The spreading coefficient of the aqueous-based solution on heptane – $K_{10}$ and of heptane on the solution – $K_{01}$ was calculated by the following relationships [1-2]:

\[
K_{10} = \sigma_0 - (\sigma_{10} + \sigma_i)
\]
\[
K_{01} = \sigma_i - (\sigma_{10} + \sigma_0)
\]

where $\sigma_0$ - is the Interracial tension of heptane, mN/m; $\sigma_{10}$ - is interracial tension at solution-heptane junction, mN/m; $\sigma_i$ is the interracial tension of an aqueous-based at solution-air junction, mN/m.

3. Results and Discussion
The results of measurements of the surface and interfacial activity for solutions of both foamers are presented in Figure 1 and Figure 2.
Film-forming fluorine foamer at an aqueous solution concentration of 1.0% wt. and higher has a positive spreading of the aqueous solution on heptane coefficient, that allow the working solutions to spontaneously form an aqueous film on the heptane surface.

The spreading of aqueous solution on heptane coefficient of hydrocarbon foamer has a negative value, i.e., these solutions are not able to spread on heptane, and they are mostly heptane wetted down, and they spread on the surface of foam films. The coefficient of heptane spreading on an aqueous solution of foam films is positive practically in the entire concentration range of a hydrocarbon foamer in an aqueous solution [9,10].

\[ \text{Figure 1. Isotherms of interracial (1) and interphase (2) tension and spreading of solution on heptane coefficient (3) for solutions of film-forming foamer} \]

\[ \text{Figure 2. Isotherms of interracial (1) and interphase (2) tension and spreading of solution on heptane (3) and vice versa (4) coefficients for solutions of hydrocarbon foamer} \]
When supplied to the burning surface of petroleum product, the foam, because of dropping, crowds into the flammable liquid, therefore the extinguishing efficiency of the hydrocarbon foamer should decrease [10-12].

The results of experimental measurements of the specific consumption and heptane flame extinction time for a film-forming foamer are shown in Figure 4, while for a foam obtained from the hydrocarbon foamer – in Figure 3 (1, 1′ - extinguishing time and specific flow rate at a foam lift of 5 cm; 2, 2′ - extinguishing time and specific flow rate at a foam lift of 10 cm; 3, 3′ - extinguishing time and specific flow rate at a foam lift of 15 cm).

![Figure 3](image)

**Figure 3.** Influence of the foam drop height obtained from “film-forming” foamer solutions on the dependence of specific consumption and heptane flame extinction time on foam application rate

The effectiveness of the foam from a hydrocarbon foamer greatly decreases as heightening of drop increases, but the fluorinated foams on the contrary increase the fire extinguishing efficiency.

The minimum specific consumption of foam from the hydrocarbon foamer increased from 2.2 to 3.7 kg/m², and the optimum rate increases from 0.065 to 0.120 kg/(m²·s).

Foam from the fluorine foamer as heightening of drop increases, reduces the minimum specific consumption from 1.2 to 0.7 kg/m², and the optimum rate – from 0.03 to 0.04 kg/(m²·s). An illustration of the foam drop height effect on the main parameters of the extinguishing process is shown in Figure 5. The result obtained can be explained on the basis of interracial tension isotherms, which are presented in Figure 1 and Figure 2. Aqueous solutions of the fluorinated foamer have a positive spreading on heptane coefficient.

Upon contact of the foam out of the hydrocarbon foamer with heptane, the hydrocarbon wets and spreads over the foam films, which leads to their contact destruction. Foam out of fluorinated foamer when exposed to heptane spontaneously forms an aqueous film on the surface of the hydrocarbon. The higher the foam sink, the stronger the foam hits the heptane surface, that lead to an accelerated solution drain-out from foam films and promotes rapid spreading of the foam. For hydrocarbon foams, impact with the surface leads to a partial immersion in heptane, which leads to contamination of the foam with fuel. In addition, the foam movement is counteracted by the surface pressure directed toward the spreading foam because of the positive spreading of the fuel on the aqueous solution coefficient [13-16].
Figure 4. Influence of the foam drop height obtained from hydrocarbon foamer solutions on the dependence of specific consumption and heptane flame extinction time on foam application rate.

Figure 5. Influence of the foam drop height obtained from the hydrocarbon and "film-forming" foamers, on the minimum specific consumption and the optimum application rate when extinguishing the heptane flame: 1, 1' - the minimum specific consumption and the optimum rate of foam lift when extinguishing by hydrocarbon foamer; 2, 2' - the minimum specific consumption and the optimal rate of foam lift when extinguishing the "film-forming" foamer.

4. Conclusions
The results of surface activity measurements of the foamers’ aqueous solutions show that the hydrocarbon foamer cannot be used for subsurface foam injection into burning heptane, since heptane will begin to spread over the foam films, destroying the foam and mixing with it during the ascent to
the surface. The obtained results confirm the opinion of specialists on the low fire-extinguishing efficiency of foam obtained from hydrocarbon foamers when the foam is lifted with compact jets for a long distance.

References
[1] Sharovarnikov A F, Voevoda S S and Molchanov V P 2000 Modern means and methods for extinguishing oil fires. M.: Kalan 420 p.
[2] Sharovarnikov A F and Punchik G I 1982 Experimental determination of the strength of foams with high foam densities. Colloid Journal. T. 44 1 p 180.
[3] Jho C 1987 Spreading of aqueous solutions of a mixture of fluoro- and hydrocarbon surfactants on liquid hydrocarbon substrates. Journal of Colloid and Interface Science. Vol. 117 1 pp 138-148.
[4] Shaefer T, Dlugogorski B and Kennedy E 2007 Sealability Properties of Fluorine-Free Fire Fighting Foams. University of Newcastle.
[5] Nurimoto N 1977 Fire extinguishing installations for oil storages injecting foam under the layer of oil product, Japan, Kasay, vol. 27 3 pp 11–19.
[6] Blinov V I and Khudyakov G N 1961 Diffusion burning of liquids. Moscow, Russian Academy of Sciences Publ., p 208.
[7] Korolchenko D A, Degaev E N, Sharovarnikov A F 2015 Dependence of Fire Extinguishing Efficacy of Low Expansion Foams Solutions Homology Sodium Sulfate on the Molecular Weight of the Surfaceactive Substances. 2nd International conference on material engineering and application: (ICMEA-2015), DOI 10.12783/dtmse/icmea2015/7238.
[8] Borkovskaya V G 2014 Complex models of active control systems at the modern developing enterprises. Advanced Materials Research. T. 945-949 pp 3012-3015. DOI: 10.4028/www.scientific.net/AMR.945-949.3012.
[9] Borkovskaya V G 2014 Environmental and economic model life cycle of buildings based on the concept of “Green Building”. Applied Mechanics and Materials. T. 467 pp 287-290. DOI: 10.4028/www.scientific.net/AMM.467.287.
[10] Borkovskaya B G and Agapov C V 2014 Standards and fire safety requirements. Fire and Explosion Safety, vol. 23 11 pp 7-14.
[11] Borkovskaya V G 2013 New requirements professional risks in fire safety. Fire and Explosion Safety, vol. 22 12 pp 9-15.
[12] Borkovskaya V G 2013 The concept of innovation for sustainable development in the construction business and education. Engineering Management, vol. 457-476 15 pp 1703-1706. DOI: 10.4028/www.scientific.net/AMM.475-476.1703.
[13] Turekova I, Balog K and Polka M 2012 Effect of fire fighting foams on the environment and fire extinguishing. Bezpieczenstwo i Technika Pozarznica. T. 25 pp 29-36.
[14] Korolchenko D A, Degaev E N and Sharovarnikov A F 2015 Determination of the Effectiveness of Extinguishing Foaming Agents in the Laboratory. 2nd International conference on material engineering and application: (ICMEA-2015), pp 17-22. DOI: 10.12783/dtmse/icmea2015/7237.
[15] Borkovskaya V G 2013 Post bifurcations of the concept of the sustainable development in construction business and education. Engineering Education, vol. 860-863 26 pp 3009-3012. DOI: 10.4028/www.scientific.net/AMR.860-863.3009.
[16] Xiang Z M, Guang M L and Chao L 2016 Study on Intelligent Fire Fighting System for Large External Floating-roof Tank. International Conference on Intelligent Manufacturing and Materials (ICIMM 2016). DOI: 10.12783/dtmse/icimm2016/6244.