

OPERATION EFFICIENCY INCREASE OF WATER FIRE-FIGHTING SYSTEMS AT FOOD ENTERPRISES

Objective. *This paper investigated regularities and manifestations of the elastic deformations of the polymer flow under conditions close to that of the real flows of the fire hoses at food enterprises.*

Methods. *The work uses the out analytical survey of the results obtained while studying polymer solutions in different hydrodynamic conditions.*

Results. *The data obtained in this study shows that when solving the problem of drag reduction of the fire suppressing liquid in the pipeline at food enterprises by injecting the polymer solutions in the boundary layer, for the development of the optimum system of the introduction, it is necessary to take into account possible effects of the elastic deformations. Decreased effect in diminution of resistance to liquid flow when feeding polymer solution into BL of a fire-hose is the result of combining deformation effect of longitudinal hydrodynamic field available in a feeding system and molecular-concentration properties of polymer solution.*

Scientific novelty. *For the first time thus it is possible to improve the effective systems of the polymer introduction into the fire hoses and therefore operation of the fire suppression systems at food enterprises using water.*

Practical significance. *Fire is the most important ecological factor that under certain conditions has the severe adverse environmental impact. There have been outlined ways of increasing the effectiveness of systems for feeding polymer solutions into fire-hoses, and hence, fire-fighting systems with water – all contributing the increase of fire protection degree at food enterprises and to decrease of environment pollution with combustion products and heat.*

Key words: *fire-fighting, polymer solution, food enterprises, polyethylene oxide.*

Due to the reduction of the hydrodynamic drag resistance in the fire hoses it is possible to improve the effective operation of the water-based fire-suppression systems at food enterprises which are the most widespread and feasible methods of the fire-fighting.

Among the well-known methods of the decrease in the hydrodynamic drag resistance through the artificial modification of the boundary layer of the fire hoses, the method of the introduction of the polymer solutions is almost unique, and certain practical results have been achieved in its development. The study has shown that the introduction of small amounts of polyethylene oxide (PEO) and polyacrylamide (PAA) into the fire-suppression liquids (water and water solutions of surfactants) make it possible to significantly (down to 75%) reduce the hydrodynamic drag resistance. This reduction, when the other parameters of the hydraulic system are unchanged, ensures that the capacity of the fire-fighting systems is 1.5-2 times higher, or the length of the fire hoses may be 3-5 times higher, or the pump power consumption may be decreased by 60-70%, or the diameter of the fire-suppression pipes may be decreased by 15-20%. Besides, it has been shown that the additions of the poly-

mers to water or surfactant solutions considerably improve their fire-suppression properties [1].

This study relates to the hydrodynamics of the polymer solutions in the pipelines and problem of the improvement of the introduction devices. The hydrodynamics of polymer solutions at the polymer introduction into the boundary layer of the fire hoses has not been given due attention.

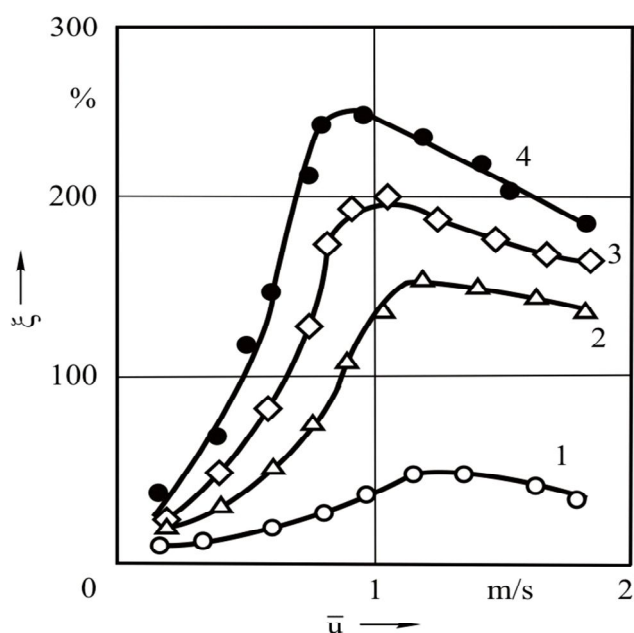
It is assumed that in case of the flow of polymer solutions through the slots and other elements of the introduction systems, essential «anomalies», which could considerably affect the Toms effect, cannot be observed. Such a conclusion is based on the analysis of the data obtained from the study of the shear laminar flows where the effects of elastic deformations are insignificant. In the introduction systems, as a rule, a complex flow consisting of superposition of the shear and predominantly longitudinal (with stretching) flow takes place. In case of such complex flows, the effects of elastic deformations become so significant that they may result in lessening the potential effect of the polymer additives, especially at high velocities of the flow of the fire-suppressing liquids.

This paper investigated regularities and manifestations of the elastic deformations of the polymer flow under conditions close to that of the real flows of the fire hoses at food enterprises. We used a special hydrodynamic bench that allows achieving the exhaust velocities of the water flow through its channel of up to 35 m/s; the channel's length was 8.5 m. Orifices for measuring the pressure and for the sensors of friction force were placed on the lower wall of the channel. The injection system consisted of a dosing unit, underslot chamber ensuring different conditions of the deformation of the polymer solution (by changing the entrance angle) at the entrance to the slot. The angle between the injected polymer stream and the wall did not vary. The following characteristics have been variable: the angle of the opening of the slot (the angle of the entrance to the slot), concentration of the injected polymer solution, velocity of the injection, molecular mass, polymer brand, and velocity of the fire suppressing liquid (water).

In Figure 1, the experimental data related to the flow of polyethylene oxide (PEO) water solutions through the underslot camera are shown.

It is clear that the phenomena, unusual for purely viscous mediums, are inherent for such flows. At a certain critical (threshold) average exhaust velocity U , the relative pressure differential increases sharply, and it is sharper at the higher polymer concentrations. The characteristics of the dependence $\xi = f(U)$ indicate the high dissipation of energy in the polymer solutions flow through the injector, i.e. the increased hydrodynamic drag resistance is observed at the supercritical flow rates.

The presented experimental data are in accordance with the results obtained from the study of the flow of the polymer solutions under the simulated conditions such as through short capillary tubes and slots. These flows were thoroughly investigated in papers [2-6]. There should be stressed the most important moments of the elastic stress effects in the polymer solution flows with stretching. Transition to a flow mode with increased energy dissipation is accompanied by formation of so called «inlet flooded jet» as a «cord» or «fillet» enclosed by secondary flows in the shape of ring-shaped vortex.



Mol. mass: $4 \cdot 10^6$, $C_{PEO} = 0,1\%$; β° : 1 – 9° , 2 – 13° , 3 – 22° , 4 – 34°

Figure 1 – Influence of u and angle of entrance into a slot on the relative pressure differential

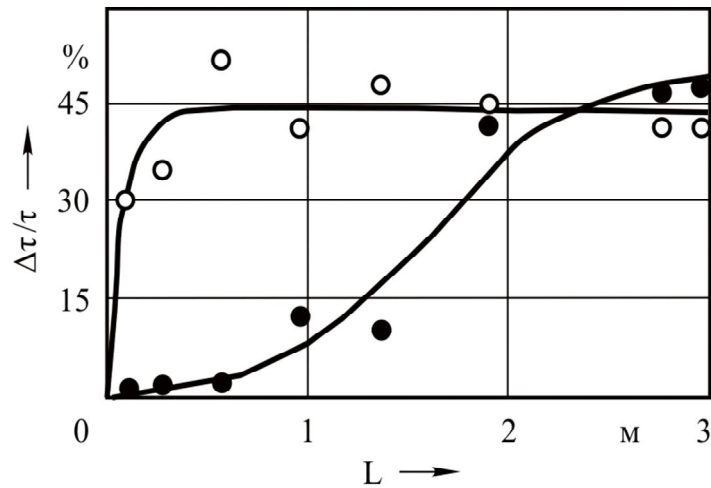
In case of the supercritical flow mode for polymer concentrations ranged from very diluted to moderately concentrated, the hydrodynamic field causes rather strong deformation effects on molecular chains. The uncoiled part of a polymer chain may be as large as 60%. In half-diluted and moderately concentrated polymer solutions, the relaxation times of the fully stretched and slightly deformed individual chains differ more than by 2 orders of magnitude.

The reason for such a large time for the curling of the polymer chain is supermolecular structures formed in the hydrodynamic field. This is reflected in the decrease of turbulent friction if the lifetime of supermolecular formations in the polymer solution at the moment of its introduction to the boundary layer is comparable to the residence time in the fire hose at food enterprises.

The results of the polymer solution injection onto the lower wall of the channel through the underslot chambers with varying angles of the entrance to the slot shows (Figure 2), that when the polymer solution is introduced onto the inner surface of the fire hose at low angles of the entrance to the slot, the drop in the tangent stresses of friction is exhibited practically right behind the point of the introduction of the polymer to the flow.

If the polymer solution is introduced into the boundary layer through the chamber with a large angle of the entrance, there is a delay in development of hydrodynamic activity of the polymer molecules.

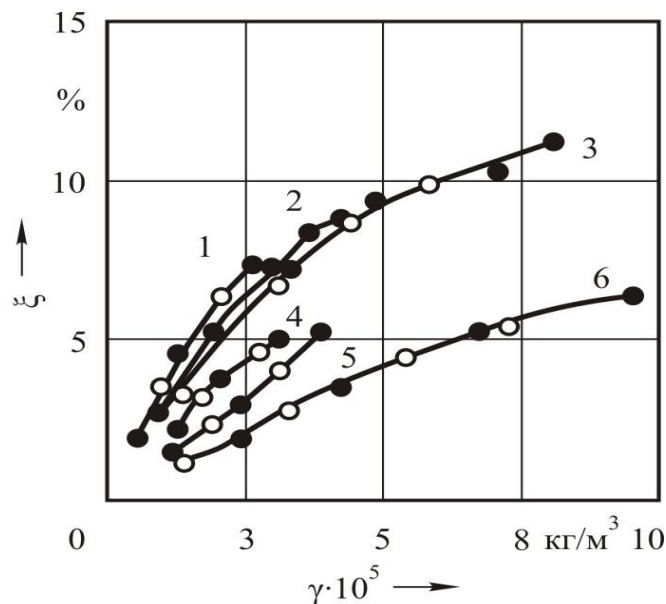
It should be mentioned that the distribution of the tangent stresses and relative pressure losses along the channel correlate with each other. As it follows from the results shown in Figure 2, the change of the mode of the polymer introduction through the underslot camera from weakly dissipative to strongly dissipative by modification of the entrance conditions results in double decrease in the drag resistance coefficient.



Mol. mass: $2 \cdot 10^6$, $C_{PEO} = 0,3 \%$, $V_0 = 16,5 \text{ m/s}$, $Q = 50 \text{ sm}^3/\text{s}$; β° : 1 – $7,8^\circ$, 2 – 165°

Figure 2 – Influence of the angle of the entrance to the slot on the distribution of the decrease in the tangent stresses along the lower wall of the channel for the injections of PEO solutions

There has been (Figure 3) registered a considerably larger divergence in the plots of the drop of the resistance versus $\gamma = Q \cdot C_{PEO} / \Omega \cdot V_0$ (where Q is the velocity of the injection, C_{PEO} – concentration of the injected polymer solution, Ω – moistened surface, V_0 – velocity of the filling flow) at the changing concentrations of the polymer in case of the introduction of the polymer onto the inner surface of the fire hose under conditions of strong deformation effect of the hydrodynamic field on the injected solution, compared to the weak gradient effect.



Mol. mass: $2 \cdot 10^6$, V_0 : ● = $16,5 \text{ m/s}$, ○ = 25 m/s ; $\beta^\circ = 7,8^\circ$ (1, 2, 3), $\beta^\circ = 165^\circ$ (4, 5, 6); C_{PEO} : 1 and 4 – $0,05\%$, 2 and 5 – $0,1\%$, 3 and 6 – $0,3\%$.

Figure 3 – Plot of the general pressure losses along the channel versus the specific concentration of PEO

The visualization of the flows of the polymer solution in the underslot chamber shows that the conditions of the entrance render influence on the drop of hydrodynamic resistance only when there is a loss of stability of the flow caused, as was shown earlier in [2-4], by the formation of the dynamic supermolecular structures which sharply increase the dissipativeness of the flow. The reduction of efficiency of the polymeric solution due to the deformation effects in the introduction system may be as large as 25% or higher at $V_0 > 15$ m/s.

The increase in the rate of the water flow results in the expansion of the area with the reduced hydrodynamic activity of the polymer.

The significance of the area with the reduced hydrodynamic activity of the polymer introduced into the boundary layer is the more, the less is the length of the fire hose. It may be explained by the fact that the lifetime of the derivative structures under conditions of the flow with stretching is in the order of magnitude of 0,1-0,2 s or higher [5].

This is the time during which the polymer after leaving the slot in the fire hose has reduced activity due to its memory. Obviously, the more is the velocity of the water flow, the larger is the area behind the slot filled with the polymer solution under this condition, and its size is defined as: $l_\lambda = \theta_{sw} \cdot V_0$, where θ_{sw} – the time of structural relaxation of the supermolecular formations. Hence, for the velocity of the water flow of 25 m/s, this area should extend downwards along the stream to 2,5 m, if $\theta_{sw} = 0,1$ s.

The estimated size of the area with the reduced hydrodynamic activity of the polymer is in good correlation with the experimentally obtained results.

The results of the experiments with the introduction of the polymer solutions of the various concentration through the underslot camera with the changing angle of the entrance (Figure 3, $\gamma = Q \cdot C_{PEO} / \Omega \cdot V_0$, where Q is the velocity of the introduction, C_{PEO} – concentration of the injected polymer solution, Ω – moistened surfaces, V_0 – velocity of the filling flow) show that for the given specific average concentration of the polymer in the boundary layer the efficiency of the reduction of drag resistance is decreased with the growth of the concentration of the injected polymer solution, and it is the stronger, the higher is the angle of the entrance. In [7], there was outlined a hypothesis that viscoelastic effects (swelling of the jet) near the slot strengthen the pull of the polymer solution by the external boundary layer and result in a faster decrease in the concentration of the polymer on the inner surface of the pipeline. The results obtained in [8; 9] make us reconsider this hypothesis because the visualization of the flow behind the slot [8] and the actual concentration of the polymer in the boundary layer [9] have not evidenced to the increased diffusion of the polymer. Most feasible is the explanation based on the impact of the effective viscosity (taken in its broad sense) that does not contradict to the results of the studies on the hydrodynamic activity of the polymers under conditions of the introduction of the polymer solution to the fire suppression pipeline.

The dynamic structures of the polymer formed in the hydrodynamic field cause its compression [2; 4], and this, of course, should cause decrease in the diffusion of the polymer in the boundary layer.

The detected regularities of the manifestation of elastic deformations at the introduction of the polymer solution to the fire-suppression pipeline allow suggesting a

method for evaluation of the flow resistance of the fire suppressant liquid with the polymer additives in it.

The flow resistance of the liquid in the pipeline at the introduction of the polymer solution to the boundary layer caused by the elastic deformations can be determined as:

$$X = \int_0^{l_\lambda} \chi(x) \tau_{wo} dx + \int_{l_\lambda}^{L-l_\lambda} \chi(x) \tau_{wl} dx,$$

where χ is the perimeter of the pipeline cross-section,

τ_{wl} and τ_{wo} – tangential stresses with the introduction of the polymer to the boundary layer and without it,

L – length of the pipeline, $l_\lambda = \theta_{sw} \cdot V_0$ (θ_{sw} – time of structural relaxation of the supermolecular formations, V_0 – velocity of the filling flow).

The data obtained in this study shows that when solving the problem of drag reduction of the fire suppressing liquid in the pipeline by injecting the polymer solutions in the boundary layer, for the development of the optimum system of the introduction, it is necessary to take into account possible effects of the elastic deformations.

The decrease in the effect of drag reduction at the introduction of the polymer solution into the boundary layer of the fire hose is due to the combination of the deformational effects of the longitudinal hydrodynamic field developed in the system of the injection and molecular-concentration characteristics of the polymeric solution.

Thus it is possible to improve the effective systems of the polymer introduction into the fire hoses and therefore operation of the fire suppression systems at food enterprises using water.

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Цель. Исследовать закономерности проявления упругих деформаций при течении растворов полимеров в условиях, характерных для внутренней задачи, применительно к пожарным трубопроводам пищевых производств.

Методика. В работе используется аналитическое исследование результатов, полученных при изучении поведения растворов полимеров в различных гидродинамических условиях.

Результаты. Представленные в работе данные свидетельствуют, что при решении задачи снижения сопротивления течению пожаротушающей жидкости в трубопроводах посредством инъекции полимерных растворов в пограничный слой в части разработки оптимальных вариантов систем подвода необходимо учитывать возможность проявления в них эффектов упругих деформаций. Снижение эффекта уменьшения сопротивления течению жидкости при подводе полимерного раствора в ПС пожарного рукава является результатом сочетания деформационного воздействия продольного гидродинамического поля, реализуемого в системе подвода, и молекулярно-концентрационных характеристик полимерного раствора.

Научная новизна. Работа впервые демонстрирует пути повышения эффективности систем ввода полимеров в пожарные рукава, а следовательно, систем пожаротушения водой на пищевых предприятиях.

Практическая значимость. Огонь (пожары) – важнейший экологический фактор, который, при сочетании определенных условий, приводит к сильнейшему загрязнению окружающей человека среды. Указанные методы повышения эффективности систем ввода полимеров в пожарные рукава, а следовательно, систем пожаротушения водой, будут способствовать повышению степени пожарозащиты пищевых производств и уменьшению загрязнения окружающей среды теплом и продуктами сгорания различных веществ.

Ключевые слова: пожаротушение, растворы полимера, пищевые предприятия, окись полиэтилена.

Мета. Дослідити закономірності прояву пружних деформацій під час витікання розчинів полімерів в умовах, характерних для внутрішнього завдання, стосовно до пожежних трубопроводів харчових виробництв.

Методика. У роботі використовується аналітичне дослідження результатів, отриманих під час вивчення поведінки розчинів полімерів у різних гідродинамічних умовах.

Результати. Представлені в роботі дані свідчать, що під час вирішення завдання зниження опору витікання рідини, яка гасить вогонь, у трубопроводах за допомогою інжекції полімерних розчинів у пограничний шар у частині розробки оптимальних варіантів систем підведення необхідно враховувати можливість прояву в них ефектів пружних деформацій. Зниження ефекту зменшення опору витікання рідини під час підведення полімерного розчину в ПШ пожежного рукава є результатом сполучення деформаційного впливу поздовжнього гідродинамічного поля, що реалізується в системі підведення, і молекулярно-концентраційних характеристик полімерного розчину.

Наукова новизна. Робота вперше демонструє шляхи підвищення ефективності систем введення полімерів у пожежні рукави, а отже, і систем пожежогасіння водою на харчових підприємствах.

Практична значущість. Вогонь (пожежі) – найважливіший екологічний фактор, що, за поєднання певних умов, приводить до сильного забруднення навколишнього середовища. Методи підвищення ефективності систем введення полімерів у пожежні трубопроводи, які запропоновано в роботі, а отже, систем пожежогасіння водою, будуть сприяти підвищенню ступеня пожежозахисту харчових виробництв і зменшенню забруднення навколишнього середовища теплом і продуктами згорання різних речовин.

Ключові слова: пожежогасіння, розчини полімеру, харчові підприємства, поліетиленоксид.

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