REDUCTION OF THE HYDRODYNAMIC FRICTION OF HYDROCARBONS BY MEANS OF SMALL ADDITIONS OF CERTAIN ORGANOSILICON POLYMERS

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The results of an investigation of the reduction of turbulent frictional resistance of hydrocarbon liquids by means of soluble high-molecular organosilicon polymers are given — polydimethyl silmethylene and polydimethylsiltrimethylene.

The dissolution of small amounts of certain polymers in liquids leads to a reduction of the hydrodynamic resistance during its turbulent motion. This effect was discovered by Toms in the case of the flow of monochlorbenzene with polymethylmethacrylate dissolved in it [1]. Certain other polymers were found subsequently, which led to a reduction of the hydrodynamic resistance of water, hydrocarbons, and other liquids. The polymers and the corresponding solvents for reducing hydrodynamic resistance known at the present time are given in [2-4]. The number of these polymers is relatively small and their efficiency varies. The dependence of the initial magnitude of the reduction of resistance on the concentration of the polymer in the solution with a constant flow rate has a maximum. The more efficient the polymer, the lower the concentration at which this maximum is achieved. As the characteristic of the polymer efficiency we choose either the concentration at which the maximum resistance reduction is achieved (optimum concentration) or the concentration at which a reduction resistance amounting to one-half of the maximum is achieved [2]. The magnitudes of the resistance reduction maxima of the most efficient polymers with identical flow velocity in the turbulent regime developed are slightly different. The stability of the polymer in solution relative to the shear degradation can be judged by the rate of reduction of the observed effect. As a stability characteristic, we can take the time of flow with constant velocity, during which the effect varies in a defined way, e.g., it is reduced by a factor of two versus the initial effect.

The most effective in relation to the concentrations necessary for reduction of resistance are water-soluble high-molecular polyoxyethylene and polyacrylamide. However, polyacrylamide does not dissolve in hydrocarbons and polyoxyethylene dissolves only at temperatures above 20°C.

Polymers that reduce resistance in hydrocarbons — polyisobutylene, polyisoprene, polymethylmethacrylate, polydimethylsiloxane, and polystyrol — are less effective with respect to the concentration necessary than polyoxyethylene and polyacrylamide in water. Thus, in order to produce identical reduction of resistance, the concentration of polyisobutylene in siloxane should be approximately two orders greater than the concentration of polyoxyethylene in water, equal in molecular weight to it [3]. Moreover, the polymers mentioned reduce the resistance in one group of hydrocarbons but do not reduce it or reduce it only slightly in another group. For example, polyisobutylene reduces the frictional resistance in aliphatic and naphthenic hydrocarbons, but does not reduce it in aromatic hydrocarbons; polystyrol affects turbulent friction in aromatic hydrocarbons but does not change the turbulent friction in aliphatic and naphthenic hydrocarbons.

In this paper we have investigated the reduction of frictional resistance resulting during the flow of hydrocarbons with additives of long-chain high-molecular organosilicon polymers — polydimethylsilmethylene (PDMSM) and polydimethylsiltrimethylene (PDMSTM). These polymers were not known previously as substances affecting hydrodynamic friction.

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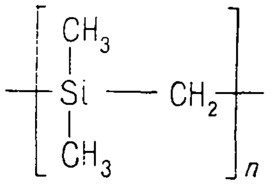
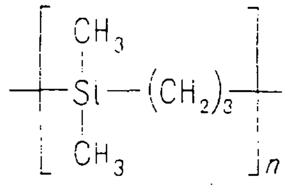


$$\left[-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\mathrm{Si}}} - CH_2 - \right]_n$$

PDMSM

and



$$\left[-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\mathrm{Si}}} - (CH_2)_3 - \right]_n$$

PDMSTM

The samples of PDMSM and PDMSTM used were obtained by the method of thermoinitiated polymerization of 1,1,3,3-tetramethyl-1,3-disilcyclobutane and 1,1-dimethyl-1-silcyclobutane [5]. Monomers were used for polymerization with a purity, determined by displacement of the melting point, of not less than 99.7%. The PDMSM was obtained at 205°C and the PDMSTM at 210°C. The PDMSM obtained by this method, with a molecular weight of about $7 \cdot 10^6$, is a colorless, highlyelastic, rubberlike amorphous product with a vitrification temperature of —100°C. The PDMSTM used, with a molecular weight of $\sim 8 \cdot 10^6$, is a colorless solid substance with a clearly defined crystallinity. Its melting point was 43°C and its vitrification temperature was —76°C. Both polymers are soluble in aliphatic, naphthenic, and aromatic hydrocarbons, but are insoluble in water, alcohols, and ketones.

The characteristic viscosity of the organosilicon polymers investigated is low in hydrocarbons; its value amounts to about 1000 dimensionless units. This special feature and also the linearity of the chain and the high molecular weight determined the choice of PDMSM and PDMSTM as substances for investigating the ability to reduce frictional resistance. Additional considerations concerning PDMSM were based on the similarity of its structural formula with the well-known frictional resistance-reducing substances — polyisobutylene (carbon in the main valence chains replaced by silicon) and polydimethylsiloxane (oxygen replaced by the CH_2 group).

The capability of the polymers to reduce hydrodynamic friction was determined by means of a rotational device, represented by a system of coaxial smooth cylinders of which the outer was set into rotation and the inner remained at rest. The inside diameter of the surrounding cylinder was 140 mm, its height 150 mm, and the radial gap between the cylinders was 10 mm. The space between the bottoms of the cylinders was connected with the atmosphere by means of a channel drilled into the spindle of the inner cylinder. During rotation, therefore, liquid from the bottom space was expelled into the radial gap space by the action of centrifugal force. As a result of this, the surplus liquid from the radial gap space overflowed into the cavity formed by the upper part of the inner cylinder wall.

In order to rotate the outer cylinder, a dc motor was used with an electromagnetic amplifier in a feedback chain. This device permitted the speed of rotation to be maintained constant with an accuracy of ±1%, even if the load moment during the experiment varied by more than a factor of two. The number of revolutions was monitored by a photoelectric sensor and a frequency meter. In the experiments the speed of rotation was constant and amounted to 2000 rpm. With this speed the development of a turbulent regime was observed.

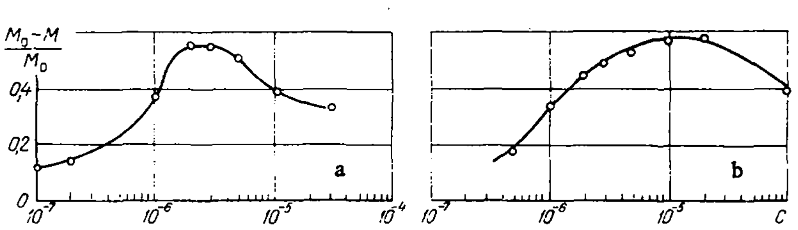


Fig. 1. Dependence of initial effect of reduction of resistance on the concentration of polydimethylsilmethylene in kerosene (a) and toluene (b).

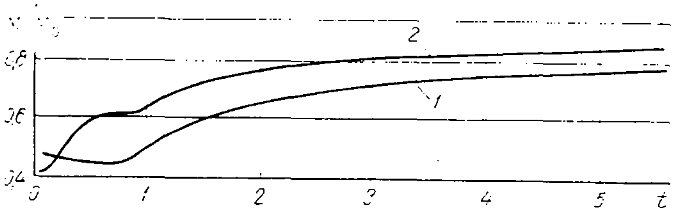


Fig. 2. Dependence of relative moment of friction on the time of operation of the facility t, min, during testing of a solution of polydimethylsilmethylene in kerosene (1) and polyoxyethylene in water (2). Concentration of solution $5 \cdot 10^{-6}$.

The moment of the hydrodynamic resistance forces was calculated from the thrust measured on a preset arm. The resulting force was measured by a capacity sensor with an elastic plate and was recorded on the plotting chart of a pen-recorder.

The experiments were conducted at room temperature.

As a result of the experiments carried out, it was established that small additions of PDMSM and PDMSTM reduce the hydrodynamic friction of hydrocarbons. The maximum effect differs only insignificantly from the maximum effect given by polyoxyethylene and other well-known effective polymers; however, it is achieved at lower concentrations. Figure 1 shows the dependence of the initial reduction of resistance on the weight concentration of polymer in solution. The relative reduction of the hydrocarbon resistance, resulting because of the dissolved polymer, is plotted along the ordinate axis; M is the initial moment of resistance obtained when testing the solution after the establishment of a specified regime (≈7 sec after switching on the facility), M_0 is the moment of resistance of the solvent. The curves show the reduction of resistance originating from the dissolution of PDMSM in kerosene T-6 and toluene. The concentration of PDMSM necessary for achieving the maximum reduction of resistance of kerosene amounts to $2 \cdot 10^{-6}$. This is lower than the optimum concentration of polyoxyethylene of the same molecular weight in water.

The efficiency of PDMSTM versus concentration is approximately the same as PDMSM, but its degradation stability is lower.

The degradation stability of PDMSM in kerosene is plotted in Fig. 2, in which the change of the relative moment of resistance is shown versus the time of operation of the facility at a constant speed of rotation of 2000 rpm. For comparison, the figure also shows the degradation curve of an aqueous solution of polyoxyethylene of molecular weight $8 \cdot 10^{6}$. The concentrations of both solutions are identical and equal to $5 \cdot 10^{-6}$. The curves show that the solution of PDMSM in kerosene has a higher degradation stability than the solution of polyoxyethylene in water.

NOTATION

M, moment of hydrodynamic resistance obtained during testing of solution after the establishment of a specified flow regime; M_0, moment of resistance of solvent; C, weight concentration of polymer in solution; t, time of holding solution in the specified turbulent flow conditions.

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