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HYDRODYNAMIC PROPERTIES OF HUMAN BLOOD PLASMA

The purpose of this research is to develop the scientific and technical basis for the use of polymer microadditives in circulatory system.

It was found out that a living organism has its own internal mechanism for regulating hemodynamics, which consists in the production of high molecular weight proteins. If the mechanism is broken, this leads to the increase of hydrodynamic resistance of vascular system and, therefore, blood pressure, i.e. to hypertension.

Keywords: hemodynamics, polymers, hydrodynamically-active polymers, reduction of hydrodynamic resistance, blood, plasma.

Introduction. In the recent decades, great attention has been paid to the phenomenon of the reduction of hydrodynamic resistance of liquids using hydrodynamically active microadditives (Toms effect). Its essence lies in the fact that small additions of synthetic and natural polymers (concentration $C = (2 \div 3) \cdot 10^{-5}$ g/cm^3 or 20-30 ppm) of high molecular mass ($M \geq 10^6$) lead to a significant (up to 80%) reduction in hydrodynamic drag during turbulent fluid motion. The effect has a prospect of wide use: to reduce hydrodynamic resistance of submarines and torpedoes, to increase the efficiency of the processes of structural materials hydrocutting and of solid rock hydraulic fracturing, in the fire fighting, etc. [1,2].

Intention and problem statement. Experimental studies have shown that the reduction of hydrodynamic resistance in small diameter pipes begins with the region of the transition of laminar flow to turbulent one. This expands the practical application of Toms effect. In particular, it allows suggesting that the addition of high polymers will have a significant impact on the movement of blood in vivo, as the Reynolds number for blood vessels vary in wide limits and reach critical values for the round pipe. Particularly, papers [3,4] have shown that the immediate reduction of blood pressure by about 30% and an increase in blood flow (2-4 times) comes with the introduction into the bloodstream of animals (dogs) of high polymers in very small doses ($C=10^{-5}\div10^{-6}$ g/cm^3). There were no side effects, because polymers are non-toxic at low concentrations and do not cause pathological changes.

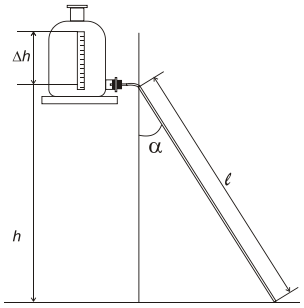
The practical application of micro-active hydrodynamically would solve two major medical problems:

1) to improve the transport functions of the circulatory system, that is, to accelerate the delivery of oxygen and nutrients to organs and tissues of the body and to increase the outflow of the metabolic products (metabolites) from cells;

2) to reduce blood pressure.

The solution of the first problem will allow accelerating recovering of the organs after diseases, and reducing the healing time of wounds received as a result of injury or surgery. The solution of the second problem will lead to a decrease in the total resistance of blood circulation, which is important for some hemodynamic pathologies, such as hypertension.

Description of the experimental installation. Preliminary experiments on defining the optimal concentration of polymer additives in various liquids were conducted on gravitational installation, diagram of which is shown in figure 1.



Tube length l	**132.7 sm**
Diameter of the tube	**0.51 sm**
Cross sectional area	**0.204 sm^2**
Water viscosity (kinematic)	**0.01012 sm^2/ sec (at t=20C)**
Tube volume	**29.08 ml**
Height of setting h	**172.5 cm** $(\Delta h >> h)$

Figure 1 – Gravitational hydrodynamic setting for the study of hydrodynamic resistance of various liquids

Investigated liquid goes through the tube with diameter d=5.1 mm out of the reservoir under the pressure of the liquid column h. To determine the flow rate $U=4V/\pi d^2\tau$, the time of the expiration τ of the volume of liquid (V=0,2÷1 л) was measured. Changing of the liquid flow rate was implemented by changing the pressure ($\Delta P=\rho gh$), under the influence of which expiration is carried out. Hydrodynamic resistance coefficient λ was defined by the formula: $\lambda=dgh(\pi d^2\tau)^2/4V^2$. Preliminarily viscosity of liquids ν was measured using a capillary viscometer VPZh-2.

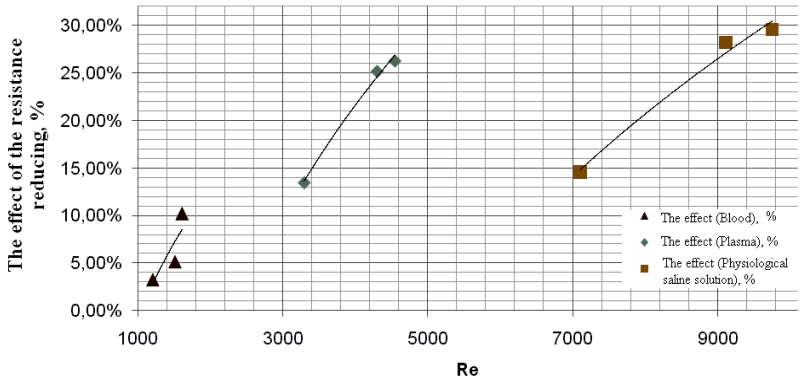


Figure 2 – The dependence of resistance reduction effect $\Delta\lambda/\lambda$ of polyethylene oxide solution WSR-301 on Reynolds number Re (PEO concentration is 25 ppm)

The results of some experiments are shown in Fig. 2, where the values of Reynolds number $Re=dU/\nu$ are plotted along the abscissa axis, and the magnitude of the effect of hydrodynamic resistance reducing is marked along the ordinate axis

$$\Delta\lambda/\lambda=[(\lambda_p-\lambda_0)/\lambda_0]\text{x}100\%,$$

where λ_p,λ_0 are hydrodynamic resistance coefficients for the flow of water and solution respectively at one and the same pressure drop.

Reciprocating capillary hydrodynamic setting, the principal scheme of which is shown in Figure 3, has been made for the experiments with blood and its components in a wide range of geometric and hydrodynamic parameters.

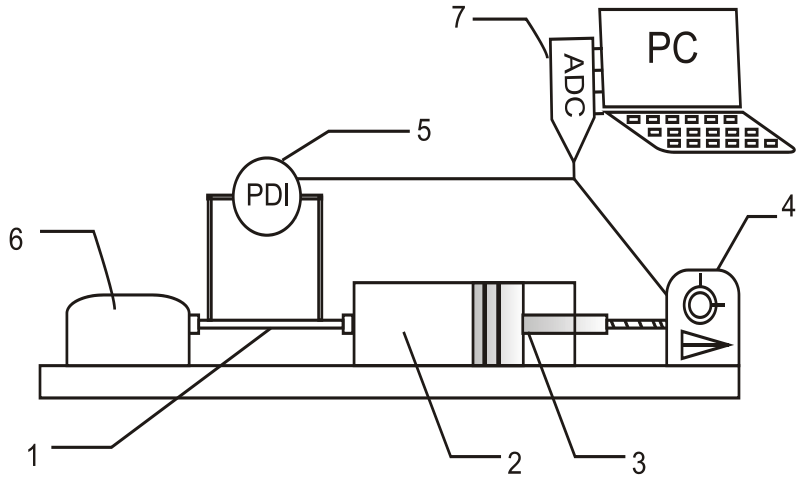


Figure 3 – Capillary hydrodynamic setting for the study of hydrodynamic resistance of different liquids:

1 – capillary (d=0,5÷5 mm); 2 – reservoir with the test liquid; 3 – piston with screw drive; 4 – reduction gear assembly with electric motor and tachogenerator PIVT 6-25/3A; 5 – differential pressure gauge, 6 – the receiving tank for liquids, 7 – analog-to-digital converter

The investigated liquid is displaced from reservoir 2 by using piston 3 through capillary 1 to the receiving tank. The piston is driven by a pair of helical gear unit with electric motor 4. The speed of the piston (hence, the velocity of the fluid in the capillary U) is defined by changing of the engine speed (by changing of the supply voltage) and is controlled by tachogenerator on the engine centerline. Friction pressure loss ΔP in the work area of the capillary (length L = 30 mm) is measured by differential manometer Metran-150. Control of operating modes and measurements results recording are performed via the management block, which is composed of: connector block I/O NI SCB 68, data acquisition board NI PCIe 6323 and a personal computer with the software package Signal Express, which are standardized products of National Instruments. Their characteristics are described in detail in [5-7].

Conclusion and findings. Investigation of hydrodynamics of human blood plasma is of considerable interest because it is known that a large number of proteins in small concentrations, many of which have large molecular weights, are contained in the blood plasma ($\sim 10^5 \div 10^6$) [8,9]. In this regard, it can be assumed that some of biopolymers (proteins of high molecular weight) dissolved in plasma are able to create the effect of the type of Toms effect. In this case it is natural to assume that, besides other possible functions, these biopolymers also perform the function of hemodynamics regulation.

To test this suggestion, we performed the experiments in defining hydrodynamic resistance in the flow of physiological saline solution, blood plasma and blood plasma with microadditives of high molecular weight polymer on the above hydrodynamic setting.

The results of some experiments are shown in Fig. 4, where (in logarithmic coordinates) Reynolds numbers $Re=dU/\nu$ are plotted along abscissa axis, the drag coefficient $\lambda=2d\Delta P/L\rho U^2$ is marked along the ordinate axis. Experimental points 1 correspond to the results of one experiment with physiological saline solution, the rest correspond to the experiments with plasma. Point 2 corresponds to experiments with pure plasma, point 3 – to plasma with the addition of high molecular polyethylene oxide WSR-301 (concentration C = 25 ppm). Laws of resistance for a Newtonian fluid: Poiseuille (laminar flow) and Blasius (turbulent flow) are shown on the graph by full lines.

Note that the blood plasma is a Newtonian fluid, because its apparent viscosity is almost independent of shear rates. The experimental points for the flow of blood plasma should be grouped near the Blasius curve. However, they are located significantly lower than the Blasius curve and

that shows a decline of the hydrodynamic resistance of blood plasma in comparison with Newtonian liquid.

The above results clearly indicate that the plasma of human blood exhibits strongly pronounced Toms effect - in the turbulent flow of blood plasma flow resistance in a straight tube is reduced compared to the flow of physiological saline solution (30%). Obviously, specified reduction of hydrodynamic resistance can be achieved only through the high molecular weight biopolymers ($M \geq 10^6$).

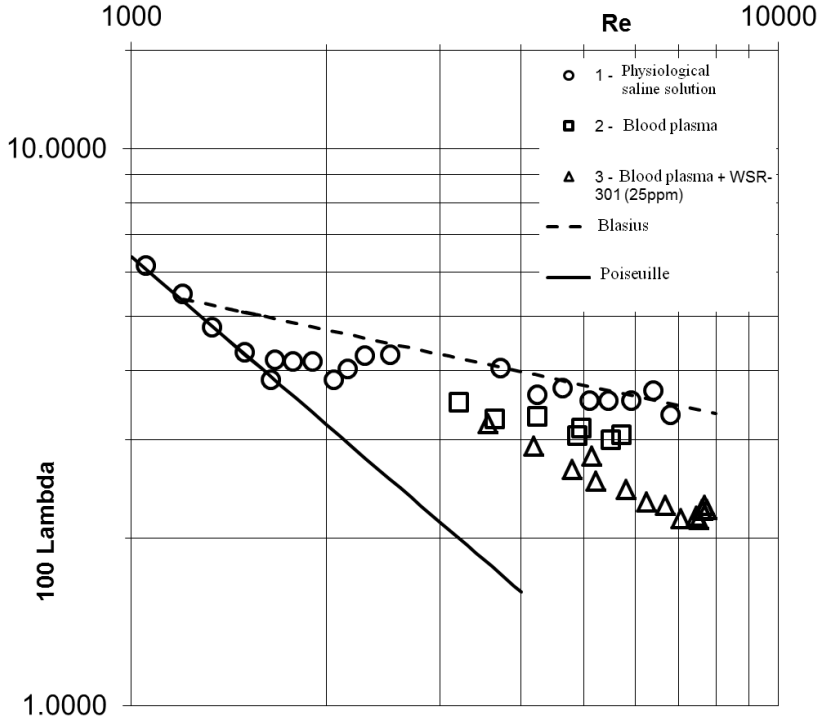


Figure 4 - The dependence of the hydrodynamic resistance λ on the Reynolds number Re:
1 – physiological saline solution (or water); 2 – blood plasma; 3 – blood plasma + WSR-301 (25 ppm)

Blood plasma is a complex biological system, containing 52% water, 7% protein and 1% fat, carbohydrates and minerals [9]. Plasma proteins represent the high molecular nitrogen containing compounds. They have a complex structure, more than 20 amino acids are included as their compounds. Connected to each other, amino acids form large molecules of different proteins, including those of fibrillar form. The latter have an elongated, threadlike structure.

Thus, the obtained results allow hypothesizing that a living organism has its own internal mechanism for regulating hemodynamics, which consists in the production of high molecular weight proteins and their supply in small amounts in blood in order to improve the hydrodynamic properties of the circulatory system (reducing its hydrodynamic resistance). In case this mechanism is broken, this leads to an increase of hydrodynamic resistance of vascular system and, therefore, blood pressure, i.e., to hypertension.

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ГИДРОДИНАМИЧЕСКИЕ СВОЙСТВА ПЛАЗМЫ ЧЕЛОВЕЧЕСКОЙ КРОВИ

Применение гидродинамически-активных полимеров при гемодинамических патологиях имеет большие перспективы. Цель настоящих исследований: разработка научно-технических основ применения микродобавок полимеров в кровеносных системах.

Ключевые слова: гемодинамика, полимеры, гидродинамически-активные добавки, снижение гидродинамического сопротивления, кровь, плазма.

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ГІДРОДИНАМІЧНІ ВЛАСТИВОСТІ ПЛАЗМИ ЛЮДСЬКОЇ КРОВІ

Використання гідродинамічно-активних полімерів при гемодинамічних патологіях має великі перспективи. Мета даних досліджень: розробка науково-технічних основ застосування мікродобавок полімерів в кровоносних системах.

Ключові слова: гемодинаміка, полімери, гідродинамічно-активні домішки, зниження гідродинамічного опору, кров, плазма.

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