INFLUENCE OF A TRANSVERSE MAGNETIC FIELD ON AN ELECTROMAGNETIC FLUID IN HYDRODYNAMIC INITIAL SECTION

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Abstract

This article is about Influence of transverse magnetic field. The study of the hydrodynamic initial section is onsidered in the work. The research in the article is devoted to the study of the deformation of the velocity plot. The authors noted the peculiarities of the conditions of flow entry into the initial section, the rheological properties of fluids and external factors (for example, how the fluid is electrically conductive). The authors also showed that Vortex creatures adjacent to the input features (country protocols, geometric properties) can have a significant effect on the input diagram. Also, the authors mention that the deformation of the velocity plot significantly affects the pressure drop. the influence of ponderomotive force on hydrodynamic initial vertex is considered. The authors conducted a study that found that the presence of a magnetic field can lead to the quenching of vortex formation at the entrance to the hydrodynamic initial section. This in turn affects the length of the hydrodynamic initial section.

Keywords: ponderomotive forces, magnetic field, Hartmann number, initial section, pressure, velocity field.

INTRODUCTION

It is known [1], [2], [3], [4], that study of fluids in hydrodynamic initial section is a problem of great interest in the field of technical hydromechanics. The reason for it is that usually in machines and devices with local resistance as working elements short channels form equipment, where the flow of fluids is unstable, and inertia forces of convective acceleration have a great impact on the flow properties. Such tasks are of great relevance in the field of mechatronics as well as hydraulic and pneumatic control systems. Significant number of researches deals with study of hydrodynamic initial section, especially for Newtonian fluids.

EXPOSITION

To a lesser extent, such problems are solved for anomalously viscous fluids. On the basis of existing studies, flow in the initial section can be described as follows [2]. It is assumed that velocity epure at the flow entrance in hydrodynamic initial section has a rectangular shape. As the fluid advances along the channel, both inertia forces of convective acceleration and viscous friction forces begin to manifest themselves. A boundary layer which provides some slowdown is formed in the near-wall region. At the same time, accelerated fluid motion is observed in the flow core. And thus, velocity epure is deformed with a rectangular distribution in the flow core. This process continues until the thickness of the boundary layer becomes equal to half of the channel's diameter, and the flow core reduces to zero. It is assumed that in this case zone of hydrodynamic initial section ends, and stable Stokes flow begins. It is also assumed that length of the initial section is determined by a cross-section where the velocity epure differs by less than 1% from the flow described by the Stokes formula. This restriction is introduced because deformation process of the velocity epure in the 1% zone can be quite large. Figure 1 shows velocity epure pattern typical for hydrodynamic initial section.

Among the factors that affect the flow pattern in the initial section zone, it is important to note special features of the flow entry conditions in the initial section, rheological properties of the fluid under consideration, and external factors (for example, magnetic field for electrically conductive fluid). Under real-life conditions,

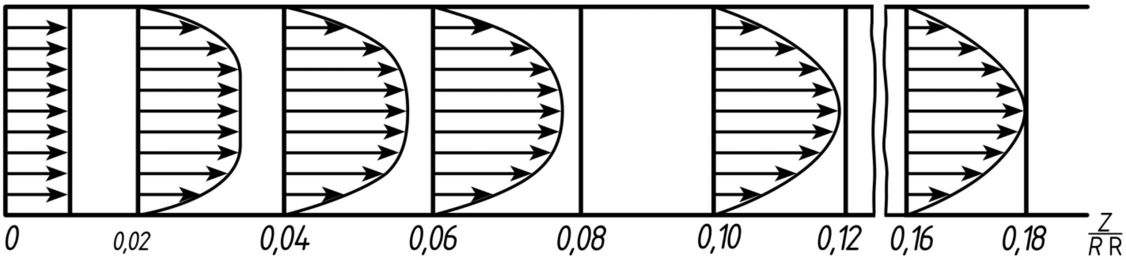

Fig. 1 *Velocity epure in hydrodynamic initial section*

it is quite rare that the velocity epure at the channel entrance is rectangular. In most cases it is a curve of some type other than parabolic. Vortex formations associated with particularities of entrance (sharp edges of the channel, geometric properties) can have significant impact on the epure at the entrance. For instance, at the entrance of the flow into the channel, there may be vortex formations in the contraction area, which would have a significant impact on deformation of the velocity epure. Figure 2 shows an example of such vortex formations in case of sudden contraction at the entrance into the channel.

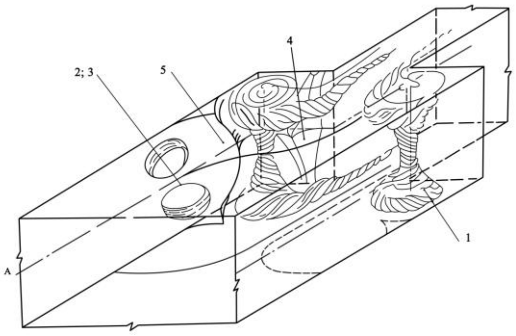

Fig. 2. *Scheme of vortex formations, based on the method of flow photography in the area of sudden contraction (fluid – 6%, PVA water solution): 1 – main vortex, 2 and 3 – secondary vortices, 4 – end "stagnant" zone, 5 – side "stagnant " zone*

Thus, length of hydrodynamic initial section depends on the entrance conditions. Another factor that has an effect on deformation of the velocity field is rheological property of the flowing fluid. If the fluid is non-Newtonian, velocity field may be affected by properties of viscosity fluctuation depending on the rheological law, for example, on the velocity gradient. For example, if a fluid is described by the rheological Ostwald-de Waele law with a flow index n other than one, then deformation of the velocity epure is in accordance with the data of Christiansen, Tyabin, Yakhno, and the epure can be represented as follows, Figure 3.

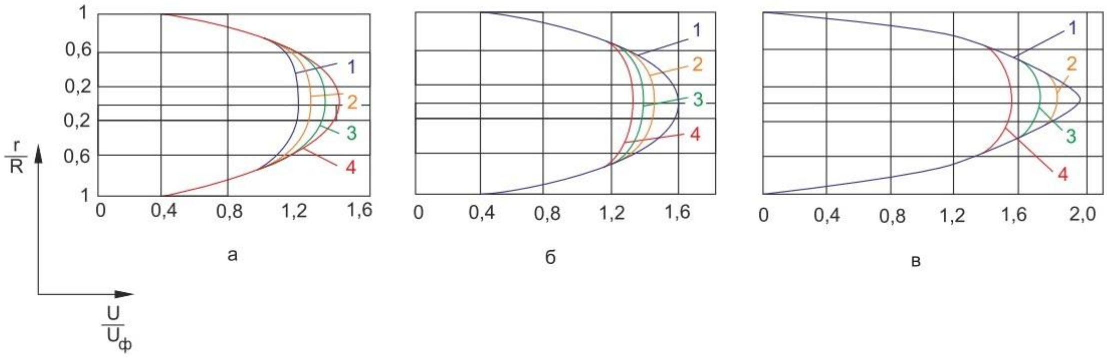

Fig. 3. Velocity distribution in the initial section of cylindrical pipe:

$1.\, n = 1;\ 2.\, n = 0{,}8;\ 3.\, n = 0{,}6;\ 4.\, n = 0{,}4;$

$a) x = 0{,}25x_0;\ б) x = 0{,}5x_0;\ в) x = x_0$

It should also be noted that deformation of velocity epure in the initial section has a significant impact on the pressure drop. Due to manifestation of the inertia forces of convective acceleration, pressure drop in the initial section is significantly higher than in the stabilized flow. According to the results of Thorner's research [5], pressure drop in the initial section can be represented as a nonlinear relationship $p(x)$of the following type, Figure 4.

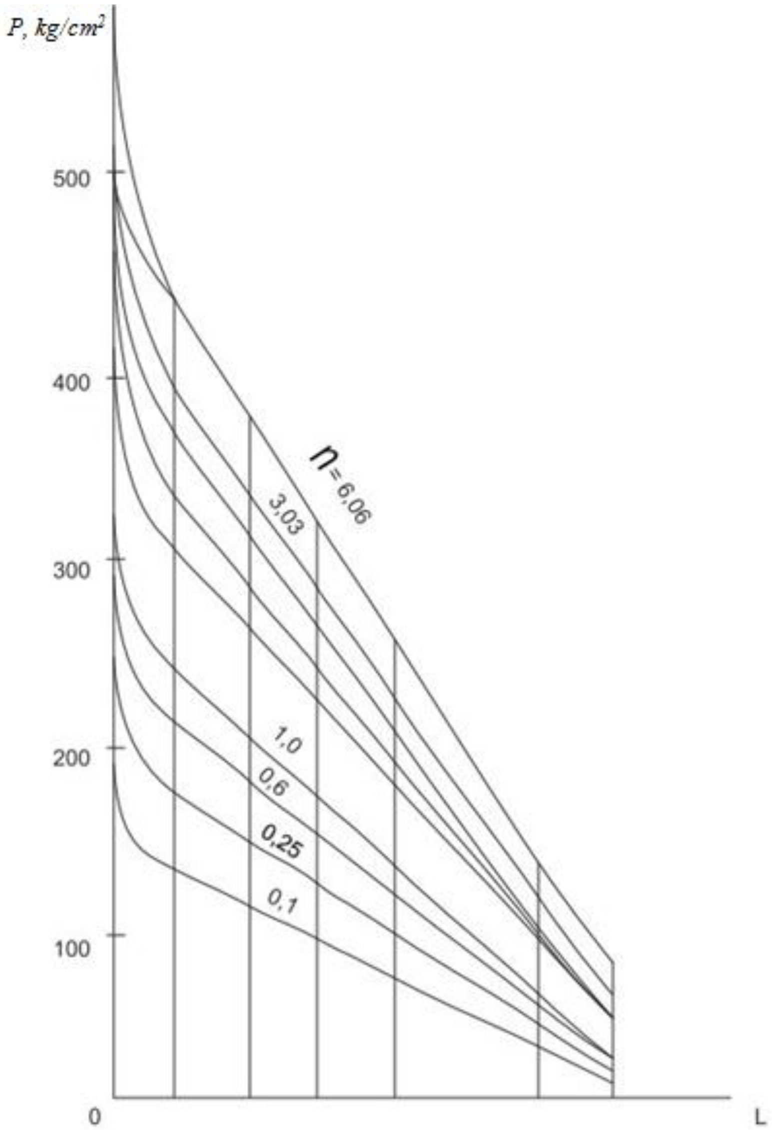

Fig. 4. *Characteristics of pressure drop in the initial section*

This figure shows curves for viscous and anomalously viscous fluids with various flow behaviour indices. n. In these two cases, length of the hydrodynamic initial section is a function of the Re number, namely:

$$L_{\text{ну}} = const \cdot Re \qquad (1)$$

In most cases, const is determined experimentally, and it takes into consideration the factors described above. Table 1 shows values of the initial section length obtained by various authors.

Table 1. Determination of length of hydrodynamic initial section

Rheological law	***Length***	***Pressure loss***	***Velocity epure type***	***Author***
Ostwald–de Waele law	$\mathcal{L}_{\text{ну}} = 0{,}122Re \cdot D$	$\frac{\Delta p}{0{,}5\rho u_{\text{ср}}^2} = \frac{[2^{n+2}(1+3n)/n]^2}{Re} \cdot \frac{L}{D} + 1{,}33$	-	*M. Collins, W. Schowalter*
Ostwald–de Waele law	$\mathcal{L}_{\text{ну}} = 0{,}101Re \cdot D$	$\frac{\Delta p}{0{,}5\rho u_0^2} = \frac{2^{n+2}[(1+3n)/n]^2}{Re} \cdot \frac{L}{D} + 1{,}22$	*Parabola in the slowdown zone*	*Tomita*
Shvedov–Bingham law	$\mathcal{L}_{\text{ну}} = 0{,}025H \cdot Re$	$\frac{\Delta p}{\gamma} = \frac{u_0^2}{2g}(\omega_2 - \omega_1)$	*Parabola in the near-wall region*	*L. S. Leibenzon*
Rheological law $[\tau_{ij}] = \mu_1[\dot{\gamma}_{ij}] + \mu_2[\dot{\gamma}_{ij}]^2 + \mu_3[\dot{\gamma}_{ij}]^3 + \cdots$	$\mathcal{L}_{\text{ну}} = AHRe,$ $A = const,$ $A = f(\mu_1, \mu_2, \mu_3)$	$\Delta p = \frac{3}{2}\left(\frac{u_n - 2}{a^2}\right)^2 + \cdots - A(2 - L)$	$u = 2u_{\text{ср}}\{1 - \frac{r^2}{R^2} + \frac{\mu_{2n+1}}{\mu_1} \cdot (\frac{AR}{2\mu})^{2n} \cdot [\frac{2}{n+2}\left(1 - \frac{r^2}{R^2}\right) - \frac{1}{n+1} \cdot (1 - (\frac{r}{R})^{2n+2})]\}$	*Kapoor, Gupta*

A special place in the study of hydrodynamic initial section is occupied by problems related to flow of electromagnetic fluid in transverse magnetic field. In this case, the flow experiences not only the action of inertia forces of convective acceleration, but also the action of ponderomotive forces, which are determined by the following formula:

$$F_{\text{пон}} = \frac{\mu - 1}{2\mu\mu_0}\nabla(B^2), \qquad (2)$$

where $\mu -$ is magnetic permeability, $\mu_0 -$ magnetic constant, $B -$ magnetic induction.

In this case, equation describing the flow in the initial section has the following form:

$$\begin{cases} \rho\left(u_x\frac{\partial u_x}{\partial x} + u_y\frac{\partial u_x}{\partial y}\right) = -\frac{dp}{dx} + \mu\frac{\partial^2 u_x}{\partial y^2} - \frac{\sigma B_0^2}{c^2} \cdot \frac{\partial u_x}{\partial y} \\ \frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} = 0 \end{cases} \qquad (3)$$

where $u_x, u_y -$ are projections of velocity on the coordinate axes;

$p, \rho -$ pressure and density of the fluid;
$\mu -$ dynamic viscosity;
$\sigma -$ magnetic field density;
$B_0 -$ magnetic field induction;
$c -$ speed of light.

In this case, deformation of the velocity epure in the initial section depends significantly on the ratio of inertia forces of convective acceleration and ponderomotive forces. Studies carried out by several authors [4], [5] show that in this case, at the end of the hydrodynamic initial section, velocity epure (Hartmann flow) takes the following form, shown in Figure 5.

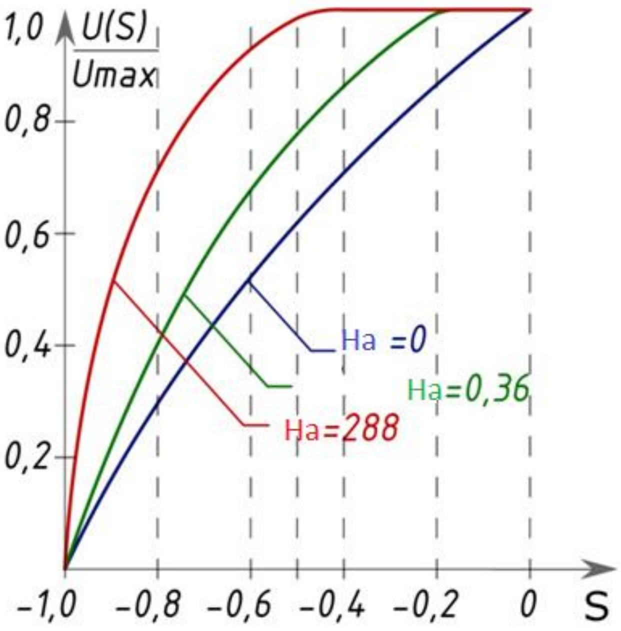

Fig. 5. *Velocity distribution in magnetic field for different Hartmann numbers*

Comparison of this epure with the velocity epure without magnetic field in qualitative terms is shown in Figure 6.

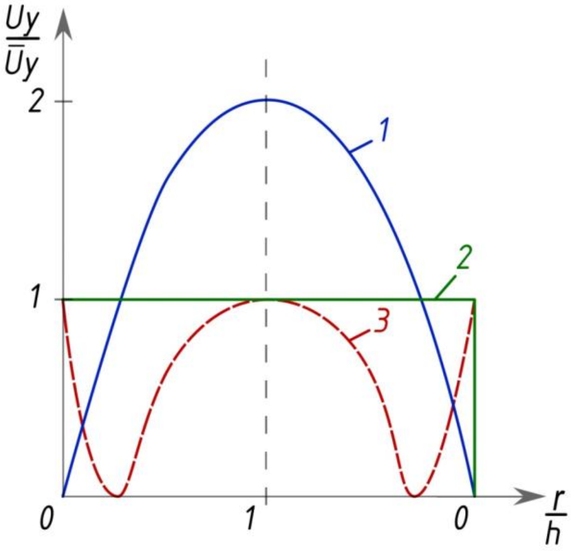

Fig. 6. *Difference in velocity epures at the entrance to and exit from the initial section*

Experimental studies carried out by several authors have shown that transverse magnetic field can have a significant impact on dampening of vortex formation. In the case under consideration, presence of magnetic field can lead to dampening of vortex formation at the entrance to hydrodynamic initial section, and hence affect the length of the hydrodynamic initial section. On the other hand, Lorentz forces can lead to slowdown of the fluid flow in hydrodynamic initial section. Our experimental studies have shown the extent of slowdown of the flow of electromagnetic fluid in the channel. This level of slowdown can be evaluated on the basis of relationship between velocity of the electromagnetic fluid flow and the pressure drop. Figure 6 shows a similar relationship, and it is evident how the flow rate changes in the presence of magnetic field, while the pressure drop remains the same.

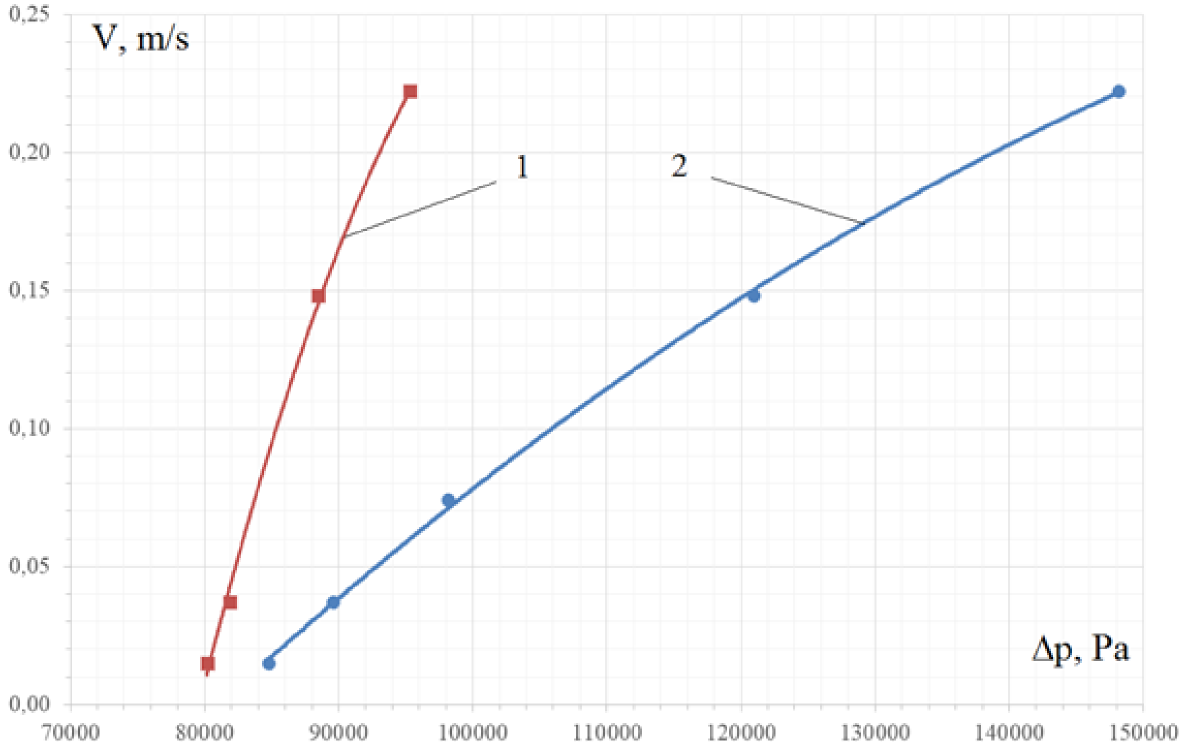

Fig. 7. *Relationship* $v = f(\Delta p)$, *where line 1 – with magnetic field, line 2 – without magnetic field*

The studies were carried out on the experimental facility with possibility to adjust pressure drop in the flow.

CONCLUSION

To sum up, it should be noted that previous studies have shown that length of the hydrodynamic initial section is a function not only of the Reynolds number, but also of the Hartmann number:

$$L_{\text{ну}} = const \cdot D \cdot Re + const_1 \cdot D \cdot Ha \qquad (4)$$

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