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# Stirring of electrolytes in the vicinity of metallic matrix in a permanent magnetic field

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Magnetohydrodynamic stirring of electrolytes in the vicinity of metallic surface in combined magnetic and electric fields is a phenomenon well known and widely used in modern technology. In the paper the phenomenon of magnetohydrodynamic stirring in the vicinity of metallic surface in the electrolytes was observed only in a magnetic field. The influences of main parameters, such as magnetic field strength and pH of electrolyte solution, on stirring process were investigated.

Key words: *magnetohydrodynamic stirring; multivortex dynamic structure; magnetic field*

## 1. Introduction

Stirring (mass transfer) in combined electric and magnetic fields is one of the most extensively investigated phenomena [1–4]. It is well known that mixing usually accelerates or changes the character of chemical and electrochemical processes occurring in electrolytes [5–9]. Stirring, widely used for intensification of heat transfer, mass transfer and chemical and biochemical processes, requires additional power sources and complex device construction. It is therefore timely to develop new inexpensive mixing methods and devices. The phenomenon of magnetohydrodynamic electrolyte mixing has served as a basis for development of improved methods of magnetoelectrochemical codeposition of several metals and inert particles, obtaining high quality of deposits, creation of chaotic magnetohydrodynamic mixing of electrolytes (such as Lagrange chaos) at very small Reynolds numbers [10]. Recently, the effect of multivortex electrolyte stirring was found in the vicinity of a solitary electrode in a magnetic field without application of external electrical field [11, 12].

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In particular, emergence of a multivortex dynamic structure of electrolyte was revealed in the vicinity of a long metallic cylinder under the influence of a magnetic field [13]. The directions of rotation in the adjacent vortexes are mutually opposite (Fig. 1). In details, hydrodynamics of multivortex dynamic structure of aqueous solution of nitric acid in the vicinity of a steel cylinder was investigated in the work [13].

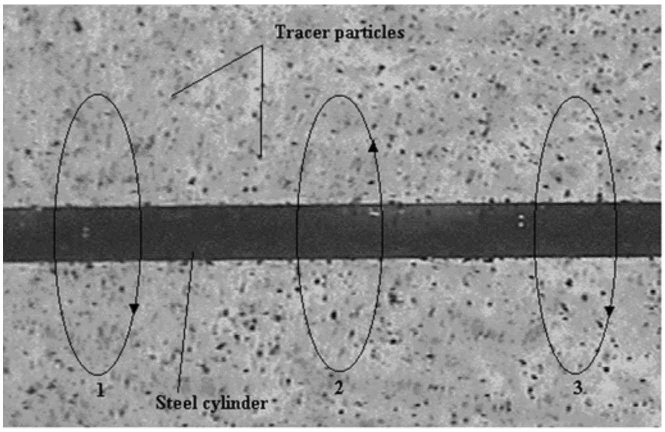


Fig. 1. Schematic drawing of the multivortex structure in the vicinity of a steel cylinder in a steady magnetic field (1, 2, 3 – electrolyte vortexes)

The purpose of the present paper was investigation of the dependence of magnetohydrodynamic mixing of nitric acid solution on magnetic field and pH. The dependence of vortex quantity on cylinder diameter was also investigated. The purpose of the study was determined by practical application requirements. One of the most important parameters characterizing an electrolyte solution is pH value. Therefore, the investigation of electrolyte velocity dependence on pH value is an interesting and necessary task. It is worth noting that pH value can be changed in industrial processes [14, 15] and can be optimized. Modern technologies allow us to use strong magnetic fields, for example, by using permanent magnets. The advantages of permanent magnets are absence of power supply expenditure and a simple construction. Thus, the investigation of electrolyte velocity dependence on magnetic field strength is also an important task. The study of the dependence of number of vortexes on the cylinder length is of interest because it characterizes the problem of uniformity and quality of mixing.

## 2. Experimental

The experiments were carried out in an installation, consisting of an electromagnet, an optical microscope, a videocamera and a computer similar to the one described in [16]. The vortex velocity dependencies on magnetic field magnitude and solution pH were investigated. The model liquid represented 7% nitric acid solution with addition of non-magnetic tracer particles for a visualisation of electrolyte movement. The free volume of the microcontainer was filled with 7% nitric acid solution with the tracer particles. The microcontainer with the steel cylinder was fixed between polar tips of an electromagnet. A slow motion of the tracer particles towards the steel cylinder surface was observed without a magnetic field application. Upon switching on the magnetic field electrolyte velocity increases significantly.

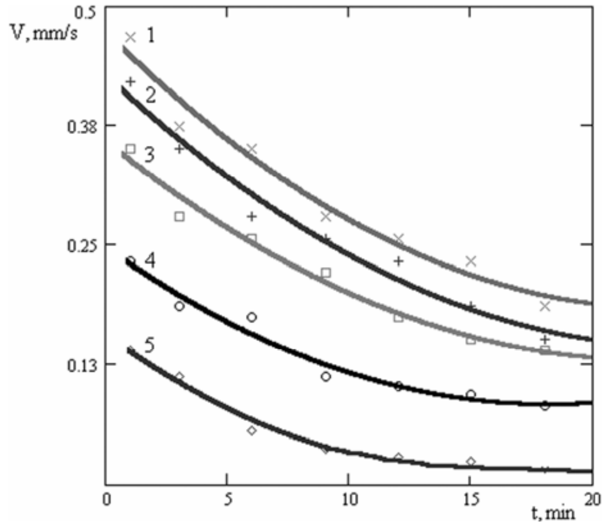


Fig. 2. Vortex velocity dependence on magnetic field magnitude in the vicinity of the steel cylinder surface. The magnetic field *H*: 1 – 1000 Oe, 2 – 2000 Oe, 3 – 3000 Oe, 4 – 4000 Oe; 5 – 500 Oe

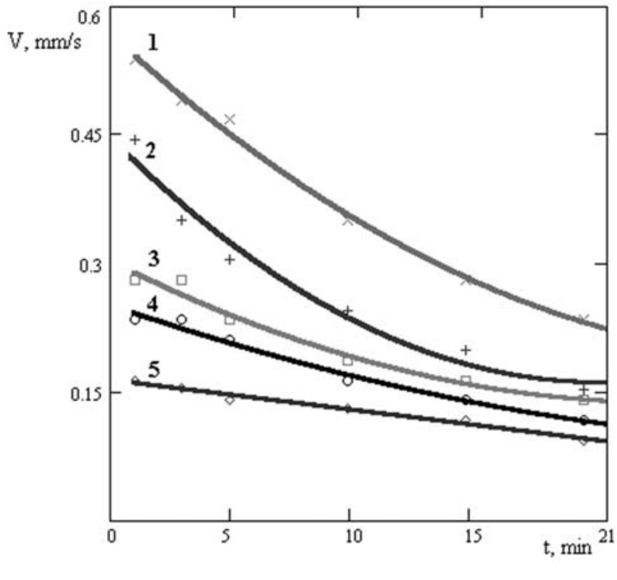


Fig. 3. Dependence of vortex velocity in the vicinity of the steel cylinder surface on solution pH in the magnetic field of 4000 Oe: 1 – pH = 1; 2 – pH = 1,5; 3 – pH = 2; 4 – pH = 3; 5 – pH = 5

The dependence of the vortex velocity on the magnetic field magnitude in the vicinity of the steel cylinder surface is shown in Fig. 2. The electrolyte velocity increases with increasing magnetic field and decreases with experiment time.

The electrolyte velocity is higher at higher acidity of solution and it decreases with experiment time. As is shown in Figs. 4, 5, the number of vortexes depends on the cylinder length *L*. The number of vortexes is different for different cylinder diameters.

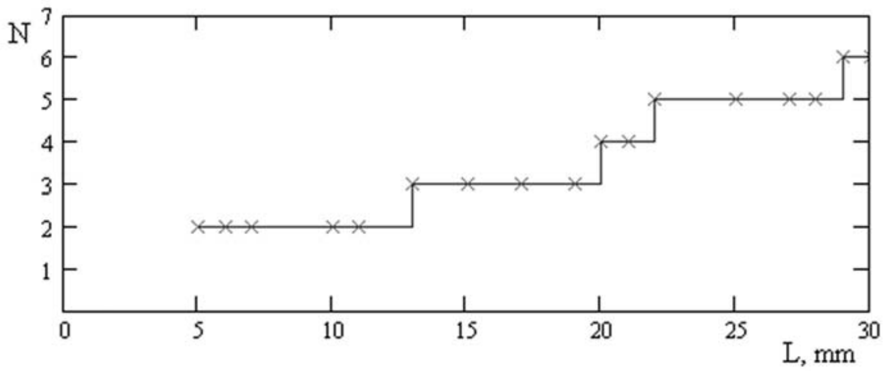


Fig. 4. Dependence of the number of vortexes on the cylinder length *L*. Cylinder diameter is equal to 0.725 mm (the experimental points are marked with ×)

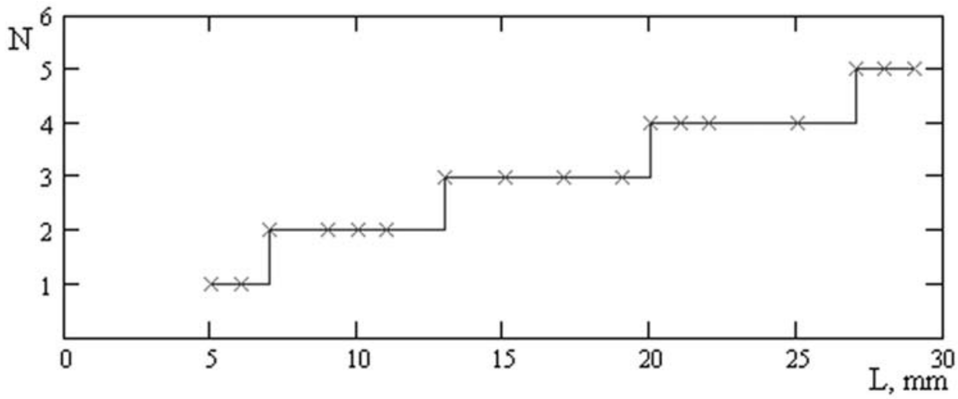


Fig. 5. Dependence of the number of vortexes on the cylinder length L. Cylinder diameter is equal to 0.250 mm (the experimental points are marked with ×)

## 4. Conclusion

The magnetohydrodynamic stirring is a phenomenon possibly to create new mixing devices that can be used for various applications, for example, mixing of microvolumes. The advantages of the proposed method are electric power economy and simplified device construction. The dependences obtained in this work allow one to get qualitative estimates in order to optimize the magnetohydrodynamic stirring process without any external electric field applied. A proper choice of pH of solution, an external magnetic field magnitude and diameter of steel wires (independently of their length) can be made based on the present investigation.

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