UDC 681.2.08
T. Yu. Kisil, ***Ph.D., associate professor***
L.G. Kunytska, ***Ph.D., associate professor***
V.V. Tuz, ***Ph.D., associate Professor***
Cherkasy State Technological University

SPECIFYING THE FORM OF IMMERSION PROBE IN THE PIEZOELECTRIC LIQUID VISCOSIMETERS FOR IMPROVING MEASUREMENT ACCURACY

The paper is devoted to the choice of the optimal form for the immersion probes in piezoelectric fluidimeters. It is known that viscosity provides the best understanding of liquids, of changing their states and can be considered as one of the main characteristics. To avoid errors of measurements conducted with the help of piezoelectric converters of the viscosity, which can occur as a result of ultrasonic radiation losses, the authors suggested to divide the converter into a vibrator and a probe that is moving in the liquid and connected with the vibrator using a rigid thrust. The vibrator should not be sunk into the liquid. The probe is the most effective in the form of a polished plate with sharpened edges. An additional point is that the cavitation bubbles can appear on the edge of the vibrator while it is moving and thus affect the measurement accuracy. Construction of the device for implementing the suggested and conducted computerized modelling is introduced, to specify the definitive probe form. Outcomes of the computerized modelling proved the polished plate with sharpened edges to be the most effective probe form. Probe linear travel (therefore, oscillation frequency and range) should be defined in the way that the Reynolds number does not exceed the critical value (Re<<2300).
Key words: *viscosity, liquid, ultrasonic method, piezoelectric measuring device, immersion probe, Reanold number.*

Introduction. Liquid - a substance in a liquid aggregate state that occupies an intermediate position between solid and gaseous states. The main property of a liquid, which distinguishes it from substances in other aggregate states, is the ability to infinitely change the shape under the action of tangential mechanical stresses, even arbitrarily small, while its volume is practically retained. The liquid state is usually considered to be an intermediate between solids and gas: gas retains neither volume nor shape while solids retain both. In hydrodynamics, liquids are divided into Newtonian and not Newtonian. The flow of Newtonian fluid complies the Newton's law of viscosity, that is, the tangential stress and gradient of velocity are linearly dependent. The coefficient of proportionality between these quantities is known as viscosity. In a non-Newtonian fluid, the viscosity depends on the velocity gradient. Viscosity provides the best understanding of liquids, of changing their states and can be considered as one of the main characteristics. [1, 2, 3].

Viscosity is the property of the liquid to provide resistance to the relative shear displacement. The viscosity appears in the fact that with a relative displacement of fluid layers, the fluid layer that is moving slower "slows down" the layer that moves faster, and vice versa [4]. The viscosity is determined by the presence of the attraction forces between the individual particles (molecules) of the fluid, which restrain the movement of the layers when one part of the liquid is moved relatively to another one. It is obvious that all liquids must be viscous, since there are always forces of both attraction and repulsion between real molecules. Balance between these forces determines the balanced state of the fluid.

The purpose of the work is to select the most optimal form for the immersion probe in piezoelectric viscometers.

As it was already noted, the attenuation of a piezoelectric converter oscillations depends on internal friction in piezoceramics, radiation losses in the liquid and the viscosity of this liquid. It was previously defined [5] that the internal friction in piezoceramics is constant, while radiation losses depend on the depth of a vibrator immersion in a fluid (piezoelectric element or ultrasonic concentrator).

In addition, cavitation bubbles [6] may occur at the end of the vibrator during its motion in the liquid. It also causes errors in the measurements of viscosity.

The motion of solids in a liquid, which equals the flowing solids around by liquids, represents one of the most important problems of hydromechanics [7]. The main task here is to determine the forces that arise in the relative movement of a body and a fluid. The body moving in the liquid meets resistance, and must apply some force to overcome it. This will be, for example, the resistance met by an airplane, car or train from the air when it's moving, or met by a ship or submarine from the water [8]. In the case when the body is motionless and the fluid flows it around, the body provides resistance for the movement of the liquid, and it takes some energy for the fluid to overcome it. An example of this is the pressure of wind on the building, the winding of a bridge with water, etc.

Let us consider *the case of* flowing a plate by a fluid, when a plate is set perpendicular to the flow velocity. The fluid jets, when meet with the plate, exert additional pressure due to the change in the direction of flow, to the surface of the plate, faced towards the flow. Resistance force equal to the magnitude of the additional force of pressure on the plate acts on the liquid from the side of the plate. Immediately behind the plate, as a result of tearing off the jet from the plate, a region of random eddy movement is formed. In this area, the pressure is lowered, resulting in an additional resistance force, also directed toward the flow. Since this force depends on the shape of the body, it is called the shape resistance.

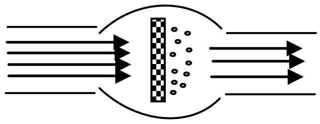


Fig.1. Flowing around a plate that is perpendicular to the direction of the flow

If the plate is located along the flow, the resistance it produces is caused mainly by the tangential forces of friction that arise on the side surfaces of the plate (the so-called frictional resistance, proportional to the viscosity).

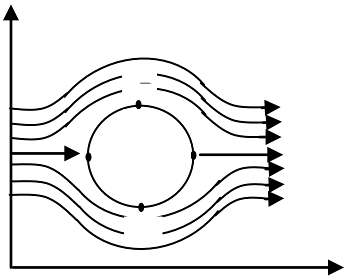


Fig.2. Flowing a cylinder around by a viscous fluid

Let us consider the flowing of a circular cylinder by a stream of non-inhomogeneous fluid (without friction).

The pattern of the flow (Fig. 2) is symmetrical: on the lateral surfaces of the cylinder the flow is accelerated, and on the front and aft surfaces it is slowed down. At critical points, the flow velocity is zero, and the pressure has a maximum value that is the same for both points.

When the cylinder is flown around by a real (viscous) liquid, particles which are moving next to its surface lose part of the kinetic energy under the influence of frictional forces. As the velocity increases, the zone of return flow increases and a large vortex is developed from it. After, the vortex breaks away from the streamlined body and flows downstream. A new vortex arises in its place, which also breaks away, etc. The formation of vortices over the streamlined body leads to a decrease of the pressure in the foramen part of the cylinder in comparison with the pressure in the unperturbed flow [9]. The distribution of pressure across the surface of the cylinder flown through a viscous liquid is shown on Fig. 3.

In the front (nasal) part of the cylinder, the pressure is practically the same as the pressure which occurs when the perfect fluid moves.

As it approaches the stern, the pressure on the cylinder surface becomes smaller than in the corresponding places of the cylinder, streamlined by an ideal fluid.

Thus, forces in front of the cylinder and behind it do not compensate each other. The equivalent forces of pressure on a streamlined body directed toward the flow of fluid, cause pressure resistance.

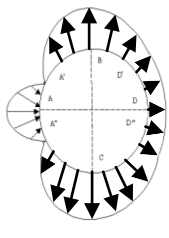


Fig.3. Pressure distribution during the flowing a cylinder around by a viscous fluid

A similar pattern is observed in the flow of liquid bodies of another form. In addition, the shape of the streamlined body significantly determines the nature of the pressure distribution, and, consequently, the value of the resistance of the pressure.

As it is known, the number of Reynolds is significantly affected by the nature of flow. For example, in the case of streaming a ball at very small numbers Re <1 the resistance coefficient is determined by the Stokes theoretical formula [10].

Table 1.

Coefficients of resistance to pressure of some bodies

Body shape	$R_{pressure}$	Re
Sphere	0,47	1000-300000
Round cylinder	0,22	>300000
Cube	1,2	<200000

Based on the material above, the probe should be made in the form of a thin polished plate with sharpened edges to reduce cavitation processes [11].

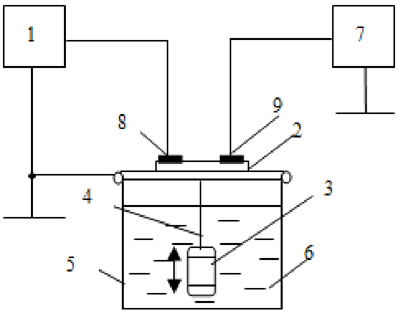
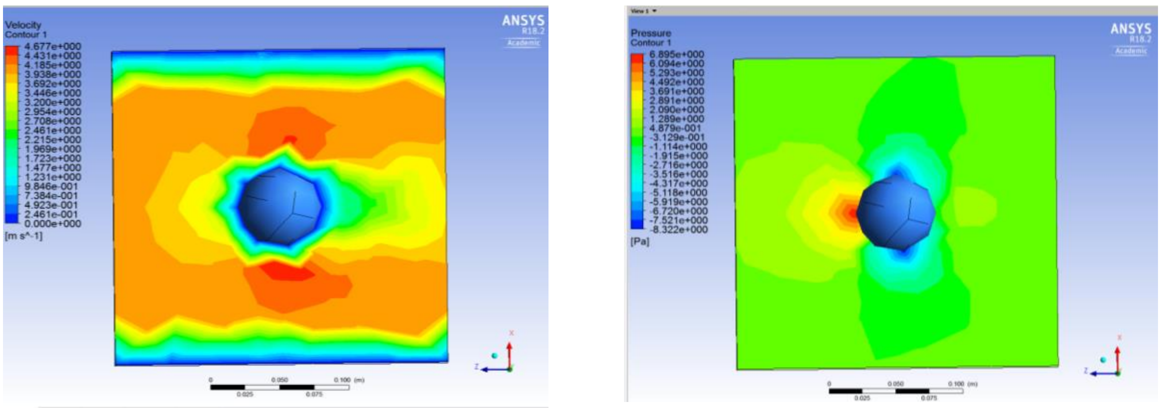
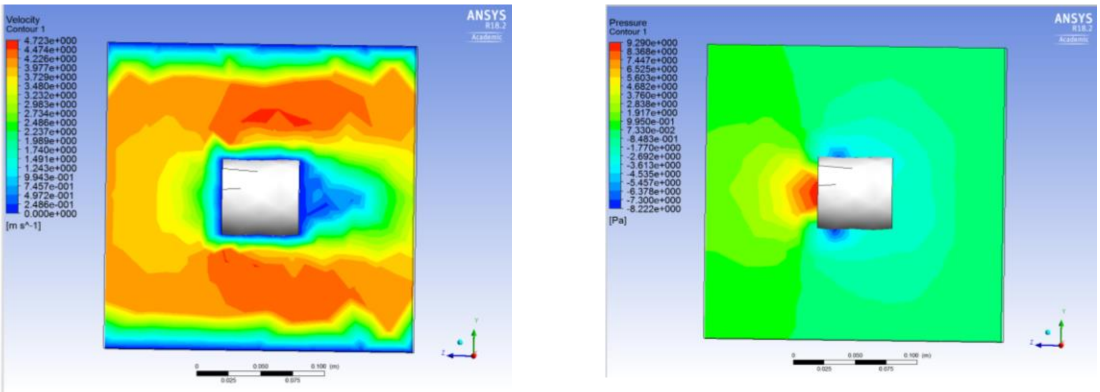


Fig. 4. Device for measuring the viscosity of a fluid with a probe:
1 - generator of electric oscillations; 2 - vibrator in the form of an asymmetric bimorphic piezoelectric element; 3 - probe; 4 - hard drive; 5 - vessel; 6 - liquid; 7 - counter; 8 - input system of electrodes; 9 - output system of electrodes

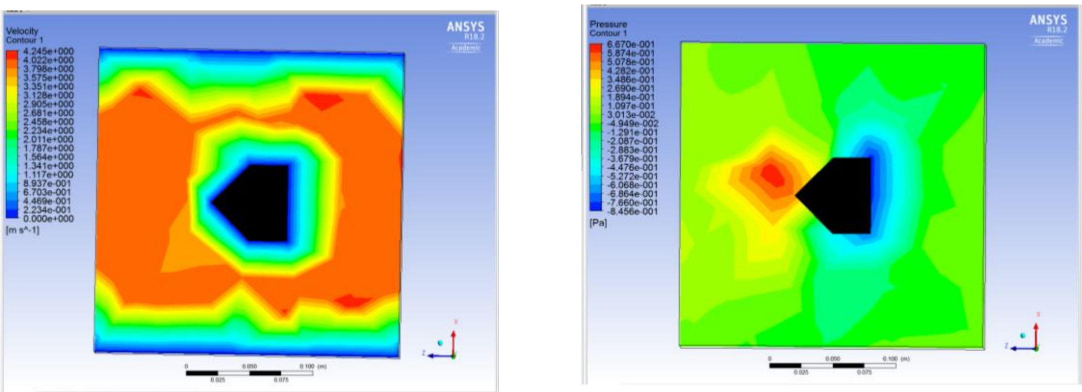
Results of the computerized modelling made using the ANSYS R18.2 program were collected. The process of fluid flowing past objects of different geometric forms – sphere, cylinder, plate with sharpened edges, was simulated (Fig. 5). Based on the matter, probe should be in the form of the fine polished plate with sharpened edges to decrease cavitation processes and therefore improve the measurement accuracy [11].



a) - sphere



b) - cylinder



c) – plate with sharpened edges

Fig. 5. Allocation of velocity and pressure when fluid flows past objects of different geometric forms: a) – sphere, b) – cylinder, c) – plate with sharpened edges

Conclusions. Thus, in order to reduce the measurement errors caused by ultrasonic radiation losses, it is possible to divide the converter into a vibrator and a probe that is moving in the liquid and connected with the vibrator using a rigid thrust. The vibrator should not be sunk into the liquid. The probe is the most effective in the form of a polished plate with sharpened edges. The linear velocity of the probe motion (and hence the frequency and amplitude of the oscillations) must be chosen in such a way for the Reynolds number not to exceed the critical value (Re <2300).

Bibliography

1. Vargaftik, N.V. Spravochnik po teplofizicheskim svoystvam gazov i zhidkostey / N.V. Vargaftik. – M.: Nauka, 1972. – 720 s.

2. Rid, R. Svoystva gazov i zhidkostey: sprav. posobiye: per. s angl. / R. Rid, Dzh. Prausnits, T. Shervud; pod red. B.I. Sokolova. – 3-ye izd., pererab. i dop. – L.: Khimiya, 1982. – 592 s.

3. Teplofizicheskiye svoystva zhidkostey / otv. red. d.t.n. Z.I. Geller. – M.: Nedra, 1973. – 546 s.

4. Shterenlikht, D.V. Gidravlika: uchebnik dlya vuzov / D.V. Shterenlikht. − M.: Energoatomizdat, 1984. − 640 s.

5. Sharapov V.M. i dr. O vliyanii davleniya na vnutrenneye treniye p'yezokeramiki TSTS// Izvestiya VUZov SSSR – Fizika,1976, №9

6. Roy I.A. Vozniknoveniye i razvitiye ul'trazvukovoy kavitatsii - Akust. zhur., №3, 1,3, 1957.

7 Aerogidromekhanika: Uchebnik dlya studentov vysshikh tekhnicheskikh uchebnykh zavedeniy/ Ye. N. Bondarev, V. T. Dubasov, YU. A. Ryzhov i dr. – M.: Mashinostroyeniye, 1993. – 608 s. 2

8. Prostakov A.L. Gidroakustika i korabl' – Leningrad – Sudostroyeniye, 1967.

9. Kisil' T. YU. Ul'trazvukovoy metod, p'yezoelektricheskiye preobrazovateli i ustroystva kontrolya vyazkosti zhidkosti povyshennoy tochnosti dlya sistem upravleniya. Kand.. dis., ONPU, 2003. – s.137

10. Konstantinov YU.M. Gidravlika // Vishcha shkola. – Kiyev, 1981. - 413 s.

11. Patent Ukraïni №61326A, G01N11/00, Byul. №11, 2003. Pristríy dlya vimíryuvannya v′yazkostí rídini // Sharapov V.M., Kísíl' T.YU.

8. Prostakov A.L. Gidroakustika i korabl' – Leningrad – Sudostroyeniye, 1967.

9. Kisil' T. YU. Ul'trazvukovoy metod, p'yezoelektricheskiye preobrazovateli i ustroystva kontrolya vyazkosti zhidkosti povyshennoy tochnosti dlya sistem upravleniya. Kand.. dis., ONPU, 2003. – s.137

10. Konstantinov YU.M. Gidravlika // Vishcha shkola. – Kiyev, 1981. - 413 s.

11. Patent Ukraïni №61326A, G01N11/00, Byul. №11, 2003. Pristríy dlya vimíryuvannya v′yazkostí rídini // Sharapov V.M., Kísíl' T.YU.

Т.Ю. Кисиль, к.т.н., доцент; Л.Г. Куницкая, к.т.н., доцент; В.В. Туз, к.т.н., доцент
Черкасский государственный технологический университет

ВЫБОР ФОРМЫ ПОГРУЖНОГО ЗОНДА В ПЬЕЗОЭЛЕКТРИЧЕСКИХ ИЗМЕРИТЕЛЯХ ВЯЗКОСТИ ЖИДКОСТИ ДЛЯ ПОВЫШЕНИЯ ТОЧНОСТИ ИЗМЕРЕНИЯ

Работа посвящена вопросу о выборе оптимальной формы погружного зонда в пьезоэлектрических измерителях вязкости жидкости. Как известно, вязкость дает наилучшее представление про жидкости, про изменение ее состояния и может считаться одной из основных характеристик. Авторами предложено для уменьшения погрешности измерения с помощью пьезоэлектрических преобразователей вязкости жидкости, обусловленную ультразвуковыми потерями на излучение, разделить преобразователь на собственно вибратор и соединенный с вибратором жесткой тягой зонд, движущийся в жидкости. Наиболее эффективен зонд в виде полированной пластинки с заостренными кромками. Кроме того, при движении в жидкости в торце вибратора могут возникнуть кавитационные пузырьки, влияющие на точность измерения вязкости. Приведена конструкция устройства, реализующего предложенное и проведено компьютерное моделирование с целью выявления оптимальной формы зонда. Результаты компьютерного моделирования доказали, что наиболее эффективный зонд в виде полированной пластинки с заостренными краями. Линейная скорость движения зонда (а следовательно, частота и амплитуда колебаний) должны выбираться такими, чтобы число Рейнольдса не превышало критическое значение (Re<<2300).

Ключевые слова: *вязкость, жидкость, ультразвуковой метод, пьезоэлектрический измеритель, погружной зонд, число Рейнльдса*

Т.Ю. Кісіль, к.т.н., доцент; Л.Г. Куницька, к.т.н., доцент; В.В. Туз, к.т.н., доцент
Черкаський державний технологічний університет

ВИБІР ФОРМИ ПОГРУЖНОГО ЗОНДУ В П'ЄЗОЕЛЕКТРИЧНИХ ВИМІРЮВАЧАХ В'ЯЗКОСТІ РІДИНИ ДЛЯ ПІДВИЩЕННЯ ТОЧНОСТІ ВИМІРЮВАННЯ

Робота присвячена питанню щодо вибору оптимальної форми погружного зонда в п'єзоелектричних вимірювачах в'язкості рідини. Як відомо, в'язкість дає найкраще уявлення про рідини, про зміну її стану і може вважатися однією з основних характеристик. Авторами запропоновано для зменшення похибки вимірювання за допомогою п'єзоелектричних перетворювачів в'язкості рідини, обумовлену ультразвуковими втратами на випромінювання, розділити перетворювач на власне вібратор і з'єднаний з вібратором жорсткою тягою зонд, що рухається в рідині. Найбільш ефективний зонд у вигляді полірованої пластинки з загостреними краями. Крім того, при русі в рідини в торці вібратора можуть виникнути кавітаційні бульбашки, що впливають на точність вимірювання в'язкості. Наведено пристрій розроблений таким чином, що реалізує запропоноване і проведено комп'ютерне моделювання з метою виявлення оптимальної форми зонда. Результати комп'ютерного моделювання довели, що найбільш ефективний зонд у вигляді полірованої пластинки з загостреними краями. Лінійна швидкість руху зонда (а отже, частота і амплітуда коливань) повинні вибиратися такими, щоб число Рейнольдса не перевищувало критичне значення (Re<<2300).

Ключові слова: *в'язкість, рідина, ультразвуковий метод, п'єзоелектричний вимірювач, погружний зонд, число Рейнольдса*

Стаття надійшла до редакції 08.05.2018.