Indonesian Journal of Electrical Engineering and Computer Science
Vol. 27, No. 1, July 2022, pp. 366~374
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v27.i1.pp366-374

The design of viscometer with smartphone controlling

Ibragim E. Suleimenov[1], Grigoriy A. Mun[1, 2], Sherniyaz B. Kabdushev[1], Adilet Alikulov[1, 2], Dina B. Shaltykova[1], Inabat Moldakhan[3]
[1]Department of Petroleum and Chemical Technologies, National Engineering Academy of Republic of Kazakhstan, Almaty, Kazakhstan
[2] Department of Chemistry and Technology of Organic Materials, Polymers and Natural Compounds, Al-Farabi Kazakh National University, Almaty, Kazakhstan
[3]Department of Radio Engineering, Electronics and Telecommunications, Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan

Article Info

Article history:

Received Sep 16, 2021
Revised May 16, 2022
Accepted Jun 2, 2022

Keywords:

Bluetooth
Optoelectronic pair
Smartphones
Stokes' method
Viscometry

ABSTRACT

New design of a viscometer based on the stokes viscosity measurement method is proposed. The principle of operation of this viscosimetr is based on the use of ball periodic alternated movement in a horizontally positioned cuvette that filled with the test liquid. The movement appears under the influence of a magnetic field that created by two electromagnets. Registration of the ball movement inside the cuvette is carried out using an optoelectronic pair. A distinctive feature of the proposed design is control by using a program that installed on the user's smartphone, which also carries out the primary data processing. Data transmission is carried out over the radio channel using a Bluetooth module. Disposable cuvettes are used for measurements. This approach makes it possible to significantly reduce both the device production costs and operating costs by eliminating most of the operations for the device preparing for working (the vast majority of existing types of viscometers require thorough flushing of all units in contact with the test medium). In addition, the proposed approach excludes the occurrence of measurement errors associated with insufficiently thorough preparation of the device for operation.

Corresponding Author:

Inabat Moldakhan
Department of Radio Engineering, Electronics and Telecommunications,
Almaty University of Power Engineering and Telecommunications
126/1 Baitursynova Street, 050013, Almaty, Kazakhstan
Email: imoldakhan@gmail.com

1. INTRODUCTION

Viscosity measurements are one of the most convenient and informative tools for studying liquids of various nature. Viscometry is widely used in analytical chemistry [1]-[3], in the physical chemistry of polymers [4]-[7], biophysics [8] (for example, to study the interaction of Deoxyribonucleic acid (DNA) with porphyrins [9]), in biochemistry [10], in pharmaceutics (for example, to study the nature of the interaction of drugs with low-molecular substances [11], which makes it possible to simulate the effect of drugs on human organism), and to study the fuel characteristics [12], [13].

The nature of changes of viscosity within a change in thermodynamic variables carries extensive information about intermolecular interactions [14], [15], and about the nature of changes in the state of macromolecules in solution [16]-[18]. Especially clearly the information content of viscometric measurements can be demonstrated by starting from the example of liquid media in which forming hydrophilic interpolymer associates (HIA) [19]. The study of HIA, in turn, is of considerable interest, including from the point of view of establishing the evolution mechanisms which preceding biological one.

HIA is an object that occupies an intermediate position between classical interpolymer complexes (the products of reaction between two types of polymers), cross-linked polymer networks (hydrogels), and the non-interacting macromolecules solutions [19]. HIA are networks that exist in a dynamic mode, i.e., the bonds between macromolecules (for example, hydrogen) are constantly formed and destroyed again [19], [20]. For studying systems of this type, the viscometric measurements are one of the most convenient: the average number of bonds between macromolecules, which characterizes the dynamic network, obviously affects on the viscosity of the medium in which the HIA is formed.

Despite the fact, that the classical methods of viscometry (capillary viscometers, and rotational viscometers) have been known for more than a hundred years, attempts to improve them are still ongoing [21]-[24]. One of the important directions here is the provision of express measurements [24]. The considerable interest in this regard presents such techniques as vibrating-wire viscometry, and imaging viscometry. Nevertheless, the most common methods for viscosity measuring are based on classical principles, in particular, capillary viscometers and their modernization are still used [25]-[27]. Capillary viscometers, rotational viscometers and devices that based on the stokes' method (measuring the speed of a ball in a viscous liquid under the influence of an external force) have proven themselves from the best side and have been used for more than a long time.

Their main disadvantages are the significant time that required to carry out measurements, as well as the necessity of careful preparation of the device for each measurement. In particular, very significant operating costs are associated with the necessity to thoroughly flush all the components of the device that are in contact with the liquid under investigation. The same factor has a significant impact on the quality of measurements.

In this report, a specific design of a viscometer that based on the stokes' method is proposed. It is demostrated a significant increase in the measurement speed due to the use of disposable measuring units which in contact with the liquid under study. This approach, which is based on the idea originally reflected in [28], among other things, significantly reduces operating costs, and also eliminates uncontrollable factors within preparing the device for measurements (careless flushing).

The advantage of the proposed approach is also a significant simplification of the production technology of viscometer proposed type. Namely, in the viscometers that currently presents on the market, a significant part of cost is accounted for by electronic components. A significant part of their function, in accordance with the approach [28], can be transferred to the software that installed on the user's smartphone.

2. PRINCIPLE OF OPERATION AND DESIGN

The operation principle of the viscometer proposed type is de facto based on the stokes' viscosity measurement method. A ball moves under the influence of an external force in the liquid under investigatinon. Measuring the speed of its movement at a known amplitude of the external force makes it possible to determine the value of the viscosity. We emphasize that there are a number of nuances here, including those related to the fact that the classical stokes' formula as shown in (1).

$$FS = 6\pi\eta r v \tag{1}$$

Linking the speed of the ball v, its radius r, the viscosity of the medium η and the amplitude of the resistance force F_S, is not always true. This can be seen especially clearly in the example of a liquid in which formed HIA [19]. The bonds in such a network, existing in a dynamic mode, are very weak, i.e. the motion of a ball in such an environment, strictly speaking, should be interpreted as a mechanochemical process.

However, establishing a connection between the parameters that characterizing the medium and the ball speed is a matter of building an appropriate theory. Accordingly, it is permissible to raise the question of developing a technique that will measure the speed of the ball in the medium under study, completed with software designed to calculate the viscosity.

In a viscometer of the proposed design, viscosity measurements are carried out using an optoelectronic circuit, which includes laser light emitting diode (LEDs) and photoresistors (Figure 1). The movement of the ball inside the replaceable disposable cartridge, provided by DC electromagnets. Electromagnets are controlled by a microcontroller, which activates them using field-effect transistor switches.

When the ball crossing the light beam that formed by the LED, there is a step change of voltage that taken from the photoresistor, which makes it possible to measure the time required to move the ball between two points in the cuvette, which correspond to the location of the optoelectronic pairs. After the beginning of the measurement process, the microcontroller activates the "right" electromagnet, which sets the ball movement in the "forward" direction. Further, the microcontroller deactivates the "right" electromagnet and activates the "left" one, as a result of which the ball moves in the "reverse" direction.

The measurement of the illumination level on the photoresistors is carried out in parallel. The words "forward" and "reverse" enclosed in quotation marks, since the circuit is symmetrical. The number of passes in the forward and reverse directions is set programmatically through the mobile application that comes with the viscometer. The schematic circuit diagram shown in Figure 2. The circuit contains two laser light-emitting diodes LED4, LED5, two photoresistors U5, U6, providing registration of the ball movement inside the cartridge. Photoresistors U5, U6 together with resistors R8, R9 form voltage dividers that connected to a 5 V power supply.

The values of the resistors R8, R9 selected in such a way that the sensitivity of the photoresistors to changes in the level of illumination is maximized. The analog outputs of the microcontroller U1 connected to the midpoint of the voltage dividers, which ensures the measurement of the illumination level. The laser diodes connected to a U2 voltage regulator.

Two DC electromagnets L1, L2 that designed to control the movement of the ball, connected to the microcontroller U7. They controlled by transistor switches consisting of field-effect transistors Q1, Q2 and resistors R11, R12, R13, R14. The transistor switches controlled by applying a high-level signal (5 V) to the gates of transistors Q1, Q2 from the digital output of the U7 microcontroller. The power supply for this circuit is the voltage regulator U2 (LM1117).

For transfer data from the microcontroller to the smartphone using U9 chip, which is a Bluetooth transceiver. The microcircuit connected to a voltage regulator U8 (R1114-3.3). Photographs of a laboratory sample of a proposed type viscometer in the on and off state, shown in Figure 3 and Figure 4, respectively.

The photo clearly shows the central illuminated part of the device, in which located the replaceable cartridge. Its' drawing with dimensions shown in Figure 5. The dimensions were selected in the way that the serially produced electromagnets ELE-P30/22 (China) could provide stable ball movement along the entire length of the cartridge. It can be seen that the design of the device is very simple.

Moreover, as shown by the simplest economic calculations, its' cost, even under conditions of pilot sample production, is two orders of magnitude less than the cost of typical viscometers that currently presented on the market. The de facto costs reduced to the manufacture of the printed circuit board and device installation using the serially produced electromagnets.

We emphasize that reducing the producing cost of a viscometer of this type is an interest not only from the point of view of market considerations. Currently, Kazakhstan is actively developing such a tool for increasing the universities economic efficiency as business educational ecosystems. Their task is to create conditions under which the results of students' master theses could give a commercial return. For Kazakhstan, solving this problem is extremely important, since despite the significant efforts of the concerned ministries, the level of implementation of the developments of young scientists into practice remains unacceptably low, which, among other things, negatively affects on the quality of education in Kazakhstan's universities, which forced to focus on income only from tuition fees.

Therefore, it is advisable to find an area of student effort in which prototyping costs are minimal. The proposed design of the viscometer satisfies this criterion. Moreover, a similar principle - the transfer of a significant part functions of the measuring device to the program that installed on the user's smartphone, can be implemented in relation to measuring equipment of other purposes. This makes the proposed structure interesting for use in a business educational ecosystem focused on ensuring sustainable interdisciplinary cooperation.

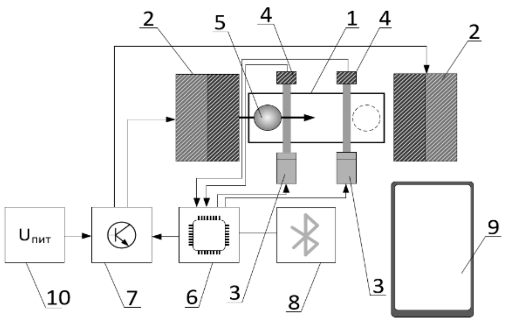


Figure 1. Functional diagram of proposed viscometer: 1-cuvette; 2-electromagnets; 3-laser diodes; 4-photocells; 5-metal ball; 6-microcontroller; 7-transistor switch; 8-Bluetooth module; 9-smartphone; 10-power supply

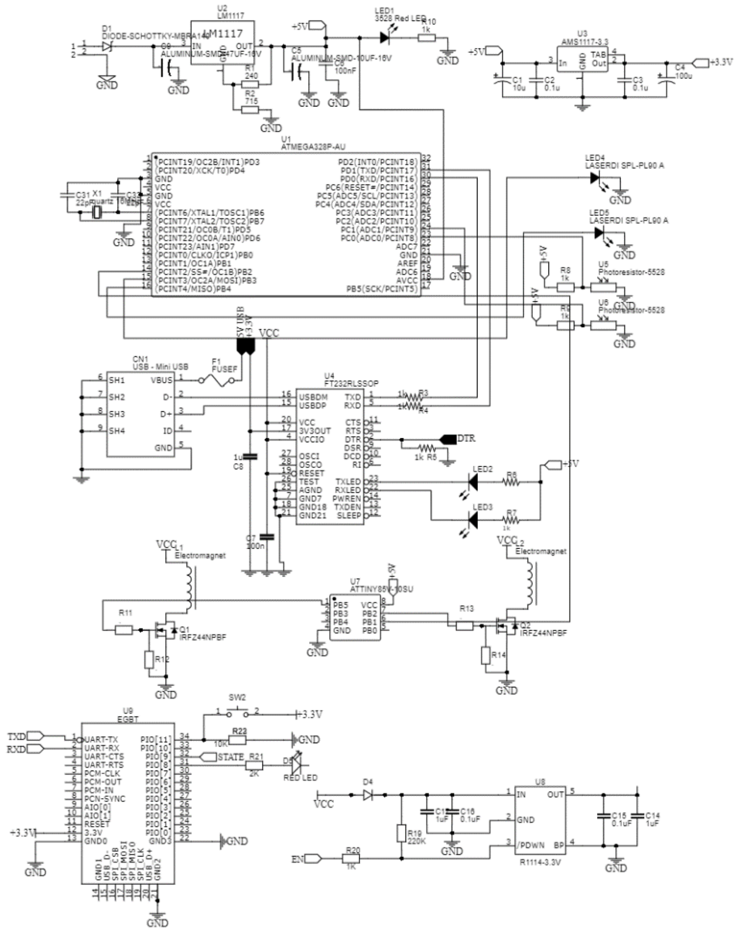


Figure 2. Schematic circuit diagram of the viscometer with control from the user's smartphone

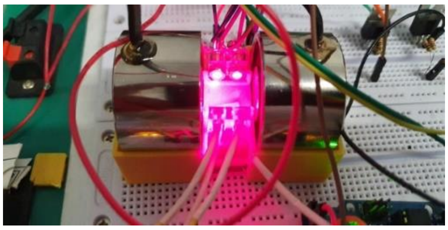


Figure 3. Photo of a laboratory sample of the viscometer while powered on

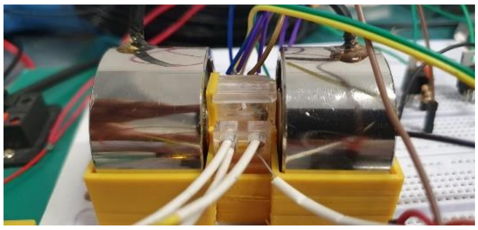


Figure 4. Photo of a laboratory sample of the viscometer while powered off

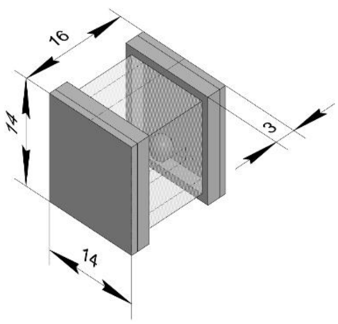


Figure 5. Drawing of a disposable cartridge which filling by the test liquid with an indication of its dimensions

3. SOFTWARE

The program flow chart for the microcontroller, which ensures the operation of the viscometer, shown in Figure 6. At the first step of the program, the clock frequency of the microcontroller is set using the F_CPU 16000000UL command and set the reference voltage source ADMUX|=(1 << REFS0) that equal to the supply voltage of the microcontroller, and the ADCSRA and ADCSRB register reset on 0. Next, the PC0, PC1 ADC ports are configured, for what is set the permission to use the ADCSRA ADC. After that, the port for conversion PC0 ADMUX|=(0 & 0x07) is selected and the pre-divider is set to 32 ADCSRA|=(1 << ADPS2) | (1 << ADPS0) and zeros are set to ADCSRA &=~ (1 << ADPS1). Then the automatic conversion ADCSRA|=(1 << ADATE) and ADC ADCSRA|=(1 << ADEN) are turned on. At the next step, variables p1, p2 of int type to store the measurement results are created.

Next, checks for the presence of input data from the serial port. If there is a "1" in the buffer, then the measurement is performed. For this is providing read of the PC0 port and PC1 port that giving a 10-bit result int res=ADCL | (ADCH << 8) and writing to the p1 and p2 variables. At the final step, the value of the variables transmitted to the user's smartphone via the UART. Then the cycle repeated.

To control electromagnets, digital outputs of the microcontroller PB2, PB5 are used. At the beginning of the program, the ports are initialized as an output with the command DDRB = 0b 00000100 and DDRB = 0b 00000010. Inside the infinite function checked the state of the digital output. If the logical unit if (PORTB & (1 << PB1)) is present on it, then the corresponding electromagnet is switched on.

Next, are written commands for electromagnets sequential switching on and off. PORTB | = (1 << 2), the "right" electromagnet is turned on and delay_ms (70). At the next step, the "right" electromagnet PORTB & = ~ (1 << 2) is turned off and the "left" electromagnet PORTB | = (1 << 5) is turned on, while the delay_ms is set (70). Then the left electromagnet 5 PORTB & = ~ (1 << 2) is turned off and the cycle is repeated again for a specified number of times. The software for a mobile device (block diagram shown in Figure 7) works as shown in.

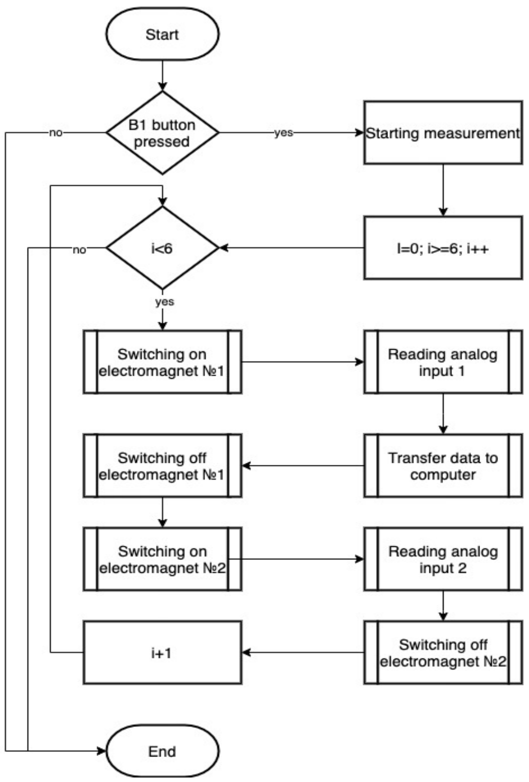


Figure 6. Block diagram of the control program (microcontroller)

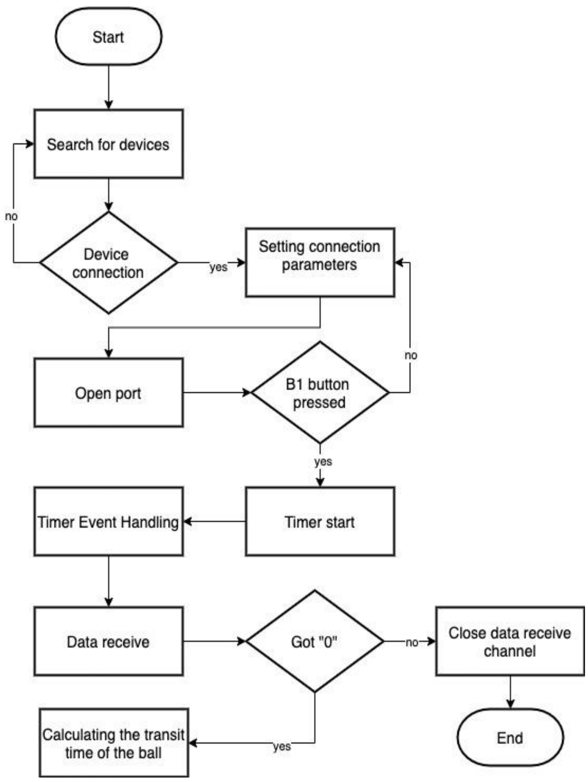
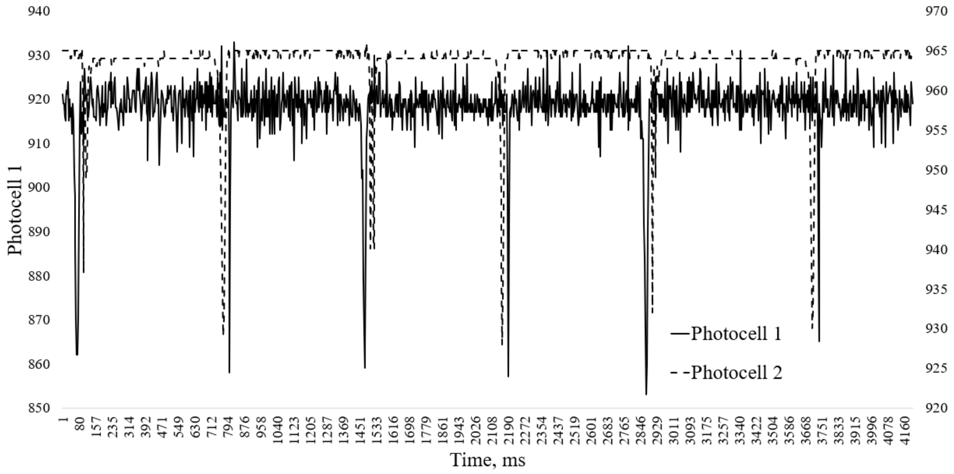


Figure 7. Block diagram of the control program (smartphone)

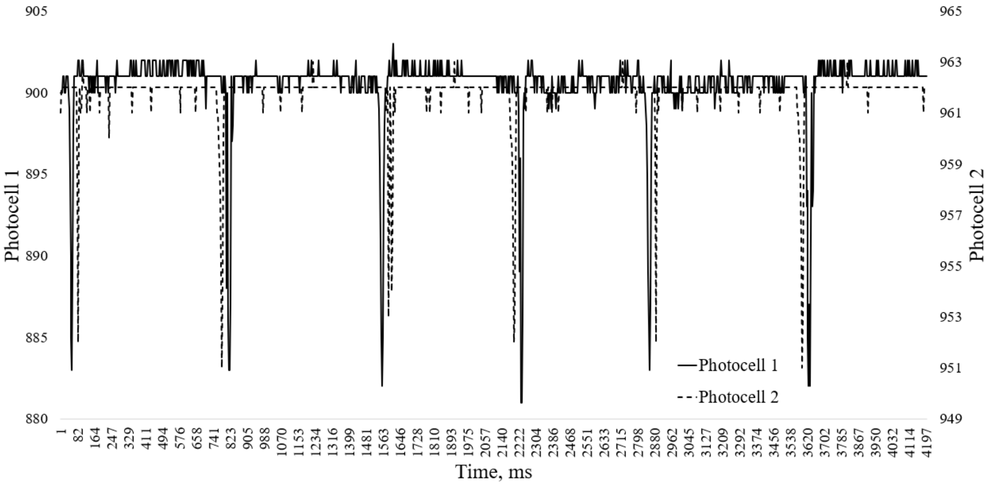
After starting the software, the Android smartphone is paired with the measuring device via Bluetooth wireless technology. After the connection is established, the main window of the mobile application, where the user will have access to a button to start measurements, opens. When you press the corresponding button, the mobile application sends a command to the paired measuring device to start testing. After carrying out measurements, the device sends data reflecting the measurement results via the wireless Bluetooth channel. Sent data contains indicators of the level change at the microcontroller ports to which connected the photoresistors, depending on time. The received data processed by the mobile application. The user receives the duration values of the metal ball transit time from one photoresistor to another for all measurement cycles.

4. TEST RESULTS AND PROSPECTS FOR FURTHER DEVELOPMENT OF THE PROPOSED APPROACH

The dependence of the relative illumination on the on-time recording photoresistor is shown in Figure 8. Examples of the data generated during measurement using the developed design are shown in Figures 8(a) and 8(b). These figures show examples of the dependencies of the relative illumination on two recording photoresistors on time. Each of the figures shows two such dependencies corresponding to two used photoresistors. It can be seen that all curves exhibit distinct inverse peaks that corresponding to the moments of time when the ball overlaps the radiation of the laser light-emitting diode. It is also seen that the developed system provides a stable recording of the delay time between reverse peaks in channels, corresponding to different photoresistors.



(a)



(b)

Figure 8. Dependence of the relative illumination on the recording photoresistors on time; the investigated medium is a solution of sugar in water in a ratio of (a) 1:4 and (b) 1:8

At this point, the tests of the device itself can be considered completed, since further data processing is already a task from the field of physical chemistry, which, however, does not exclude the possibility of using a variety of methods of digital signal processing, including those built on the basis of multivalued logic [29], [30]. This is especially true for such objects of research as liquids, in which HIA are formed. We also note that from the point of view of the classical methodology of using the Stokes' method, the usage of a cuvette with limited volume is not optimal. However, such difficulties are surmountable already at this stage of research, since it is permissible to use calibration curves to determine the viscosity of specific liquids, which, among other things, removes the question of the necessity of using a consistent theory of spherical body motion in a liquid with the limited volume.

An additional advantage of the proposed design is the ability to study the specifics of such objects as HIA. This achieved due to the fact, that in the design under consideration, the speed of the ball can be controlled within a sufficiently wide range, which makes it possible to detect mechanochemical processes.

5. CONCLUSION

Therefore, it is possible to propose a simple and cheap-to-manufacture viscometer design that uses the Stokes' viscosity measurement method, which also provides a significant reduction in the cost of measurements, eliminating almost all factors associated with insufficiently thorough the device preparation for operation. This result is achieved through the using of replaceable disposable cartridges, as well as the exchange of data between the program that installed on the user's smartphone and a microcontroller that controls the device via a radio channel. The final processing of the primary data, obtained by registering the ball movements in a horizontally located cuvette by optical means, is also carried out by an application that installed on a smartphone. This approach, among other things, provides the variability of the methods used for conducting viscometric measurements. Depending on the nature of the problem that being solved, various mobile applications installed on a smartphone can be used. In addition, the proposed approach creates the basis for the development of measuring instruments for other purposes, in which a significant part of the functions is performed by a mobile application. This direction in chemical instrumentation important not only from the point of view of reducing the cost of manufacturing laboratory equipment, but also from the point of view of improving business educational ecosystems.

ACKNOWLEDGEMENTS

Authors thanks the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP08856723) for a financial support.

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BIOGRAPHIES OF AUTHORS

Ibragim E. Suleimenov Senior researcher of National Engineering Academy of the Republic of Kazakhstan. Graduated from the Physics Department of the Leningrad University in 1986; defended his thesis for the degree of candidate of physical and mathematical sciences in 1989 at the same university. In 2000, he defended his thesis for the degree of Doctor of Chemical Sciences at the Al-Farabi Kazakh National University. Academician of the National Engineering Academy of the Republic of Kazakhstan (since 2016), full professor (since 2018) according to the official certificate of the Ministry of Education and Science of the Republic of Kazakhstan. Actively develops interdisciplinary cooperation, including between natural science and humanities. He pays considerable attention to the interdisciplinary study of intelligence, both using mathematical models and at the level of philosophical interpretation. He can be contacted at email: esenych@yandex.kz.

Grigoriy A. Mun head of Department of Chemistry and Technology of Organic Substances, Natural Compounds and Polymers of Al-Farabi Kazakh National University, Academician of the National Engineering Academy of the Republic of Kazakhstan. He graduated from Mordow State University in 1977 and got his Ph.D. degree in polymer chemistry in Moscow State University in 1984. In 1991 he was promoted to an associate professor, in 1999 received his D.Sc. degree in polymer chemistry and in 2001 was promoted to a professor. Scientific interests: Chemistry, Physics and Technology of Polymers and Polymer Materials, Water-Soluble and Water-Swelling Polymers, Synthesis and Characterization of Stimuli-Responsive Polymers, Interpolymer reactions and complexes, Biomedical Related polymers, Radiation Chemistry of Polymers, Synthesis and Characterization of Hydrophilic Polymers and Interpolymer Complexes for Application in Nanoelectronics and Nanotechnology, Polymer Nanocomposite materials. He can be contacted at email: mungrig@yandex.ru.

Sherniyaz B. Kabdushev is a PhD student at the Almaty University of Power Engineering and Telecommunications. He received his master's degree in 2014 with a degree in radio engineering and communications at the Almaty University of Power Engineering and Telecommunications. From 2013 to 2014 he worked at Huawei Almaty LLP as an engineer of the radio network. At the moment he is researching in the field of radio engineering, electronics and telecommunications in accordance with the topic of his PhD dissertation. He can be contacted at email: sherniyaz.kabdushev.hw@gmail.com.

Adilet Alikulov is a PhD student of the Al-Farabi Kazakh National University. In 2014 he received a bachelor's degree, and in 2016, a master's degree in engineering and technology in the specialty «Chemical Technology of Organic Substances». He works as senior lecturer at the Department of Chemistry and Technology of Organic Substances, Natural Compounds and Polymers of Al-Farabi Kazakh National University. Actively studies and researches in the field of Chemistry, Physics and Technology of Polymers and Polymer Materials, Water-Soluble and Water-Swelling Polymers, Synthesis and Characterization of Stimuli-Responsive Polymers, Interpolymer reactions and complexes in accordance with the topic of his PhD dissertation. He can be contacted at email: light_is@list.ru.

Dina B. Shaltykova is a leading researcher at the National Engineering Academy of the Republic of Kazakhstan. She graduated from the Kazakh State University named after S.M. Kirov (Alma-Ata) in 1987, Faculty of Chemistry, Department of Chemistry of High-molecular Compounds. She defended her thesis for the degree of candidate of chemical sciences in 1996 at the same faculty. At the present time, he is actively developing interdisciplinary cooperation, performing work at the intersection of polymer chemistry, artificial intelligence and other areas of information theory. She is one of the initiators of work in the field of molecular informatics in Kazakhstan. She can be contacted at email: dina_65@mail.ru.

Inabat Moldakhan is a PhD student at the Almaty University of Power Engineering and Telecommunications. She received her master's degree in 2011 with a degree in radio engineering and communications at the Almaty University of Power Engineering and Telecommunications. From 2010 to 2019, she worked at KaR-Tel LLP (a mobile operator operating under the Beeline brand) as a leading engineer of the radio network monitoring and control department. At the moment she is engaged in research in the field of radio engineering, electronics and telecommunications in accordance with the topic of her PhD thesis "Development of new approaches to digital signal processing based on ternary logic". She can be contacted at email: imoldakhan@mail.com.