Kinematic viscosity of liquid media and providing metrological observability of experimental results

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Abstract. The subject of this study is to explore modern methods for control of dynamic and kinematic viscosity of liquid media, the state of its metrological support in the republic as well as to see findings from the experiments to ensure metrological control in the International System of Units. The results from this study are found relevant for wide use in agricultural and food products, biologically active additives in assessing quality and safety, metrology. It is also considered relevant in connection with the wide use of viscosity measuring tools in the oil- and fuel industry, medicine, cosmetology, geological and construction and other industries, to evaluate the quality and safety of products, control technological processes at production sites. Scientific and practical recommendations and decisions on improvement of scientific, technical, organizational and regulatory framework of metrological provision of viscometers in the field of ensuring uniformity of measurements and its practical solutions. The findings from the study can be applied with metrological services. Based on the results of the research, metrological examination of various scientific, theoretical and functional viscometers, final conclusions were developed.

1 Introduction

In the world and in the republic, the tasks of development of scientific research in the areas of standardization, certification and metrology in the fields of genetics of agricultural products, energy efficiency, synthetic fibers, biologically active food additives and harmonization of the level of metrological supply with international requirements are defined. In particular, in the assessment of the quality and safety indicators of agricultural products, food biologically active additives, the control of dynamic and kinematic viscosity of liquid media and its metrological support play an important role. At the same time, viscosity measuring tools are widely used in the oil industry, fuel industry, medicine, cosmetology, geology and construction industry, as well as in other environmental sectors, to evaluate the quality and safety indicators of products, and to control technological processes under production conditions. According to the conducted analysis, there is a need

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for metrological inspection of more than 15,000 working viscometers in industrial enterprises today. Organization of metrological inspection (comparison, calibration, certification) of working measuring viscometers used in economic fields is one of the urgent tasks.

2 Main part

It is an important issue to create conditions for improving the quality and competitiveness of local products by developing and improving the calibration system of measuring instruments, and to develop mutually effective cooperation mechanisms in metrology with international and regional metrology organizations. In order to facilitate the integration of the Republic of Uzbekistan as an equal partner in the international systems of ensuring the unity of the international economy and measurements, the state standard O'z DSt ISO/IEC 17025:2019 has been introduced is considered one of the important technical requirements of organizations.

Today, the creation and implementation of the primary sample complex device for the formation of the viscosity unit of the liquid was approved by the BIPM on October 14, 1999 (Paris, France) CIPM MRA is an urgent issue in fulfilling the requirements of the international standard. This is considered an important stage in the presentation of national measurement capabilities to the international database of calibration and measurement capabilities of the Republic of Uzbekistan (KCDB) and allows to modernize the technical capabilities of the state system.

CMCs are an important indicator of every national metrology organization at the international level. For this, it is necessary to actively participate in important international and regional comparisons of national and primary benchmark. Figure 1 provides information on important comparisons of regional organizations led by the BIPM [1].

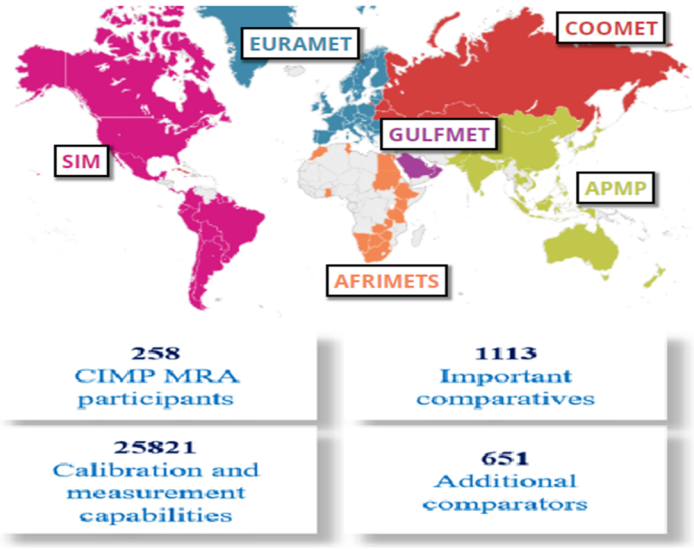

Fig. 1. 1907 Regional metrological organizations and important comparison statistics.

Uzbekistan is a member of the COMET regional metrology organization. The performance of these and other organizations in important comparisons is shown in Figure 2.

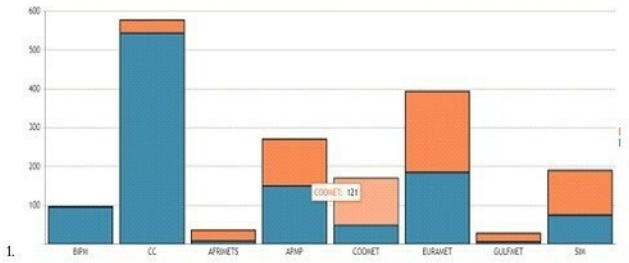

Fig. 2. Regional metrological organizations and important comparison statistics.

In particular, about 30 production enterprises are operating in the oil and gas industry. These enterprises produce gasoline, diesel fuel, aviation kerosene, various oils, fuel oil, bitumen, various types of polyethylene, commodity natural and liquefied gas, petrochemical and chemical equipment, cylinders for liquefied gas and other products [2-8].

These measures should ensure not only an increase in the amount of oil products produced and a decrease in inefficiently processed raw materials, but also an increase in product quality. Gasoline, kerosene, aviation, fuel oil, diesel fuels, oils, lubricants, bitumen, petroleum coke, etc. are produced by the oil refinery. Uzbekistan is a member of the COMET regional metrology organization. One of the main quality and safety indicators is kinematic viscosity [9-15].

In accordance with the law which is "On Metrology" № ORQ-614, these measuring instruments must undergo primary, periodic, extraordinary, inspection or expert metrological comparison. GOST 8.025-96 "Comparison of viscosity measuring instruments. "Scheme of state comparison of instruments for measuring the viscosity of liquids" should be carried out by the method of direct comparison using standard samples of the second category, which are standard samples of liquid viscosity, or reference liquids. The need for a large nomenclature of standard samples of the viscosity of liquids is determined by the functionality and characteristics of viscosity measuring instruments.

According to the results of the research, today it is an urgent issue to create working benchmarks of viscometers for measuring the viscosity of liquids, which are stable and homogeneous in the range of certified values at temperatures from -40 °C to $+100$ °C.

The creation and development of state working benchmarks that preserve and transmit the unit of magnitude of the dynamic and kinematic viscosity of liquids at temperatures from-40 °C to $+100$ °C will increase the technical capabilities of metrological supply and ensure metrological traceability of measurement results. This, in turn, is the basis for the development of the state system for the results of monitoring the dynamic and kinematic viscosity of liquid media.

In this temperature range, standard samples can be compared, certified and used as liquid comparators in the calibration of benchmarks. The results of viscosity measurement are provided with a hierarchical sequence of metrological traceability up to the international system of units (Figure 3).

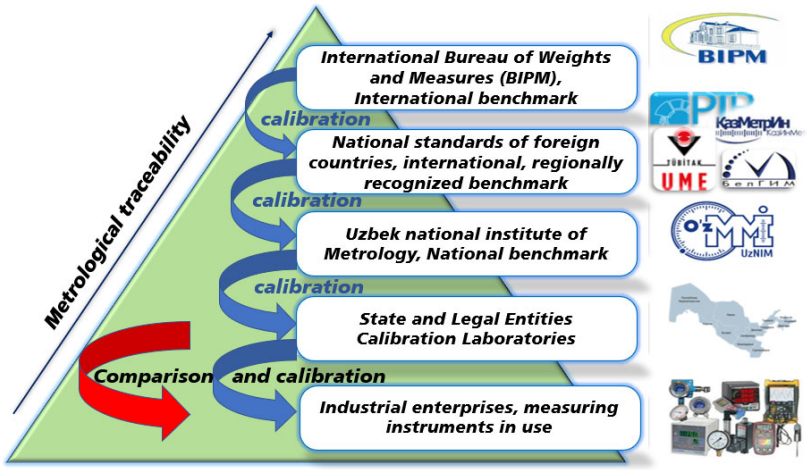

Fig. 3. Hierarchical stages of ensuring metrological observability in measuring the viscosity of liquid media and stages of size transfer.

Creating and using viscometers of various products with high metrological properties based on energy-saving technologies in the world, improving their technical and metrological characteristics and developing high precision measuring instrument, working viscometers, as well as control of dynamic and kinematic viscosity of liquid media [16-22].

In the intelligent information measurement systems of metrologically developed countries, creating a unit of size, with special emphasis on storage and transmission.

3 Material and methods

The Figure 4 shows classification of modern methods of control of dynamic and kinematic viscosity of liquid media.

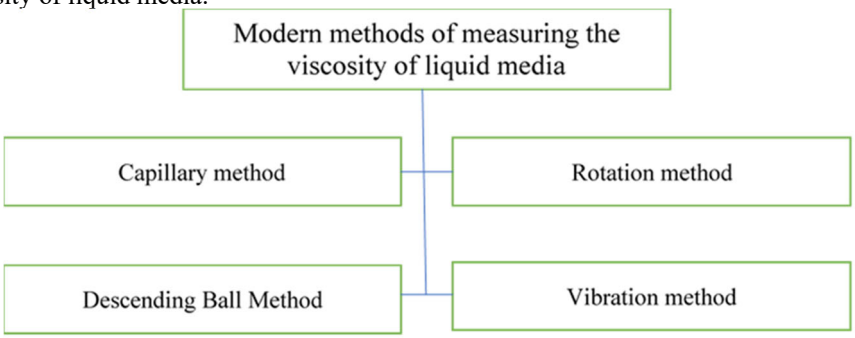

Fig. 4. Classification of modern methods of control of dynamic and kinematic viscosity of liquid media.

3.1 Capillary method

The most common method of measuring viscosity: - the capillary method; - is explored below. There are several methods for determining viscosity, of which the capillary method and the falling ball method are the most commonly used.

The main metrological advantages of capillary viscosity measurement are:

- the viscosity of liquids in the range from 0.2 mm2/s to 1.0*105 mm2/s, the relative error of which does not exceed (0.2−10.0);
- simplicity of construction;
- reliability and high accuracy of experimental results;
- the availability of the ability to measure viscosity at high temperature and pressure intervals.

The main metrological disadvantages of capillary viscosity measurement are as follows:

- large volume of work in viscosity measurement;
- relatively long duration of the measurement process;
- according to Poiseuille's law, systematic mistakes occur when the liquid flow deviates from the laminar regime.

It should be noted that according to the research results, the most accurate method of control of dynamic and kinematic viscosity of liquid media in modern metrology is the capillary method.

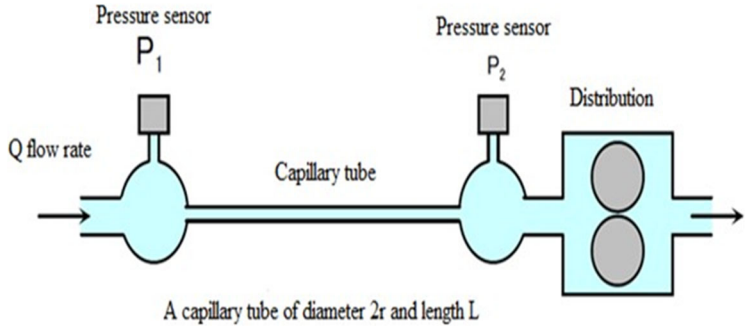

Fig. 5. Classification of modern methods of control of dynamic and kinematic viscosity of liquid media.

Figure 5 shows the working principle of a capillary viscometer.

As shown in Figure 5, the flow rate per unit time when a liquid flows through a cylinder tube is denoted by the symbol Q. Here 2r is the diameter; L - capillary tube length;

P1 and P2 is the differential pressure $P_1 - P_2 = \Delta P$, and the flow rate Q is directly proportional to the pressure gradient ΔP/L. This phenomenon is called Poiseuille's law and is expressed by the following equation:

$$Q = \frac{\pi \cdot r^4}{8 \cdot \eta} \cdot \frac{\Delta P}{L}, \quad (1)$$

From expression (1), the value of viscosity η can be determined by the following expression:

$$\eta = \frac{\pi \cdot r^4}{8 \cdot L} \cdot \frac{\Delta P}{Q}, \quad (2)$$

Therefore, with a capillary viscometer operating as shown in Figure 5, the flow rate Q of the medium passing through the capillary tube and the differential pressure ΔP at the ends of the capillary tube can be obtained by measuring. This measurement method is based on the laws of physics. Naturally, it allows you to get the viscosity value according to its definition. This method is called absolute viscosity measurement method.

There is another type of capillary viscometer, which is made of glass. It is shown in Figure 6. Although the processing of such a capillary tube is quite complicated, its working principle and structure are very simple. Due to the simplicity of the principle of operation, this design has been used for many years and is constantly being improved. Such a capillary viscometer measures the kinematics by measuring the time required for a freely falling sample to pass

through a capillary tube, viscosity ν can measure. Each viscometer has a viscometer constant C that is determined by calibration using a standard calibration solution.

The working principle and structure of the capillary viscometer are simple, but in order to achieve accurate results, it is necessary to pay close attention to the measurement procedure. This is a very complicated process. For example, cleaning the inside of a capillary tube requires great care. Before starting the measurement, it is necessary to carry out several ultrasonic cleaning operations using a cleaning liquid such as gasoline. Then the tube is dried and once again ultrasonically cleaned. Then the tube is dried again with acetone and finally the tube is washed with purified liquid. Temperature control is also important, with glass temperature causing thermal expansion/contraction, especially in the low viscosity range. This may cause measurement mistakes. Thus, the measurements require a lot of attention and take a lot of time.

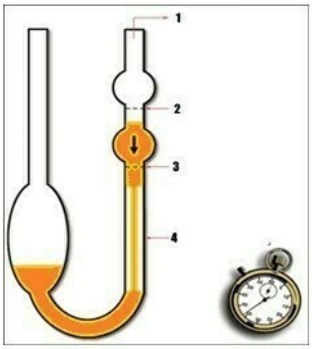

Fig. 6. Capillary viscometer. 1-suction pulls fluid to start mark; 2-start mark; 3-stop mark; 4-capillary section.

4 Result

According to the results of the conducted research, studies were conducted on standard samples in order to experimentally obtain the metrological properties of the base values for comparing and calibrating viscometers, certifying different types of viscometers. Table 1 shows the experimental results obtained by standard samples in the assessment of metrological properties of viscometers.

Table 1. The main metrological characteristics of the standard sample Own DSN 04.3039 with a nominal volume of 500.

Temperature		**Viscosity**		**Density, g/ml**
°C	**°F**	**Kinematic, mm²/s (cSt)**	**Dynamic, mPa·s (cP)**	
20.00	68.00	2.907	2.348	0.8076
25.00	77.00	2.621	2.108	0.8041
37.78	100.00	2.065	1.642	0.7950
40.00	104.00	1.988	1.577	0.7934
50.00	122.00	1.693	1.331	0.7864
60.00	140.00	1.464	1.141	0.7793

Uz DSN (State standard sample) 04.3039 standard sample, a negative, strong correlation r=-0.9865 is observed between temperature and kinematic viscosity, with a relative mistake of Δ=7.3% at T=60 °C in the linearity range. A strong positive correlation r=0.9736 was observed between kinematic viscosity and density values (Figure 8). Figure 7 shows the relationship between temperature and kinematic viscosity through a linear function using the least-squares method.

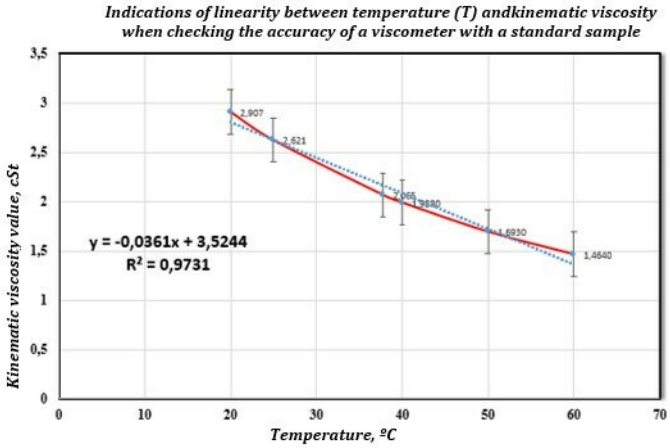

Fig. 7. Indicators of linearity between temperature (T) and kinematic viscosity when checking viscometer accuracy with a standard sample.

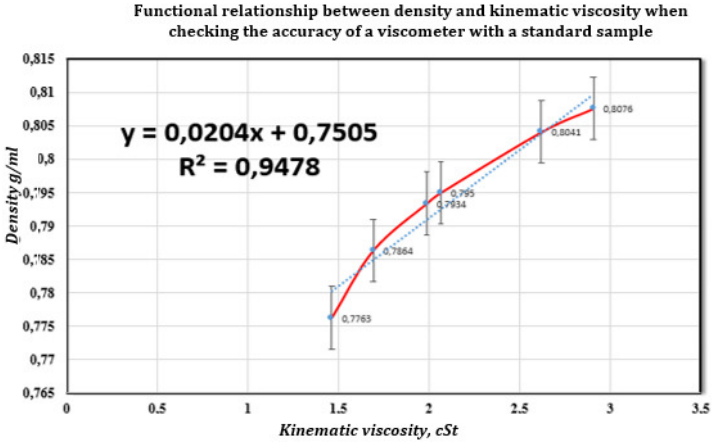

Fig. 8. Indications of linearity between temperature (T) and density when checking viscometer accuracy with a standard sample.

Experimental data on the assessment of the expanded uncertainty of the metrological properties of viscometers are presented. Processing of experimental results was carried out according to ISO, ILAC standards. Table 2 presents the quantitative values of the expanded uncertainty.

Table 2. Built-in expanded uncertainty in liquid viscosity measurements.

Viscosity measurement range	Expanded uncertainty of kinematic viscosity, mm²/s (cSt)	Expanded uncertainty of dynamic viscosity, mPa·s (cP)
0.3 to 7.4	±0.07	±0.07
7.4 to 10	±0.09	±0.09
From 10 to 30	±0.12	±0.12
From 30 to 72	±0.14	±0.14
From 72 to 180	±0.15	±0.15
From 180 to 520	±0.17	±0.17
520 to 1000	±0.19	±0.19
1000 to 2700	±0.20	±0.20
2700 to 8000	±0.22	±0.22
8000 to 82500	±0.23	±0.23

A weak, positive correlation r=0.5265 was observed between the different viscosity measurement ranges and the extended uncertainty, with an increase in the relative mistake value between the measurement range 0.3 to 7.4. Figure 9 shows the relationship between the viscosity measurement range and the expanded uncertainty as a result of the application of the least squares method through a linear function.

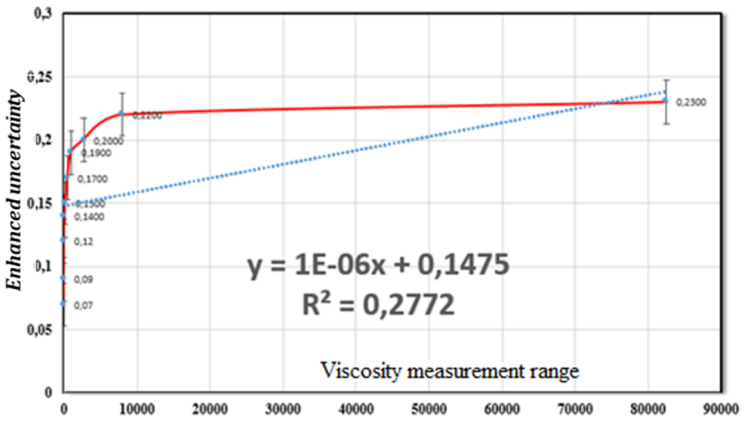

Fig. 9. Extended uncertainty and linearity indicators across the viscosity measurement range.

The main metrological characteristics of the Uz DSN 04.3037 standard sample with a nominal volume of 500 were determined. The main technical and metrological characteristics of this device are presented in Table 3.

Table 3 shows the expanded uncertainty values at different calibration points of the viscosity measurement range for the standard sample Uz DSN 04.3037.

Table 3. Extended Uncertainty Values Built in Liquid Viscosity Measurements.

Temperature		Viscosity		Density, g/ml
°C	°F	Kinematic, mm^2/s (cSt)	dynamic, mPa·s (Cp)	
20,00	68,00	12,19	9,953	0,8165
25,00	77,00	10,32	8,392	0,8132
37,78	100,00	7,083	5,701	0,8049
40,00	104,00	6,674	5,362	0,8034
50,00	122,00	5,211	4,152	0,7967
60,00	140,00	4,181	3,303	0,7901
80,00	176,00	2,875	2,234	0,7769
98,89	210,00	2,149	1,642	0,7643
100,00	212,00	2,115	1,615	0,7636

DSN 04.3037 standard sample, a negative, strong correlation r=-0.9304 was observed between temperature and kinematic viscosity, and the largest error was found at T=100 °C [22-28]. A strong positive correlation r=0.9296 was observed between kinematic viscosity and density values. As a result of the application of the method of least squares, it is shown that the relationship between temperature and kinematic viscosity is connected by a linear function (Figures 10, 11).

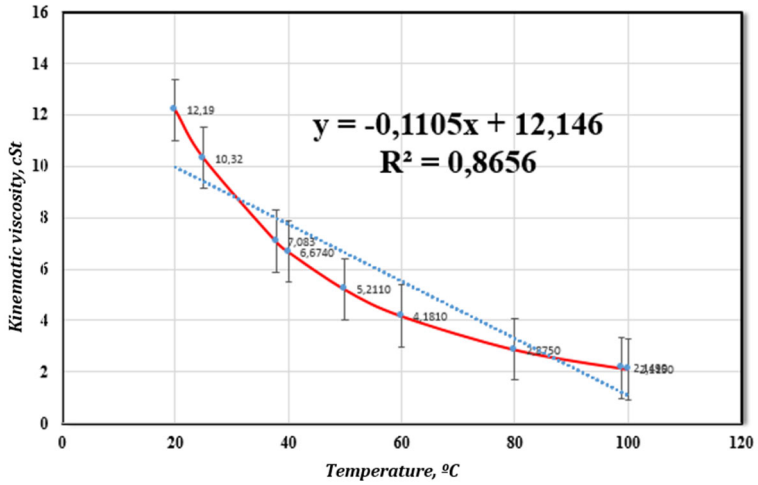

Fig. 10. Indicators of linearity between temperature (T) and kinematic viscosity when checking viscometer accuracy with a standard sample (DSN 04.3037 for a standard sample).

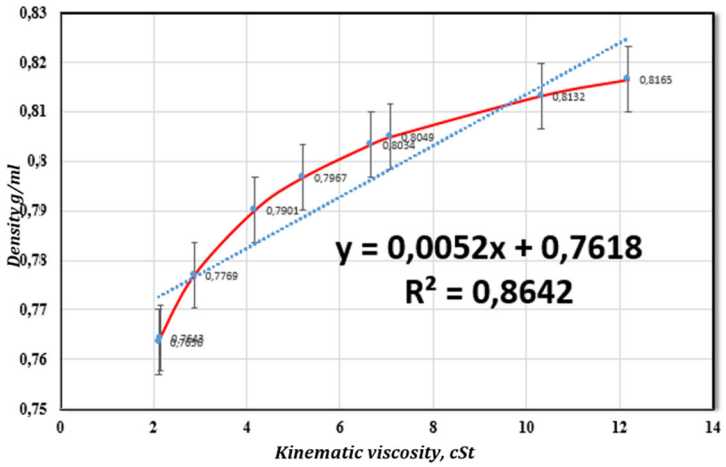

Fig. 11. Indicators of linearity between temperature (T) and density when checking viscometer accuracy with a standard sample (DSN 04.3037 for a standard sample).

Table 4. Fixed extended uncertainty values in the measurement of liquid viscosity (for own DSN 04.3037 standard sample).

Viscosity measurement range	**Expanded uncertainty of kinematic viscosity, mm²/s (cSt)**	**Expanded uncertainty of dynamic viscosity, mPa·s (cP)**
0.3 to 7.4	±0.07	±0.07
7.4 to 10	±0.09	±0.09
From 10 to 30	±0.12	±0.12
From 30 to 72	±0.14	±0.14
From 72 to 180	±0.15	±0.15
From 180 to 520	±0.17	±0.17
520 to 1000	±0.19	±0.19
1000 to 2700	±0.20	±0.20
2700 to 8000	±0.22	±0.22
8000 to 82500	±0.23	±0.23

Metrological traceability of the set viscosity value to the primary standard is ensured, the kinematic viscosity of pure water at 20 °C (ITS-90) η=(1.0034±0.17) % [29-31].

5 Discussion

According to the results of the research, the analysis and monitoring of the state of theory and practice of metrological supply of liquid viscosity measurement in order to determine the directions for solving the problem of non-availability of means of comparison, calibration and certification of measuring instruments in the temperature range from -40 °C to +150 °C

was carried out and the mechanisms of action and functional relationships of the main influencing factors were determined.

The kinematic viscosity of first discharge liquids in the range of values from -0.4 mm2/s to 1.0·105 mm2/s based on the creation of the necessary measurement conditions and the research of methods of increasing accuracy, the justification and selection of the most promising method for the device implementation of the control of dynamic and kinematic viscosity of liquid media creation of unit size transfer algorithm ensures creation of normative-technical basis of metrological supply.

Today, "Uzbekistan National Metrology Institute" is working on the development of methodologies for calibration and metrological certification that are compatible with international normative standards. The drafts of these documents are at the stage of metrological expertise. In particular, using the primary model complex device and conducting experiments to generate the kinematic viscosity unit of the normative basis. The following two international ASTM documents were selected for development:

1. ASTM 445-18;
2. ASTM D2162-17.

The capillary method was chosen as the optimal method for measuring the kinematic viscosity of liquid media based on a comparative analysis of experience and patent searches. A strong correlation was established in the measurement of kinematic viscosity, mainly with temperature and density at high values.

6 Conclusion

The following conclusions were drawn from the research results:

- on the basis of development and research of the unit initial reference complex of kinematic viscosity of liquids, improvement of metrological support for control of dynamic and kinematic viscosity of liquid media in a wide temperature range from -40 °C to $+100$ °C, as well as the creation of a size dimension from the primary model complex device that created the unit of kinematic viscosity of liquids , there are practical needs to develop the theoretical and practical foundations of methods and means of storage and transfer to working measuring instruments in harmony with international metrological practice;
- there is a need to create and research a working benchmark of kinematic viscosity to ensure the reliability of measurements of kinematic viscosity of liquid media in a given temperature range;
- experimental results comparing the viscosity of liquid media, conducting pilot tests and metrological inspections, after studying the metrological properties of standard samples, a strong correlation between temperature (T) and kinematic viscosity (η) was observed.

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