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THE METHOD OF CONTINUOUS MEASUREMENT AND THERMOPHYSICAL FLOW
CHARACTERISTICS CONTROLLING BY THE METHOD OF LAMINAR-FLOW CONDITIONS

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The table of symbols

<p>a - thermal diffusivity, m^2/s; cp - volumetric heat capacity, $J/(m^3 \cdot K)$; d - internal tube diameter, m; Q - liquid flow rate, m^3/s; U - liquid temperature value, $^{\circ}C$; R - internal tube radius, m; Re - Reinold's criterion.</p>	<p>T_1, T_2, T_3, T_4 - temperatures, measured in thermometers group, $^{\circ}C$; T_b - measurable bulk liquid temperature, $^{\circ}C$; $T_1^*, T_2^*, T_3^*, T_4^*$ - calculated temperature data on a tube wall, $^{\circ}C$; T_b^* - calculated bulk liquid temperature, $^{\circ}C$; λ - thermal conductance, $W/(m \cdot ^{\circ}C)$.</p>
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Introduction

Flows of real manufacturing liquids in most cases are the disperse systems (suspensions, emulsions or liquid-gas mixtures), which effective values of TFC can be measured only in a flow. When the flow is stopped, real manufacturing liquids are separated on its components. Also solid particles of suspensions precipitate, emulsions break, small gas bubbles escape from liquid-gas mixtures [1, 2].

Traditional methods and instruments for thermal measurement are based on the assumption, that the model of the investigated liquid in measuring process must be in a stall quasi-solid position (the model mustn't have convective heat transport). That is why these methods and instruments are useless for measuring effective TFC flows of real manufacturing liquids [1, 2].

Conducted investigations showed that the most suitable for measuring effective TFC flows of manufacturing liquids are, the so-called, methods of laminar-flow conditions [1, 2]. The advantage of these methods is the capacity of temporally continuous measurement of TFC flows of real manufacturing liquids in a flow with measuring instruments.

The paper considers the measurement method, the design of measuring apparatus, the algorithm of measurement data analysis and error estimation in the process of experimental defining the thermophysical liquid characteristics in the laminar flow. In the course of measurement and following data analysis within a computer program the next characteristics of the investigated liquid are defined: thermal conductance λ , $W/(m \cdot ^{\circ}C)$; thermal diffusivity a , m^2/s ; volumetric heat capacity cp , $J/(m^3 \cdot K)$. The suggested method can be used for continuous control of thermophysical liquid characteristics in the course of manufacturing process.

1. The design of measuring apparatus

Basic structural blocks, included in the measuring apparatus, are shown on the Figure 1. The main block here is the measurement device. Its physical model is considered in the next section.

Thermophysical characteristics are defined for the laminar liquid flow. It can be separated from the main flow of the manufacturing liquid with the by-pass line. At the entry of the measurement device, liquid flow must have constant temperature and discharge. Fluid discharge is chosen in such a way that Rainold's criterion inside the measurement device doesn't exceed the critical value for the laminar-flow conditions. Let us assume (with an adequate reserve), that $Re_{cr} = 2300$, then we obtain the following formula for the maximum discharge calculation of the analyzed liquid with measuring instruments:

$$Q_{\max} = 575 \frac{\pi d \mu}{\rho}$$

where d is the internal tube diameter in the measurement device, m (see below the description of the physical sensor model); μ is dynamic viscosity of the analyzed liquid, $Pa \cdot s$; ρ is the density of the analyzed liquid, kg/m^3 . Liquid discharge at the entry of the device must be constant and stable, without any pulsations and vibrations.

The temperature of the analyzed liquid at the entry into the measurement device must coincide with the temperature of the heat-transfer agent, which is delivered into the heat-exchanger of the measurement device. To fulfill this condition, an additional heat-exchanger can be set at the entry of the device. Besides, it's desirable for the temperature of the liquid and the heat-transfer agent to coincide with the temperature of the surroundings at the place, where the measurement device is set. It will decrease the heat-exchange between the device and the surroundings and increase the accuracy of measurement.

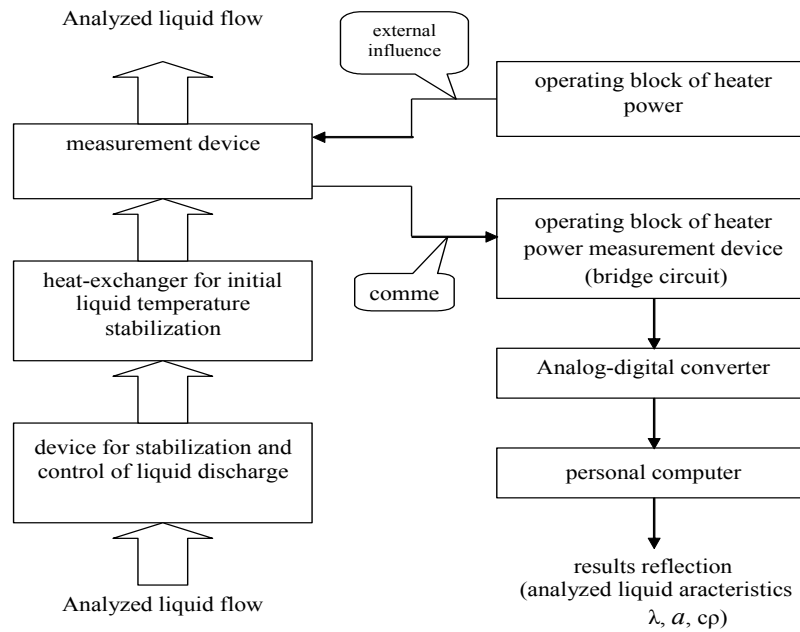


Fig. 1. The structural scheme of the measuring apparatus

Inside the measurement device there is a heater. This heater capacity is regulated by a special block and it is one of the discharge parameters. The measurement device is connected to a block of sensors, which provides for each measuring line a special bridge circuit (temperature characteristics in the sensor are measured with the help of copper resistance thermometers, connected by a three-wire circuit). Signals from the resistance thermometers through analog-digital converter income to a personal computer, where they are processed with a special program in accordance with the offered below algorithm (see the method of solution of an inverse boundary problem). After the calculation is done, the required thermophysical liquid characteristics are displayed on the screen. When there is enough arithmetic power, an inverse boundary problem can be solved just in the measuring process, i.e. liquid characteristics can be controlled at real time.

2. The method of an inverse boundary problem solution

The solution of an inverse boundary problem can be found when such values of thermal conductance λ and thermal diffusivity a of the analyzed liquid are selected, that the calculation temperature data on a tube wall T_1^* , T_2^* , T_3^* , T_4^* and bulk liquid temperature at a tube exit T_b^* [6] correspond to the data, obtained from the corresponding channels from the measurement device (T_1 , T_2 , T_3 , T_4 , T_b). The implemented at present algorithm allows to select any two temperatures using two variable characteristics (λ and a). In terms of error minimization the most preferable alternative is the use of temperatures T_3 and T_b , or T_2 and T_b . In case of failure of the channel for measuring bulk liquid temperature at a tube exit, thermophysical characteristics can be valued using the temperatures T_2 and T_3 . Though in this case the influence of measurement uncertainty of temperature on the errors of the tested thermophysical liquid characteristics increases (see the estimation of metrological characteristics of the measurement device).

Values λ and a are selected by the modified alternating-variable descent method, adapted for the given problem. In the course of multiple numerical experiments it was determined, that the temperature, being measured on a tube wall T_3 , characterizes liquid thermal conductance best, while bulk liquid temperature at a tube exit T_b characterizes liquid heat capacity $c\rho$.

The algorithm of selection includes the following stages:

1. Initial estimates for λ and a are chosen. Initial coefficients $\delta\lambda$, δa , used as the relative increments λ and a in the course of iteration, are specified.
2. The calculation temperature datum T_3^* is compared to the datum T_3 , obtained from analog-digital converter. If the calculation temperature datum turned out to be more than the measured one, then both values λ and a are multiplied by the quantity $(1+\delta\lambda)$. If the calculation temperature datum turned out to be less than the measured one, then both values λ and a are divided by $(1+\delta\lambda)$.
3. If a deviation sign of the calculation temperature datum from the measured one on the given iteration doesn't agree with the previous iteration, then an incremental step of λ falls in twice. A new value $\delta\lambda$ will be used on the next iteration.
4. If a relative departure of the calculation temperature datum T_3^* from the measured value T_3 is less than some defined value, we pass to the fifth stage. Otherwise, the current values λ and a are used as the following approximation. The most permissible relative deviation of the calculated temperature value from the measured one is calculated as a function from the coefficient δa . In this way, if to approach to the desired value of thermal diffusivity, then requirements for the selection accuracy of thermal conductance will raise.

5. The calculated bulk liquid temperature at a device exit is compared to the corresponding measured value. If the calculated value is larger than the measured one, then the current value a is divided by $(1 + \delta a)$. If the calculated value is less than the measured one, then value a is multiplied by $(1 + \delta a)$.

6. If the deviation of the calculated temperature value T_b^* from the measured value T_b on the given iteration differs from the previous iteration, then the coefficient δa falls in twice.

7. The coefficient $\delta \lambda$ is calculated as the function from δa . It is a necessary stage, because after the invoked step on the parameter a , an approximation on λ is to be started all over again.

8. The obtained on this stage values λ and a are used in the next calculation of a temperature field, i.e. on the next iteration. The criteria of the calculation termination, i.e. the adjustment of the true thermal conductance and thermal fluid diffusivity values, is fulfilling the conditions: $\delta a < \varepsilon_a$, i.e. getting some minimal increment on thermal diffusivity.

The given algorithm was much used in calculating the inverse problems for a number of operating conditions of the method and the measurement device under study. In the course of calculation the signs of instability and incorrectness of the received data were not found out.

3. Estimation of the metrological characteristics of the measuring apparatus

Let us analyze the basic sources of inaccuracy while defining thermophysical liquid characteristics. This error will include the following factors: the error, caused by the abstract mathematical model deflection from reality, the error of temperature calculation T_2 , T_3 , T_b and the initial liquid temperature T_0 , the error of solution of the direct value problem of thermal conductance (i.e. finding the values T_2^* , T_3^* , T_b^*), the error of solution of the inverse boundary value problem.

The first of these factors encloses the error, caused by partial inadequacy of the mathematical model of a real plant, presence of assumptions (see the list of basic assumptions in the section Mathematical model of the measurement plant [6]), the error in selecting geometric and thermophysical sensor characteristics, instability of the heater power and so on. The influence of this factor can be reduced due to the application of corrections after conducting a series of sample experiments with the liquids of the known characteristics.

The error of temperature calculation is summed from the error, made by the resistance thermometers, interface and analog-digital converter. It is possible to assume, that measurement of temperature with an absolute error less than $0,01$ °C and reasonable cost of a measuring apparatus can't be completed. In the existing experimental facility the error of temperature measurement on each channel doesn't exceed $0,05$ °C.

The error of the direct value problem solution is connected with a finite difference approximation of a differentiating equalization and value problems. The chosen designed diagram, a number of mesh points and a pitch distance along each axis, including time, the approximation method of boundary conditions, an instant of counting values (the criteria, which allows to judge about reaching a stationary temperature field) influence it.

It was defined after a series of numerical experiments that the use of the balanced difference scheme (the scheme of alternating direction) with one and the same increment pitch leads to the least errors in a steady-state operation, than the use of the implicit scheme (the local-univariate scheme with $\sigma = 1$). In the present paper only the numerical scheme is used, which implements the method of alternating directions. Though in the computer program, used for calculation, the same local-univariate implicit scheme is implemented, described in detail in [4]. With a significant step reduction in time, the implicit scheme converges with the same value, as the balanced scheme does, but the former one converges much faster. This result corresponds well with the asymptotic stability criteria, obtained in [5] for the balanced and implicit difference schemes.

Besides, the influence of a number of mesh points in different layers on the error of the calculated temperature values was investigated. Unfortunately, for the present it's impossible to state accurate recommendations how to choose a mesh point in certain layers of the measuring apparatus. The only assumption here, which is corroborated by the numerical experiments, is that a minimal feasible mesh point should be chosen in the layers, where heat flow ($q = \lambda \partial U / \partial r$) reaches its maximum from the absolute value. But it should be noted, that if a certain relation between step in time and step in axis is topped, the balanced scheme is not stable any longer.

The error of thermophysical liquid characteristics definition is actually the error of the inverse value problem solution of thermal conductance. In the course of this solution some additional factors appear, which influence the cumulative errors. One of the significant moments is the criteria choice, which influences the decision making concerning the fact that the calculated temperature field corresponds the experimental one (i.e. obtained during the calculation values λ and a are the real values). As it was already mentioned, except the initial liquid temperature T_0 , the following temperature values are measured: T_1 , T_2 , T_3 , T_4 , T_b . Temperatures T_1 and T_4 on the first and the last sections of the measuring apparatus are influenced greatly by the heat outflow along the copper tube, which can't be accurately taken into account in the analyzed model. That is why the basic measured characteristics are temperatures T_2 , T_3 , T_b . It's possible to assume, that the measurement error of all temperature values is equal (though, indeed, the bulk liquid temperature is measured a bit accurately, than the temperatures on a tube wall). To select two thermophysical characteristics (λ and a) at least two measured temperature values are needed. A greater number of characteristics can be taken into account, but in this case computational complexity and the solution time of the inverse value problem increases.

As the result of carrying out a series of numerical experiments, the following estimation of the relative error of thermophysical liquid characteristics defining was obtained, subject to how accurate the temperatures are measured and in what way these temperature characteristics are used in calculation.

Absolute error of temperature measurement ΔT , °C	Relative error of defining thermal conductance λ , %			Relative error of defining thermal diffusivity a , %		
	On T_2, T_3	On T_2, T_b	On T_3, T_b	On T_2, T_3	On T_2, T_b	On T_3, T_b
0,005	2,78	0,18	0,18	7,18	0,35	0,35
0,01	5,55	0,36	0,35	14,71	0,69	0,69
0,05	27,69	1,83	1,74	83,22	3,45	3,31
0,1	-	3,77	3,50	-	6,91	6,70

As it is seen from the table, the least error is obtained when the temperature T_3 is used on the last but one section of the measuring part and the bulk liquid temperature T_b at a sensor output. In whole, judging by the table, it is possible to assume that the relative error of thermal conductance defining makes up about 3...5% and the error of thermal diffusivity defining makes up about 7...8 diffusivity %.

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THE MINERAL CONTENT OF SOME YEMENI HONEYS

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Introduction

The mineral and trace elements content in honey samples could give an indication of environmental pollution and herewith also an indication of the geographical origin of honey [Anklam 1998].

Some areas, in where there is a human activity, have heavy metal pollution due to different sources such as home wastes, straw and traffic wastes. Plant which grown under the effects of these pollutants can contain different range of heavy metals. High heavy metal concentrations in plant body can cause increasing of heavy metal concentrations in honey bee because bees collect pollens from different kind of flowers [Demirezen and Aksoy 2005].

The target of this investigation was to verify the content of some mineral elements in six kinds of Yemeni honeys.

Materials and Methods

Chemicals

All chemicals were ultra pure grade. HNO_3 (Merck/Germany); H_2O_2 (BDH/England); H_2O (Milli-Q UV- Plus system, Millipore Corporation, USA).

Standard Working Solutions

1. Multi-element calibration standard (Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, Hg, In, K, Li, Mg, Mn, Na, Ni, Pb, Rb, Se, Sr, Ti, U, V, Zn). Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 1000 $\mu\text{g/L}$. (Perkin Elmer, USA). 2. Multi- element calibration standard (Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, Hg, In, K, Li, Mg, Mn, Na, Ni, Pb, Rb, Se, Sr, Tl, U, V, Zn). Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 200 $\mu\text{g/L}$. (Perkin Elmer, USA). 3) K, Na, Ca, Mg, Fe, Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 1000 $\mu\text{g/L}$. (Perkin Elmer, USA).