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DETERMINATION OF THERMAL CONDUCTIVITY IN LIQUIDS BY MONITORING TRANSIENT PHENOMENON

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Abstract - Thermal properties of liquids, especially thermal conductivity, are important issues in the designing, developing and application of products. In this paper, the method of thermal conductivity determination is based on heat transfer process analysis during transient phenomena caused by an energy pulse, with application of parameter value estimation of process model. Essentially, influence of energy pulse on the liquid condition in the measuring cell is negligible.

Keywords: liquid thermal conductivity, hot-wire method, parameter estimation

1. INTRODUCTION

Numerous papers describing different measuring procedures and construction of the cell for determination of thermal conductivity of liquids have been published. The procedures applied can be divided in two categories. The first category's is based on the comparison of heat flow through the measuring sample and reference material. The second category of measuring procedures characterizes the fact that the measuring is based on observation of heat transient phenomena within the sample.

Having system approach as the basis, we designed a method of dynamical determination of the thermal conductivity in liquids within the measuring cell, that enable disregarding of seen change in the heat accumulation of a liquid.

The experimental research cover design of the thermal conductivity measuring cell for homogeneous liquids, and examining balance of the sensor and the measured liquid. The suggested method relies on the identification theory and the methods of parameter value estimation.

2. METHOD OF DETERMINATION

During the transient phenomena caused by electrical current pulse within the wire that is located in axe of the measurement cell, one observes a short period change in the heat accumulation within the sample, which is dependent primarily on the thermal properties of the sample. By measuring the transient phenomena it is possible to determine the thermal conductivity of liquids.

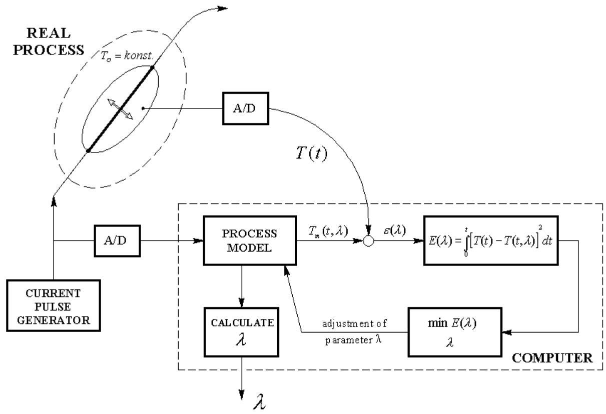

Fig. 1. Scheme of described method

If the temperature of the bath is stabilized to reach the order of magnitude punctuality better than the measuring uncertainty of the thermal conductivity that is being determined, the task of determination of the thermal conductivity could be reduced to the task of process model parameter estimation. The designed method offers various options for development of this procedure, depending on assumed form and complexity of a model, assumed estimation procedure and, finally, on the measurement uncertainty itself.

Use of simplified Fourier's equation as process model is the base of the approach, in which one should estimate the thermal conductivity of a liquid as parameter of that model. The starting point is a dynamical mathematical model of the following form:

$$\frac{dT}{dt} = f(T, I, \lambda)$$

where T represents measured temperature, I magnitude of electrical current pulse within the wire (input variable), and λ is the thermal conductivity of the measured liquid.

Dynamical behavior of measuring sensor is being taken into account, in order to reduce the measuring uncertainty to the lowest level possible.

Unknown value of parameter λ is being estimated as follows: the discrete output value of the real process, $T(t_i)$ is being compared with the model output value, $T^*(t_i, \lambda)$. The error is defined as follows:

$$\varepsilon(\lambda) = T(t_i) - T^*(t_i, \lambda)$$

For the purpose of the thermal conductivity determination the following error criterion is being defined, e.g.:

$$E(\lambda) = \int_0^t \varepsilon^2(\lambda)dt$$

The procedure of evaluation $\min_{\lambda} E$ has been implemented using the method of steepest descent.

3. MATHEMATICAL MODEL OF PROCESS

Mathematical model of process is based on the five heat accumulation segments inside measuring cell (wire, three supposed segments within liquid and the cell wall). Fundamental equation of the dynamic heat balance is used to describe segment's heat accumulation.

$$\frac{dQ_i}{dt} = Q_{in,i} - Q_{out,i}$$

where dQ/dt, $Q_{in,i}$, $Q_{out,i}$ represent heat accumulation of observed segment, the heat flow in the observed segment, the heat flow out of i-th segment, respectively. The heat accumulation is affected primarily by the thermal conductivity of measured liquid and of thickness of assumed layer of liquid.

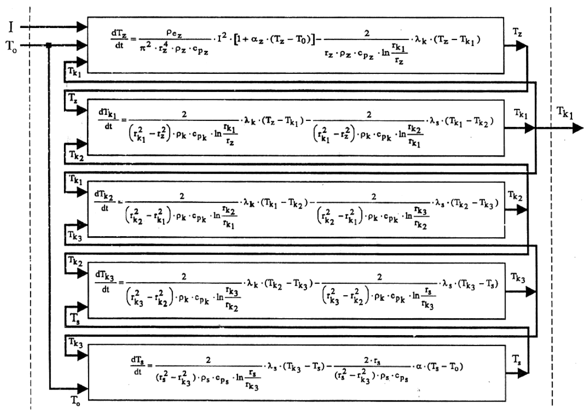

Fig. 2. Structural representation of model.

Structural representation is used to show the interactions of the output variable (T_{K1}) and the input variables (electrical current pulse, I, as manipulated variable and ambient temperature, T_O). The heat accumulation in the process is characterized by temperatures of five heat accumulation segments (T_W, T_{K1}, T_{K2}, T_{K3}, T_S). Unknown parameter of the model is the thermal conductivity coefficient λ.

Described model can be rearranged and shown in the state space form:

$$[\dot{T}] = [A(\lambda)]\cdot[T] + [B]\cdot I$$

where $[T]$ is vector of state variables, $[\dot{T}]$ vector of state variables rate changes, $[A(\lambda)]$ process characteristic matrix, $[B]$ is forcing function matrix, and I represents forcing function (the magnitude of electrical pulse within the wire).

4. EXPERIMENTAL SETUP

The measuring cell has special construction, adapted for described method. It is shaped in a cylinder form with height of 8 cm and diameter of 0,6 cm. Precisely defined electrical current pulse is passed through Pt-wire located at the cell axis. Thermistor is placed at the adequate distance (d) from cell's axis.

The scheme of measurement cell is shown on Figure 3.

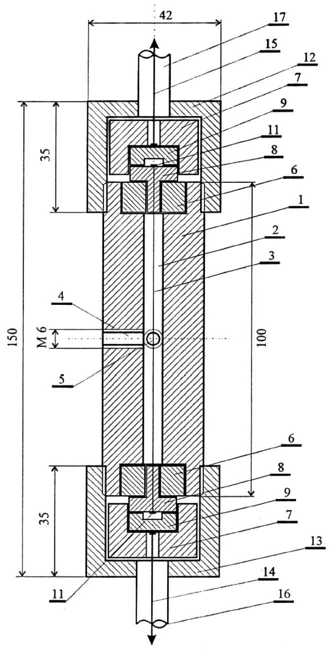

Fig. 3. Scheme of measurement cell

4. EXPERIMENTAL RESEARCH

From numerous results here are shown just characteristic ones.

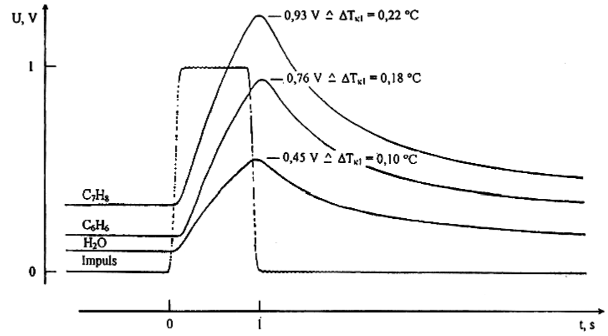

Fig. 4. Pulse forcing function and response curves for water, benzene and toluene for input energy pulse of Q = 0,081 J: the temperature changes at sensor location d = 0,4cm.

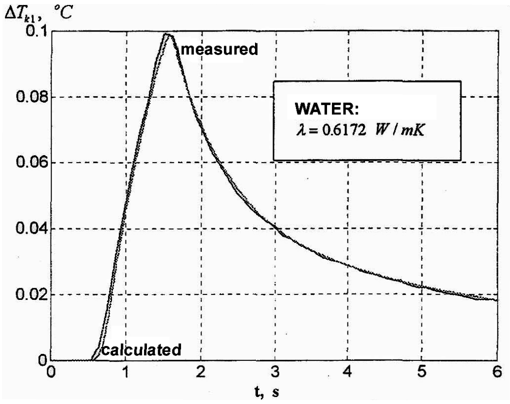

Fig. 5. Comparison of model and actual process at the end of the parameter estimation procedure for water thermal conductivity.

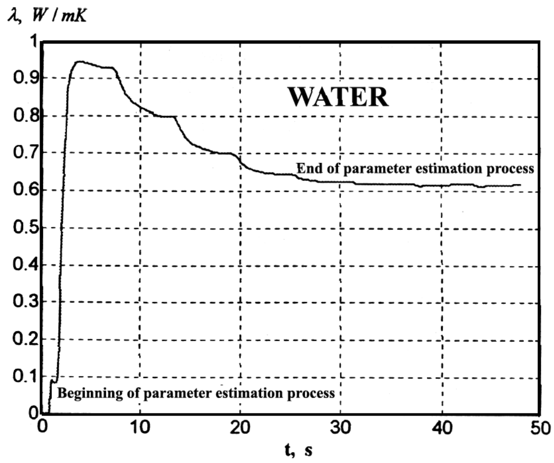

Fig. 6. Dynamic changes of the thermal conductivity of water during parameter estimation process

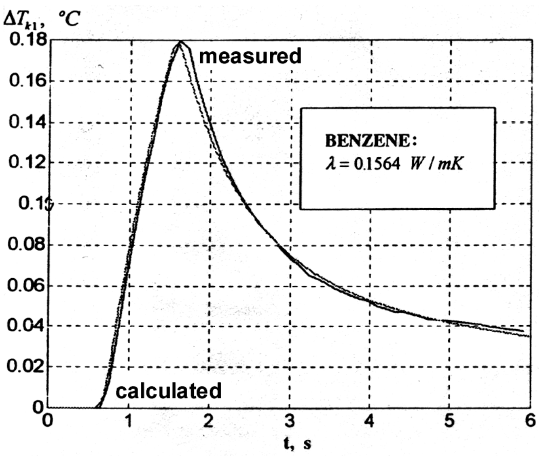

Fig. 7. Comparison of model evaluation and actual process at the end of parameter estimation procedure for benzene thermal conductivity.

5. CONCLUSIONS

The method of dynamic thermal conductivity determination by using small sample of liquid has been developed. This method is based on the parameter estimation procedure for process model by searching transient responses dissaccordance between actual process and the model of process. The method is characterized by small energy pulse input that is introduced in the measuring sample.

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