Considerations Regarding the Improvement of the Heat Boundary Layer Flowmeter Performances

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Abstract: Due to its importance, flows measurement constitutes a great field of interest approached by most of the research collectives. Improving the mechanical technologies allowed the quick development of the measuring systems based on mechanical principles. The chemical engineering constitutes a special field from this point of view due to acid or basic environments, being thus necessary the study and development of other principles for flows measuring. Among this, there is also counted flows measurement through electro-thermal methods, field approached by the authors collective of this work. The carried out studies took into consideration finding new practical solutions for realizing a high performances prototype.

Keywords: chemical engeneering, flowmeter, heat transfer, analogue-numerical interface.

1. Introduction

The heat boundary layer flowmeters (DSLT) are part of the category of thermal flowmeters where the proper measuring is based on heat transfer realized through a thin layer of liquid close to the pipe wall, called heat boundry layer. The functioning of the heat boundary layer flowmeter is based upon the following principle [1]: the pipe where there circulates the liquid whose flow is measured, is heated by a heat source realized electrically, determining the appearance of a temperature difference in the liquid, depending on the flow rate of the liquid (flow), the heat consumption and the constructive-functional conditions. Based on the equations of thermal transfer in the conditions of neglecting the heat losses, there is obtained the general equation of electro-thermal flowmeters functioning.

$$\Phi_N = K \cdot Cp \cdot \Delta\theta \cdot q_m^n \qquad (1)$$

where :

Φ_N - thermal flow [W];
K - constant depending on constructive-functional parameters of the apparatus;
Cp - the specific heat [J/kg·grd];
$\Delta\theta$ - the temperature difference between the heat transfer surface and the fluid [^{o}C];
q_m - liquid weight flow [kg/s];
n - constant depending on the flowing regime (n = 0.33 for static flow; n = 0.8 for eddy).

Constructively, the necessary thermal flow is assured by heating resistance R_i which dissipate the power P_i. The study was carried out in the following conditions:
1. The constant keeping of disequilibrium voltage Ud by correspondingly modifying the heating power P_i. In this case, according to the relation (1), the temperature difference $\Delta\theta$ being constant, the value determination of the liquid weight flow is made on the grounds of the heat power;
2. The constant keeping of the heating power P_i. In this case, the flow value will be determined according to the

relation (1), by measuring the temperature difference $\Delta\theta$ by the help of thermally sensitive resistances. This means that the disequilibrium voltage Ud of the bridge is a measure of the flow.

2. Experimental

In Figure 1 is illustrated the block diagram of the heat boundry layer flowmeter [2].
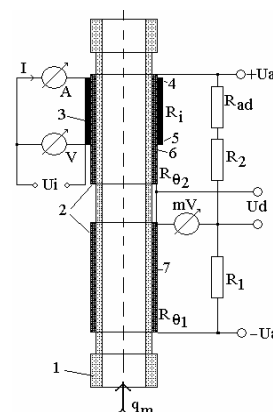

Figure 1. The block diagram of the heat boundry layer flowmeter
where:
1 - steel pipe;   2 - termally sensitive resistances;
3 - heating resistance;
4, 5, 6, 7 – temperature measuring points;

Resistance values (20 ^{o}C) :

$R_{\theta1}$= 294 Ω	$R_{\theta2}$= 293 Ω
R_1 = 307 Ω	R_2 = 332 Ω
R_{ad} = 10 Ω	R_i = 17.1 Ω

Heating voltage: Ui = 30 V; Heating current: I = 1.82 A
The supply voltage of the measuring bridge: Ua= 11 V.

The heat boundary layer flowmeter is made of steel pipe 1 where there are enveloped two thermally sensitive resistances $R_{\theta1}$, and $R_{\theta2}$. $R_{\theta1}$ has the role to measure the liquid temperature. Over $R_{\theta2}$ resistance, the heat resistance is winded. It is supplied through the agency of a variable

voltage source with voltage Ui measured by the voltmeter V. The current I of the circuit is measured with the help of ammeter A [3,4]. The two themally sensitive resistances are included in a bridge circuit on whose diagonal the disequilibrium voltage Ud is measured, directly, through the agency of milivoltmeter mV, or with the help of a numerical measuring system. The bridge is supplied with stabilized voltage Ua.

In order for the carried out determinations be more precise, there has been used an automatic flow control system realized with industrial equipments (Figure 2) [1].
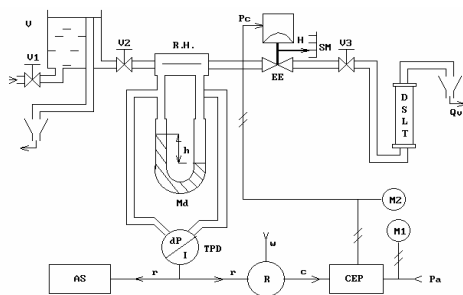

Figure 2. Diagram of the automatic flow control system

3. Results and discussion

In order to characterize the automatic flow control system there have been traced the static characteristic of hydraulic resistance RH, used as sensitive element for measuring the flow, and of the pneumatic execution element EE, presented in Figure 3 and 4.
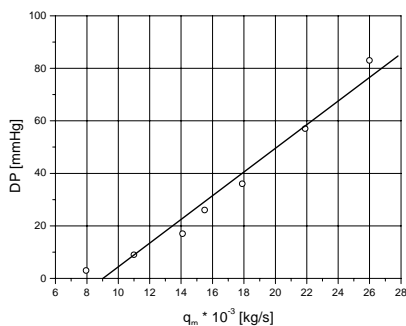

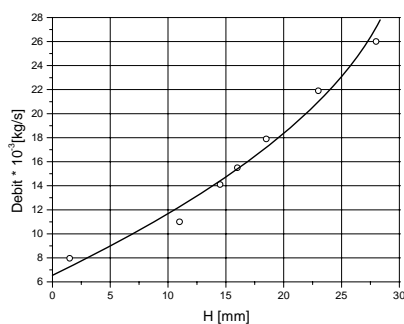Figure 3. Static characteristic of hydraulic resistance

Figure 4. Static characteristic of pneumatic execution element

The static characteristic of hydraulic resistance presented in Figure 3 is linear, and of the pneumatic execution element is logarithmic (Figure 4). There is found that due to the pneumatic execution element, the automatic flow control system is not linear.

Dynamic behavior

In order to obtain information regarding the dynamic behavior heat boundary layer flowmeter, there has been watched the disequilibrium voltage variation Ud in time for the following operating conditions: 1- initial coupling of heating voltage in the absence of flow (period 0-300 seconds); 2- providing a minimum flow (period 300-750 seconds). The obtained results are presented in Figure 5.
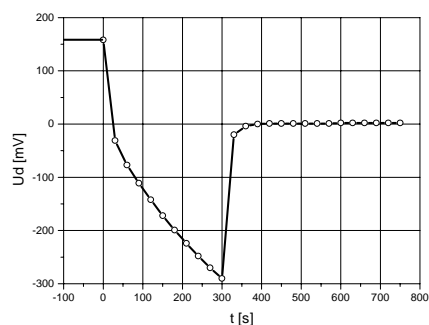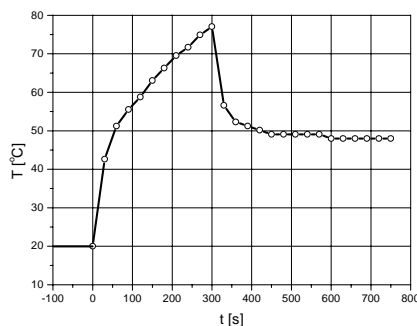

Figure 5. The disequilibrium voltage variation

Figure 6. The variation of temperature in the measuring point 4.

In Figure 6 is presented the modification of temperature measured in point 4 in the same conditions of test carrying out. The thermal accumulation phenomena in the heating area takes place in the absence of a minimum flow. The variation form of voltage (Figure 5) and of temperature (Figure 6) from moment t = 300 s allows approximation of time constant of the apparatus at value of t = 30 s. The time constant is low, which proves the possibility of using this system when measuring flows in the conditions of obtaining high performances.

The study of heat boundary layer flowmeter with variable thermal flow

The usage of an adjustable voltage source of high precision allows a delicate modification at a constant, precise value of Ui voltage. The carried out study has been

elaborated for different initial heating powers (voltages). For different values of the flow, there has been modified accordingly the heating voltage, so that the disequilibrium voltage remain constant.

In case the initial heating power is $P_i = 40$ W, the relatively low value of the temperature measured at point 4 suggests the need to increase the heating power. When using an initial heating power $P_i = 56.64$ W, the temperature values measured in point 4 indicate a good stabilization thermally speaking of the operating conditions of heat boundary layer flowmeter.

In Figure 7 is illustrated the static characteristic of heat boundary layer flowmeter with variable thermal flow:
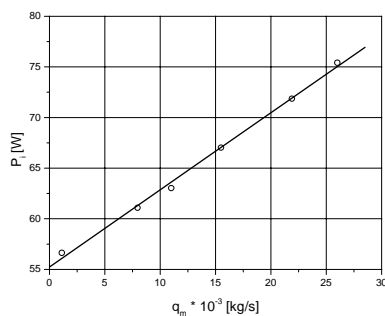

Figure 7. Static characteristic of heat boundary layer flowmeter with variable thermal flow

Based on the experimental data, the following linear dependency has been obtained:

$$P_i = 55.245432 + 0.761589 \cdot q_m \qquad (2)$$

which represents the static characteristic of this flowmeter, having the correlation coefficient R = 0.998294.

The important increase of the initial heating power to $P_i = 75$ W (almost double the previous case) determines a raise of temperature in point 4, which could lead, through the thermal accumulation phenomena, to the apparatus destruction.

As a conclusion, for this heat boundary layer flowmeter, the best results were obtained for an initial heating power of 56 W ($U_i = 30$ V).

The study of heat boundary layer flowmeter with constant heating power

Based on the carried out study in the previous case, there have been chosen the following functioning parameters of the heat boundary layer flowmeter, in regime of constant heating thermal flow:

$U_i = 30$; I = 1.82 A.

The minimum provided flow is of $q_m = 3.5 \cdot 10^{-3}$ kg/s.

For a high viability of the used system, there has been given up to the implementation of a potentiometer used for the equilibration of the measuring bridge. In this way the initial disequilibrium voltage of the bridge was modified by the additional resistance R_{ad}.

For $R_{ad} = 0$ Ω there has been obtained Ud = 3 mV.

Based on the experimental results there has been obtained the static characteristic of flowmeter, presented in Figure 8, for which the linear and polynomial regression calculations showed the following results:

$$q_m = 1.766223 + 0.407852 \cdot Ud \qquad (3)$$
$$R = 0.997275$$

$$q_m = 2.521937 + 0.334719 \cdot Ud + 1.12085 \cdot 10^{-3} \cdot Ud^2 \quad (4)$$
$$R = 0.996696$$
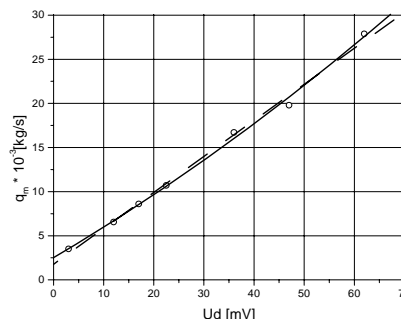
where R − correlation coefficient.

Figure 8. Static characteristic of heat boundary layer flowmeter with constant heating power

The corresponding variation of temperature in measuring point 4 is presented in Figure 9. The obtained results mark out the fact that, within the conditions of the carried out experiment, the static characteristic can be easy to be made made linear without essentially modifying the measuring error.
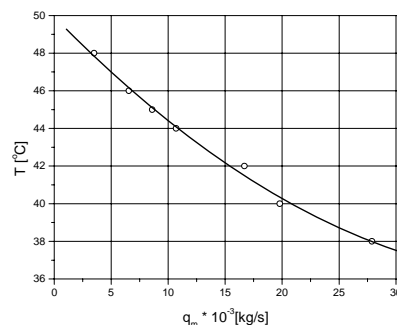

Figure 9. Temperature variation in measuring point 4

Temperature distribution on the flowmeter pipe length

Seeing that there has been chosen Ud = 0, we may calculate the temperature difference $\Delta\theta$ with relations 5 and 6:

$$\frac{R_1}{R_1 + R_2 + R_{ad}} = \frac{R_{\theta 1}}{R_{\theta 1} + R_{\theta 2}} \qquad (5)$$

$$R_{\theta 2} = R_{\theta 20} \cdot (1 + \alpha \cdot \Delta\theta) \qquad (6)$$

Measuring the temperature in five points with the help of some Iron-Constantan thermocouples (Tc), using an

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analogue-numerical acquisition system (Figure 10) [5], there is traced the distribution of temperature on the length of the flowmeter's pipe and temperature distribution on the heating resistance length (Figure 11).

a. Input circuit T 21
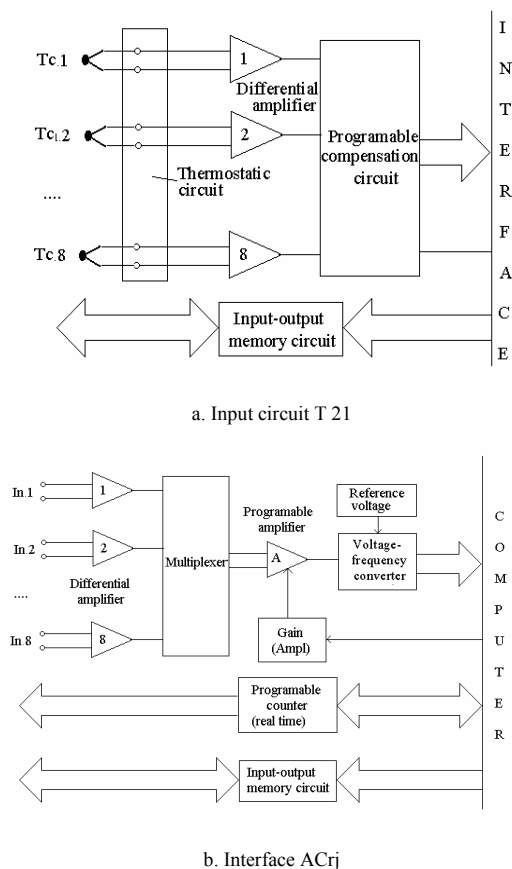

b. Interface ACrj

Figure 10. Block diagram of the used analog-numerical acquisition system

The measuring system is made of the analog-numerical interface ACrj and the input circuit T 21, both manufactured by the company Strawberry Tree USA, which also puts the needed programs at the user's disposal.
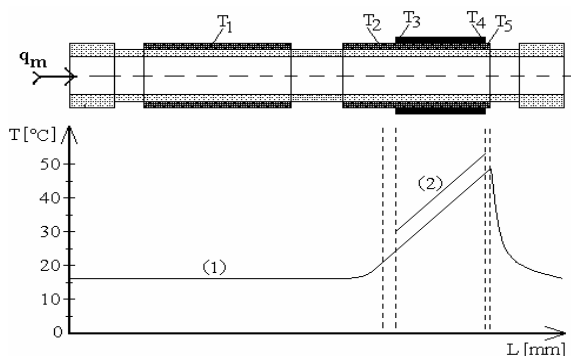

Figure 11. Distribution of temperature: (1) on the length of flowmeter pipe; (2) on the length of the heating resistance.

4. Conclusions

Due to the current technologies, the electro-thermal principle for determining flows may be successfully used within complete and updated measuring systems, as that realized by the authors.

The study of the prototype marks out the possibility of obtaining some high performance heat boundary layer flowmeters.

Obtaining these performances was possible by:

- Appropriate choice of the flowmeter's pipe material and its wall thickness, so that the thermal transfer is as good as possible.
- Corresponding positioning and dimensioning of thermally sensitive resistances;
- Corresponding positioning and elaboration of the heating resistance;
- Usage of a high precision voltage source for heating;
- The proper choosing of the supply voltage of the measuring bridge;
- Using a high impedance measuring system for the disequilibrium voltage, that will not influence the measuring system;
- The suitable choosing of the thermal regime by measuring the maximum temperature.

The heat boundary layer flowmeter represents a good technical solution because the reciprocal influences between the apparatus and environment are negligible.

The use of the current analog-numerical systems has facilitaded the real measurements of the temperature distribution in static and dynamic conditions.

The carried out experimental installation has a good sensitiveness. Also we can notice a linear dependency between the flow and the voltage. This is revealed by a very good value of correlation coefficient (R=0.99).

The heat boundary layer flowmeter can be successfully used as measuring transducer for automatic controlling of low liquid flows.

5. References

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