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SMALL GAS FLOW MEASUREMENT- A MICROCOMPUTER APPLICATION

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Abstract − This paper presents a flowmeter design applicable for measurement of low gas flow amounts. The designed flowmeter with a time – of – flight sensor represents a microcomputer application with a control and evaluation procedure. The mathematical model of energy and temperature balance is simulated in the FEMLAB environment. The designed measurement device was used for research of a reaction kinetics of biodegradation reactions successfuly.

Keywords: microcomputers, simulation, sensors

1. INTRODUCTION

The necessity of extract an accuracy measuring of fluid flows is a classical and standard task in industrial process control. However, there is a wide range of gas and liquid flows and the utilization of unified measuring principle is impossible. The biogas flow measurement produced in biodegradation reactions of plastics gives the stimuli for the micro - flow measurement study. The produced biogas at the biodegradation reactions consists of methane CH_4 and carbon dioxide CO_2. The reaction kinetics of these reactions are studied by gas flow measurement, the gas flow range is (30 – 140) *ml/hr* [1]. For measurement of small flow in mentioned range was designed a thermal mass flowmeter that measures the passage time of a heat pulse over a known distance. At the relatively low flow rates, the time difference depends mainly on the diffusivity of the fluid medium [2]. This article describes the flowmeter design based on the principles of a time - of - flight sensor in operating flow range (30 – 200) *ml/hr.* The designed sensor consists of a heater and one temperature sensor downstream [3]. The mathematical model of the designed flowmeter was simulated by the FEMLAB program.

2. GENERAL CONCEPTS OF FLOW MEASUREMENTS

The thermal mass flowmeter is one of promising principles for low gas flows in the range (30 – 50) *ml/hr*. This flowmeter type utilizes a heated sensitive element and thermodynamic heat conduction principles to determine the real mass flow rate. A mass flow rate is determined by observing the effects of heat energy added to the flow stream as governed by the equation of the heat transfer:

$$Q = mc_p\Delta T \qquad (1)$$

where Q is a heat, m is a flow mass, c_p is a heat capacity of the fluid and ΔT is a temperature difference. For measurement of small flow in range (30 – 200) *ml/hr* was used a thermal mass flowmeter that measures the passage time of a heat pulse over a known distance. This sensor consists of a heater and one or more temperature sensors downstream, see Fig. 1.

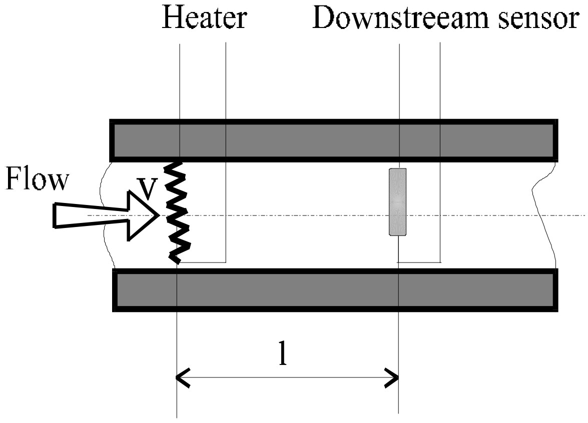

Fig. 1. Principle of a time-of-flight sensor

The heater is activated by periodical equidistant current pulses. The transport of the generated heat is a combination of diffusion and forced convection. The resulting temperature field is detected by a temperature sensor located downstream. The detected temperature output signal of the temperature sensor is a function of time and flow velocity. The sensor output is the time difference between the starting point of the generated heat pulse and the point in time at which a maximum temperature at the downstream sensor is reached, Fig. 2. At the relatively low flow rates, the time difference depends mainly on the diffusivity of the fluid medium. At the relatively high flow rates, the time difference tends to relate to the ratio of the heater – sensor distance and the average flow velocity [3] .

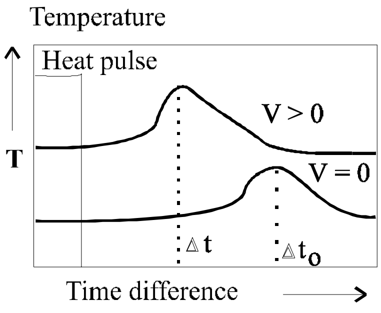

Fig. 2. Temperature at downstream sensor

3. MODEL FOR TIME - OF - FLIGHT SENSOR

The mathematical model of the designed flowmeter can be successfully simulated by the FEMLAB program. The simulated time – of – flight sensor type is a multiphysics model. It involves more than one kind of physics [6]. In this case, there are an Incompressible Navier – Stokes equations from fluid dynamics together with a heater transfer equation, essentially a convection – diffusion equation. There are four unknown field variables: the velocity field components u and v, the pressure p and the temperature T. They are all interrelated through bidirectional multiphysics couplings. The pure Incompressible Navier-Stokes equations consist of a momentum balance (a vector equation) and a mass conservation and incompressibility condition [4]. The equations are

$$\rho\frac{\partial u}{\partial t}+\rho(u.\nabla)u=-\nabla p+\eta\nabla^2 u+F \qquad (2)$$

$$\nabla.u=0 \qquad (3)$$

where F is a volume force, ρ is a fluid density and η is a dynamic viscosity.

The heat equation (4) is an energy conservation equation, that says only that the change in energy is equal to the heat source minus the divergence of the diffusive heat flux

$$\rho c_p\frac{\partial T}{\partial t}+\nabla.(-k\nabla T+\rho c_p Tu)=Q \qquad (4)$$

where c_p is the heat capacity of the fluid, and ρ is fluid density as before. The expression in the brackets is the heat flux vector and Q represents a source term. The heat flux vector contains diffusive and convective terms, where the latter is proportional to the velocity field $\boldsymbol{u}$ [5].

In this model, the above equations are coupled through the F and Q terms. Free convection is added to the momentum balance with the Boussinesq approximation. In this approximation, variations in density with temperature are ignored, except insofar as they give rise to a buoyancy force lifting the fluid. This force is put in the F-term in the Navier-Stokes equations.

3.1. Geometry of model and boundary conditions

For design of the flowmeter was used different constructive materials (steel, cooper, aluminium and plastic). 2D geometry of the designed flowmeter is depicted in Fig. 3.

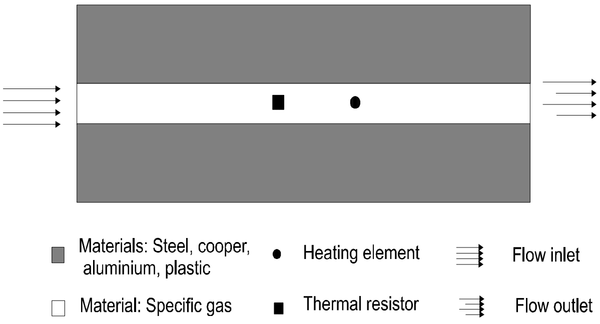

Fig. 3. 2D geometry of the designed flowmeter

The boundary conditions of the flowmeter model are shown in Fig. 4. The gas flow is modeled by no – slip, zero – velocity condition on all solid wall surfaces in inner wall of the sensor tube. The heating element is driven by pulse current, length of the current pulses is 20 *ms*.

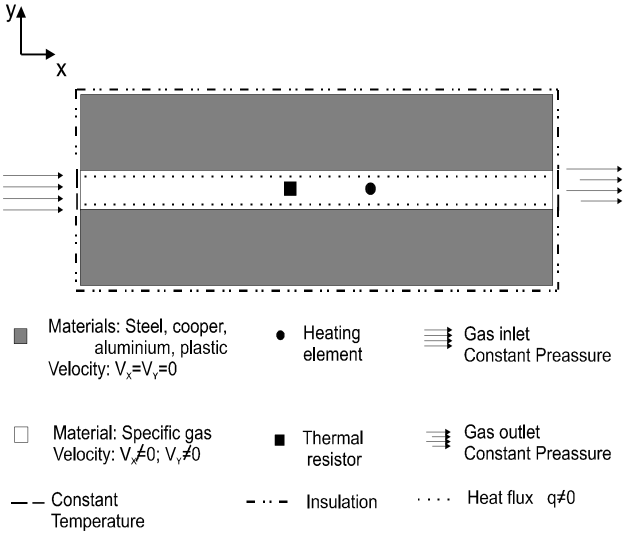

Fig. 4. Boundary conditions of the flowmeter model

3.2. Modeling results

The simulation results of a heat transport are shown in Fig. 5. and Fig. 6. The distance between the heating element and the temperature sensor is 15 *mm* and the initial temperature of running gas is 20 ^0C. Fig. 5. shows the temperature profiles of agitated air in the sensor tube (constructive material is steel). The heat transfer coefficient between the heater and air is 5,2 $Wm^{-2}K^{-1}$ and the heat transfer coefficient between air and the temperature sensor is 3,8 $W\,m^{-2}K^{-1}$.

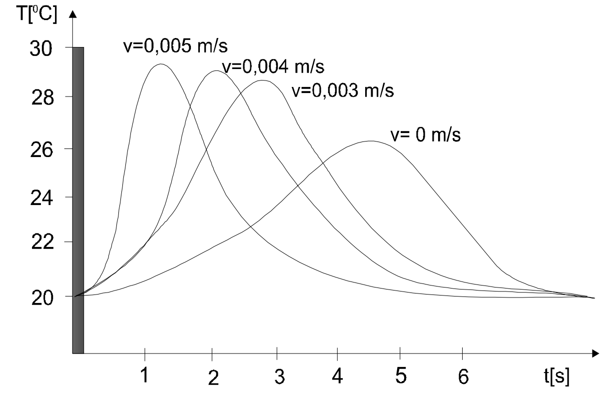

Fig. 5. Temperature profiles of agitated air in sensor tube

The temperature profiles of agitated CO_2 are depicted in Fig. 6. (constructive material of the sensor tube is plastic). The heat transfer coefficient between the heater and CO_2 is 4,1 $Wm^{-2}K^{-1}$ and the heat transfer coefficient between CO_2 and the temperature sensor is 3,1 $Wm^{-2}K^{-1}$. The presented heat transfer coefficients were computed by the Nusselt number [5].

The static characteristics of the modeled flowmeter are depicted in Fig. 7.

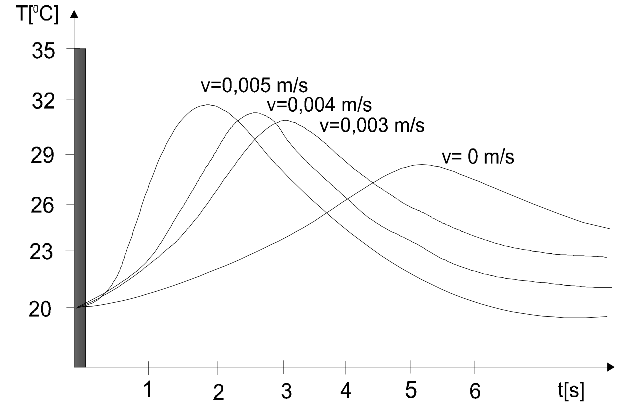

Fig. 6. Temperature profiles of agitated CO_2

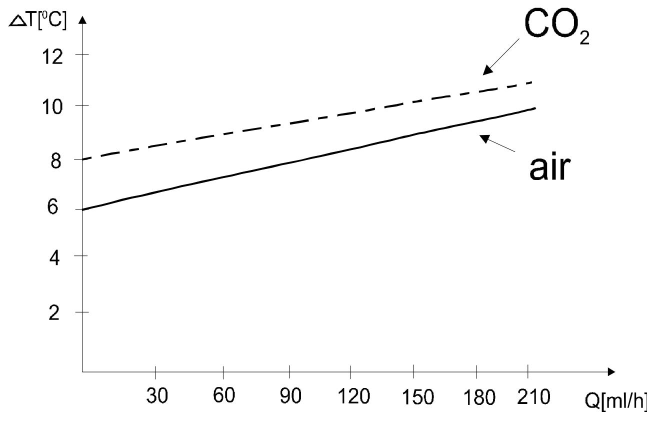

Fig. 7. Static characteristics of the modelated flowmeter

4. DESCRIPTION OF THE MEASUREMENT SYSTEM

The designed device has only one sensitive sensor (thermal resistor). The current pulses that activate the heater have a rectangular shape and their length are 20 *ms*. These excitation pulses are generated periodically with a period of generation 500 *ms.* The thermal resistor that scans temperature field downstream is connected to the Wheatstone bridge. In this circuit, the second temperature sensor is virtual and it is simulated by microcomputer. The simulation of the second temperature sensor allows raised sensitivity of the flow sensor [4]. The measurement principles of the flowmeter are based on the evaluation of the thermal waves propagation velocity.

The measurement system is shown in Fig. 8. The expansive thermal waves are registered by the thermal resistor R_T which is connected to a current source. The current thermal resistor supply is 50 μA. The excitation thermal waves are regulated by microcomputer (switch S), the heating circuit power is 0,028 *W*. A voltage drop on the thermal resistor is evaluated via the differential operational amplifier (DA_1). This measured voltage U_1 is brought to the A/D converter (measuring channel 1). Voltage U_1 is evaluated by the microcomputer ADuC812, the equivalent voltage is brought to the D/A converter and the differential operational amplifier (DA_2). This differential amplifier evaluates the same voltages, a drop voltage is amplified via amplifier (A). The thermal waves are recorded via thermal resistor, a voltage drop ΔU on the thermal resistor is measured by measuring channel 2. The circuit RS 232 is used for PC communication.

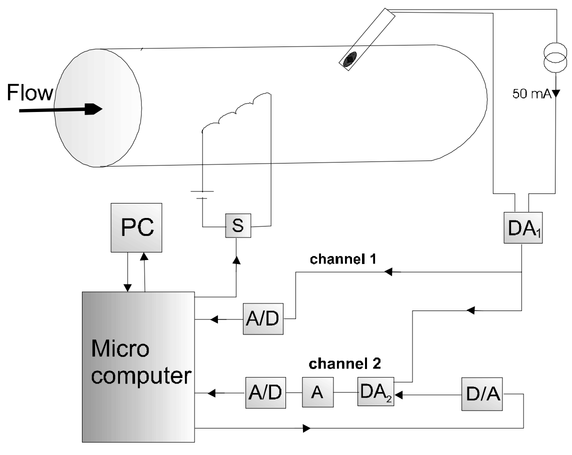

Fig. 8. The block diagram of the designed flowmeter

5. CONTROL PROGRAM

The control program philosophy is based on the algorithm shown in Fig. 9. The diagnostic test is executed at the beginning of the control program. If the electrical circuit is disturbed, an error is written subsequently. A differential voltage U_1 is measured before bracing of the heating circuit. Voltage drops are measured in very short time periods, a period of measuring is 5 *ms*.

6. EXPERIMENTAL VALIDATION OF MODELING RESULTS

The validation of the finite-element/analytical model of the designed flowmeter is to directly compare model generated results with experimental data.

For the calibration of the designed flowmeter was used the peristaltic pump. The designed flowmeter is calibrated for agitated air and CO_2. The static characteristics for different gases are depicted in Fig.10.

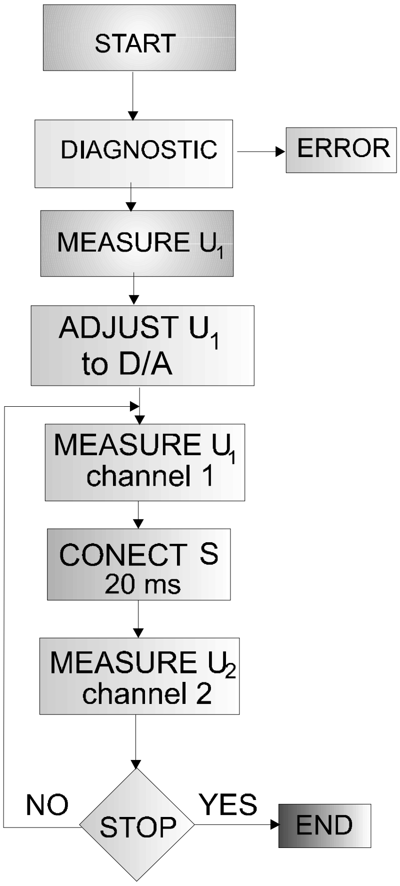

Fig. 9. Flow chart

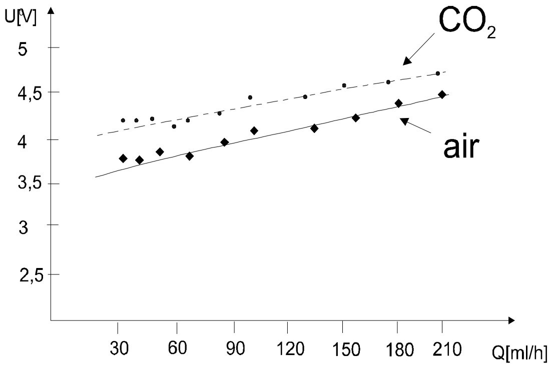

Fig.10. Static characteristic of the fowmeter

7. CONCLUSIONS

The validation of the finite-element/analytical model of the designed flowmeter was to directly compare model generated results with experimental data. For the calibration of the designed flowmeter was used the peristaltic pump. The designed flowmeter was used in the biochemical laboratory at the Department of Automatic Control of Tomas Bata University successfully.

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