Design and Simulation of MEMS Based Flow Sensor

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Abstract: In this paper, We have designed a Flow sensor based on calorimetric principle using COMSOL Multiphysics v5.0. The Sensor is capable of measuring the velocity from 0 to 1 m/s with a resolution of 0.001m/s. The system works with intrusive type mechanism in which the fluid flows across the sensor and interacts with heating element and sensing unit. Temperature gradient measured across the inlet and outlet sensing units used as a parameter to calculate the flow rate and velocity of the fluid profile by solving Navier Stokes Fluid Flow equation. Conjugate heat transfer module and fluid dynamics mesh are used as special cases for this study purpose.

Keywords: Thermal Heating, Calorimetric Principle, Temperature gradient, Temperature Distribution Contour Flow Measurement.

1.Introduction

Thermal sensor exhibits high conductivity at short span of time. Thermal sensors of extrusive type can be used for flow measurement which has a drawback of measuring the flow rate at less accuracy. Thermal sensor offers excellent Start-up response time and has low vibration Different types of Flow sensors include hot wire anemometers, Time-of-Flight Sensors, have the drawback of identifying the reverse flow. The proposed system eliminates that and it is capable of measuring the reverse flow. Thermal sensors are mostly used in automotives, gas flow identification and sensing, submarines, detecting the mass flow of inflammable/ low pressure gases. Whereas in fluid flow measurement system, thermal sensors are independent of pressure and temperature of the fluid. Since the thermal properties of the fluid varies with the pressure and temperature and it is considered to be small in most of the applications.

1.1Literature Review

The flow of the system can be determined by using acoustical [1], Doppler [2], Optical Time of Flight [3]. Doppler system measures the flow rate by transmitting an acoustic wave of frequency in which the wave hits any object and reflects back to the receiver. The frequency difference between the transmission and reception determines the velocity [1]. In this method, the Doppler colour Sensor is used. The flow rate can be measured by observing the fringe pattern of reflection obtained back from the particles. The flow profile layer with the velocity of 1000m/s can be measured in this system [2]. In this optical method, an optical probe consists both the transmitting and the receiving optics are embedded in a single optical probe. The Transmitting node and the receiving node are designed in such a way that it acts as both upstream and downstream nodes with a single flow marker on the top of the probe for the clarification. The time elapsed between the upstream and downstream of the ray optics (i.e the time elapsed between the transmissions of the rays to the reception of the optical rays) determines the flow rate [3].

2.Thermal Sensor

2.1Design

The Proposed system works on the calorimetric principle. The sensor is a MEMS based intrusive type thermal micro sensor that is directly in contact with the flow system, measures the flow rate. Forced convection makes the heater temperature to dissipate by the means of fluid flow. The temperatures are observed at the sensing elements. The temperature recorded at the outlet and inlet resulting temperature gradient which can be used as a parameter in the Navier stokes fluid flow equation. The other parameters are density (ρ), thermal conductivity (κ), Specific Heat Capacity (C_p) is also employed in the equation to calculate the velocity.

The optimum condition for the proposed system design is the distance between the sensing element and the heater. Distance between the heating and the sensing element plays a major part in defining the sensitivity of the Thermal Sensor. For the proposed model, the distance between the sensing elements data is taken from reference [12].

1) The distance between the upstream sensors to the heater is about **1004µm** which is approximately 1000µm and the downstream sensors to the heater element distance are **840µm** that is approximately 800µm.

2) The material should possess high thermal coefficient rate and the sensing element materials should have higher operating range, higher melting and boiling points.

3) For low flow velocities, the flow regime of Reynolds Number should be less than 500 i.e (Re<500).

Figure(2) shows the design of the proposed thermal sensor which has the dimensions of 9600µm x 9600µm and 500µm Thick outer boundary layer. The Heater, with the dimensions of 590µm x 590µm located at the centre. The Sensing Elements are (dimension of 300x800µm) placed at 90º perpendicular to the sensing element in all the four directions.

2.2Working Mechanism

The sensing elements are placed n the four navigational directions (N, S, W, E). If the flow is from north to south direction, the north sensing element measures the temperature of the fluid and it considered to be as inlet sensing element and after passing through the heater, fluid gets heated. The fluid temperature is increased and is measured in the south sensing element and it is considered to be as outlet sensing element, The boundary layer which is located at the north acts as a inlet and in south acts as a outlet since the flow is from north to south direction.

To minimize the heat dissipation between the sensing elements to the heater structure, placing the sensing elements as per the condition. Minute flows can be observed by providing thermal insulation to the sensing elements from the heater by the means of placing at a distance. Borosilicate glass is used as the substrate material which has the resistance to withstand the high pressure.

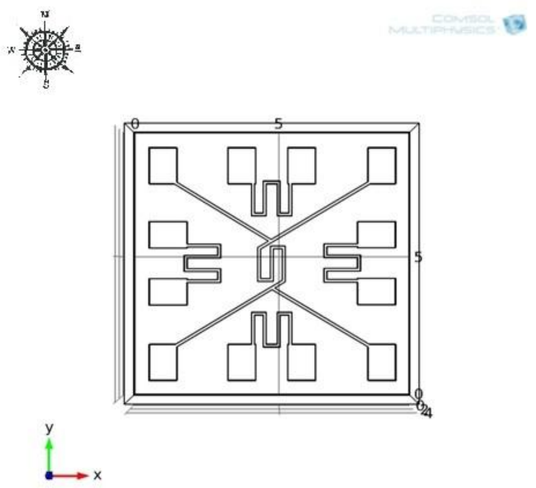

Figure 1. Cross Sectional View of Thermal Sensor

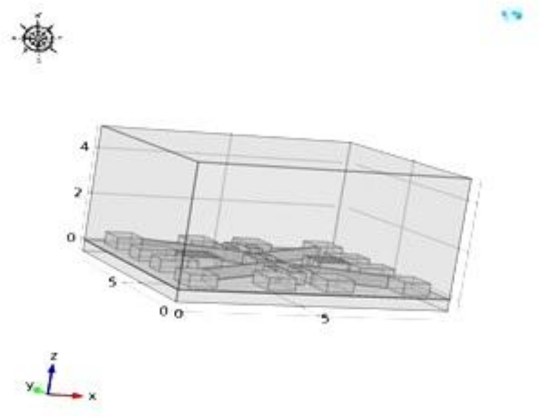

Figure 2. Thermal Sensor with Borosilicate Glass Substrate

Nickel is used as Heater material because of its thermal properties varies from -60ºC to +300ºC.

Platinum is used as sensing material which has high melting point (1772ºC) and high thermal coefficient ratio (0.00392 ohms/ºC). Borosilicate Glass offers low thermal expansion coefficient ($32.5*10^{-7}$/ºC). Water is used as fluid material in the fluid domain. The properties of water are changed to seawater salinity level and as per the standards [14], for 35g/kg of Salinity Thermal Conductivity, Specific Heat Capacity, Density of the water varies. These Parameters are calculated and the same is used for the analysis.

3.Design and Analysis

3.1Simulation

Analysis is performed using COMSOL Multiphysics V5.0 Conjugate Heat transfer module is used in the stationary mode of study.

In the Simulation, the flow is along the 90º angle perpendicular to the heater to analyze both forward and reverse mode of operation. The Average velocity of inlet was set to 0.001 to 1m/s with no viscous stress and zero Pressure with suppressing backflow. The outlet domain was set to zero atm. The domain side walls and top wall were set to no slip and slip conditions respectively. The heater, sensing elements and the borosilicate glass substrate were set to ambience temperature. Fluid Dynamics Mesh is set to the water domain to observe the minute flows with coarse element size.

4.Results and Discussions

A. The Forced Convection dissipates the heat from the heater to the downstream sensing elements by the means of Liquid Flow. Due to the heat dissipation, there is a temperature difference exists between the upstream and the downstream sensing elements. Figure(3) shows the flow direction and heat dissipation in the fluid domain for the velocity with the resolution of 0.001m/s.

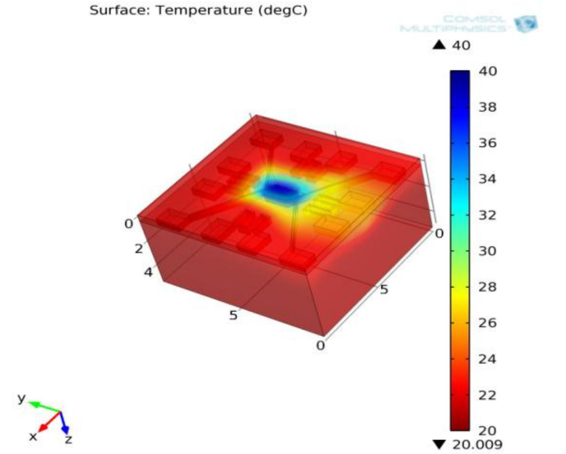

Figure 3. Flow Direction and Heat Dissipation

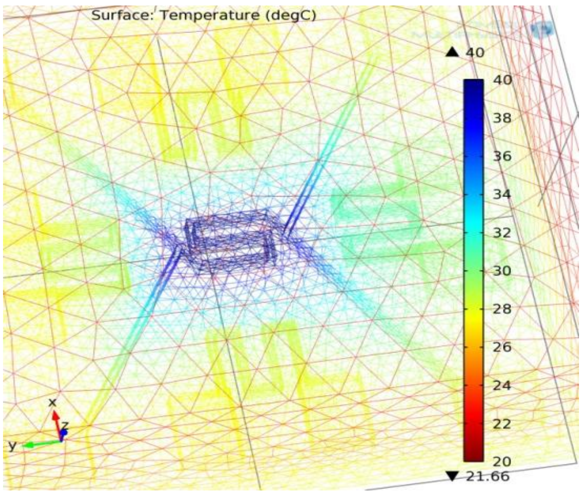

Figure 4. Wireframe view of heat dissipation

By varying the inlet velocity, temperature at the sensing element changes and decays as the velocity at the inlet is increased.

B. A Cut plot is plotted along the axis of the downstream sensing element at 90º angle and the variation in temperature along the axis is measured.

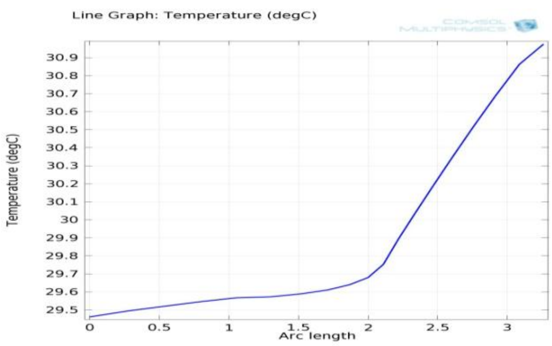

Figure 5. Model Graph of the Cut Plot along 90º axis at 0.001m/s. The maximum temperature is observed to be 30.974ºC and Minimum Temperature is 29.46ºC

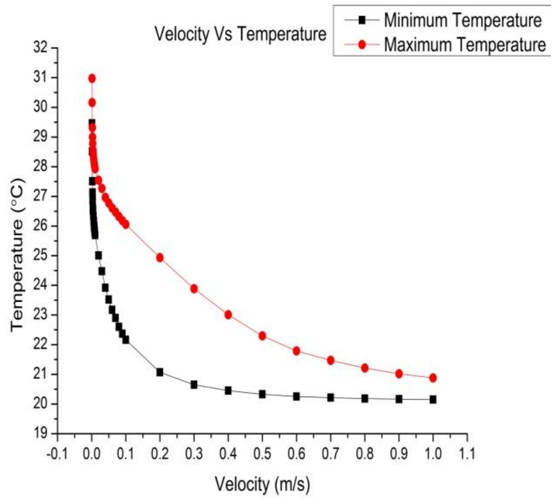

Figure 6. Overall Graph: Velocity Vs Temperature

From the overall Graph, the temperature decays exponentially as the inlet velocity increases and the system is able to measure the velocity from 0m/s to 1m/s.

5.Conclusion

Design of Thermal sensor for flow measurements is done using COMSOL multiphysics and analysis has been carried out for various flow ranges at 90º flow angle. The sensor is capable of measuring the velocity from 0m/s to 1m/s and has resolution of 0.001m/s with the exponential decay of temperature.

6.References

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