Experimentation and Analysis of thermal sensors for flow measurement

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Abstract*—A simple thermal sensor is used, this sensor in-cased within a polymer housing insulated against external temperature and electrical interferences. The sensor enclosed in the house is a glass-encapsulated & heat-resistive negative temperature coefficient (NTC) self-heating thermistor. With the focus being the development of a simple yet effective water flow meter the need for a secondary sensor for the ambient temperature of water was presumed redundant. Multiple circuit layouts tested and experimentation using various sensors holding into account the material of its construction, and housing materials. The conclusion of said experiments led to prototyping a model for maximum sensitivity. A T-joint like polymer tube used for the housing with appropriate insulation. Graphs for the setup under various conditions including fluid velocity derived. Using for-mentioned setup a calibration curve was modelled.

Keywords: Thermal, NTC, sensor, flowrate.

I. INTRODUCTION

Sensors are essential for a consistent and accurate result in a system. The ability for detection of wanted and unwanted changes to a system intrinsically increases efficiency. Flow meters are sensors substantially researched upon, with the use of thermal sensors four methods are employed: thermal time-of-flight, heat loss, thermo transfer principle, micro thermo transfer principle. The heat loss method consists of a single electrically heated element. Heat loss method contains two modes of operation: constant power and constant temperature; the simplest being constant power where power is constant and temperature of the element is measured [1].

The heat loss methodology allows for development of a simple flow meter system with effective calibration. Using the constant temperature in heat loss method, holding the temperature of the element constant and measuring the power. The power being visual representation in the form of voltage or current [2].

Self-heated thermistor flowmeters, based on the flow-related cooling principle, have for many years been used for measuring large gas and liquid flows, such as coal gas, fuel and water, and some successful results on thermistor flowmeters have been reported.

The idea for this work is to design a small, obstruction free, and simple to manufacture flow meter. Implementing the constant temperature method, the controlling the heat of the electrically heated element in-order to analyse and derive results in a static regime.

II. THERMAL SENSOR

A. Selection of ideal heating element

The implementation for a thermal water sensor eliminates the problems cause due to factors such as clogging of pipes due to presence of flow meter hardware such as turbines or shredder bars in mechanical flow meters. In accordance with the set guidelines established using the final objective the heat loss methodology is selected as the ideal strategy to pursue it allows for the development of a simple and obstruction free flow meter system with effective calibration. Using constant temperature in the heat loss method, holding the temperature of the element constant and measuring the power. The power being visual representation in the form of voltage or current. The heating element needs to withstand sudden changes in temperature without breaking down or behaving unresponsive. Furthermore, the heating element with use under such conditions must retain its sensitivity and physical shape and structure ensuring no deformation cause due to temperature changes within the operation range. The heating element is highly resistive in nature to ensure heat build up. Consideration for a coating on the heating element for protection against corrosion more importantly even distribution of heat. A ceramic or glass-based coat is favorable and fulfils the requirements. Ceramic and glass hold and distribute large amounts of heat evenly and without deforming and causing fractures. Metal and plastic coats are not viable, as plastic is inherently a bad conductor of heat and will throttle heat conduction, metal on the contrary transmits heat rapidly and unevenly. The size of the NTC thermistor is also an important factor, a small bead shaped component is preferred over standard larger discs with contact surface diameter larger than 6mm. This size and larger can cause variations in results from different tests.

Model No.	Resistance (Rn) 25 °C	Tolerance	Thermal dissipation factor	Thermal time constant	Response time	Coating material
B57550G1103F005	10kΩ	±1%	7.5 mW/°C	7sec	< 3 sec	glass
ND03S00224J	220kΩ	±3%	5 mW/°C	10 sec	< 3 sec	epoxy-phenolic resin
ND03J00102J	1kΩ	±3%	5 mW/°C	10 sec	< 3 sec	epoxy-phenolic resin

Table 1: Theoretical parameters of the NTC thermistors [4]

B. *System Setup*

Tests were carried out using all three NTC thermistors. The system was setup to insure no external electrical or thermal interferences. The PVC T-joint with the sensor fixed in is shown in Fig. 1. The insulation material used is Teflon tape and heat resistant plastic film. The insulation material is symmetrically wound in two layers around each sensor. The inlet and outlet pipes to the PVC T-joint are kept as short as possible to avoid any noise (thermal) interference. A calibrated flow-meter is connected downstream to avoid any unforeseen problems with water flow in-turn affecting the reading from the NTC thermistor for accurate readings. The flow-meter used is a small factory calibrated turbine flow-meter the YF-S201 Hall Effect water flow meter, with an output flow rate reading between the range of 0-30 liters per min. A diaphragm booster pump is used with an upper flow rate limit of 1.6 liters per min. The pipes used are 1/4 inch aeroflex pipes compatible with all the components of the water loop.

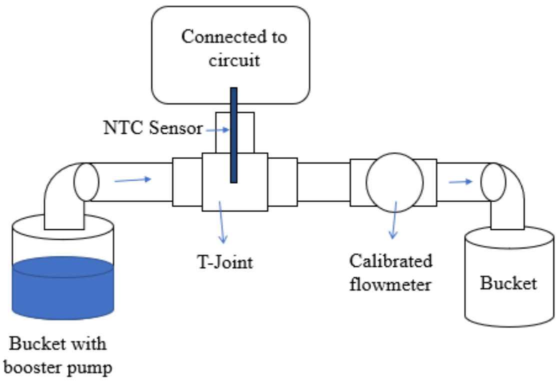

Figure 1: Set up Diagram

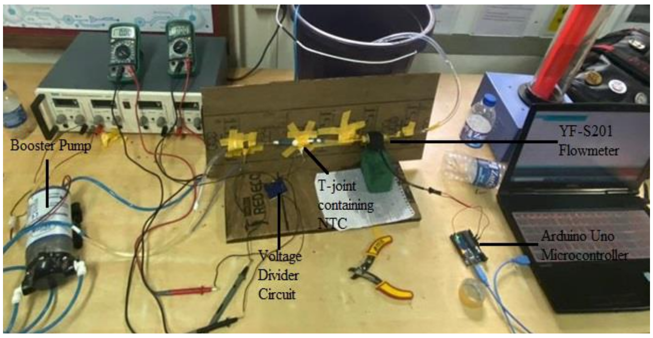

Figure 2: Hardware setup

The circuit used to test the NTC thermistors is a Voltage divider circuit. The supply voltage for the circuit is set to 15 Volts DC. Live data capture was setup for the calibrated flow meter as well as the NTC Circuit. The output of this circuit is connected to the input of a voltage sensor circuit as shown in Fig. 4. The output of the circuit is connected to an analog input pin on an Arduino UNO. The live data capture software used with the Arduino Software (IDE) and stores for later review. The Arduino UNO and live data capture were tested and were accurate and sensitive for detecting miniscule differences in voltage readings.

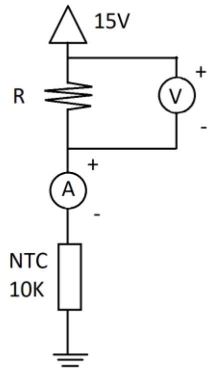

Figure 3: Circuit diagram for the voltage Divider test with 15V power supply

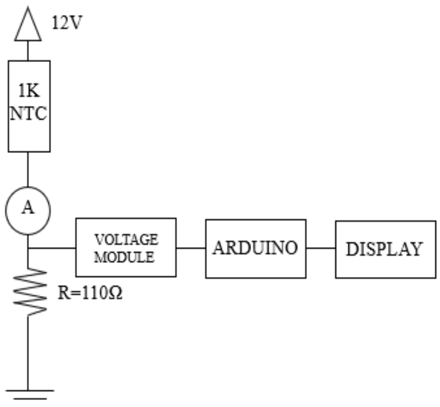

Figure 4: Voltage Divider with live capture setup

The setup of the equipment was carried out with an intention to maintain noise to a minimum.

III. Experimentation

A. Calibration

1. YF-S201 Hall Effect Water Flow Meter is a factory calibrated with a tolerance of ±10% (Used for initial proof of concept). The calibration of the flow-meter was further verified with a simple manual test using pre-measured volume of water and a stop watch. Orienting the flow meter vertically with the inlet facing up and outlet down. Releasing water in the flow meters inlet attached to a pipe and funnel, water was allowed to flow without any applied pressure. Steady readings acquired from the test verified the flow-meter is calibrated.

2. Diaphragm Booster Pump is used in the experimentation setup of 24 VDC rating. At the maximum voltage of 24 volt DC in open condition the booster pump provides a flow rate of 1600 millilitres per minute. The pump voltage can be varied to achieve different flow rates. The minimum operation voltage for the booster pump was found around 6-8 volts DC. And furthermore the YF-S201 flow meter was used to measure the maximum flow rate along with varying the voltage to achieve different flow rates. The tests were successful, the booster pump was calibrated with a tolerance of ±5-10 millilitres.

3. Interfacing of the YF-S201 flow meter, the system circuit is done with the Arduino UNO. The YF-S201 flow meter the flow rate was calculated in millilitres per minute using the formula:
   Flow Rate = (pulse frequency * 60)* (50/3)/ Calibration Factor)
   Where, Flow Rate is the flow rate in ml/min,
   Pulse frequency is the pulse reading from the sensor
   Calibration Factor is a predetermined value assigned to each specific flow meter. For the YF-S201 flow meter the calibration factor is 4.5.

B. Testing

1. Selection of an ideal resistor value

- It is highly important to test the ideal value of Resistance to ensure maximum flow of current across the NTC ensuring less resistance to the flow of water to give a highly accurate flow rate for a wider range of Voltage supply without burning the NTC.
- To do so it is important to find the breaking point of the NTC. 1K NTC was connected to a variable power supply with an ammeter in series. Voltage was slowly increased until the NTC burned out and corresponding current reading was recorded. **:** NTC burned out when a supply of 11V was given which passed a current of 172mA through the NTC. In order to meet the 50% heating point, a current of ~90mA must be reached. This was obtained with a 110Ω resistor in series and a supply of 12V.

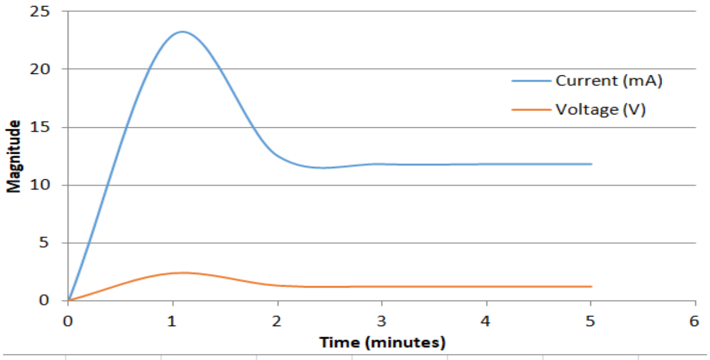

Figure 5: Testing of 110Ω resistor in the voltage divider circuit with a 12V power supply with change in pump voltage with a diffference of 5V every 1 minute interval

2. Testing of NTC B57550G1103F005 (10KΩ)

- The complete setup ready and calibrated as per requirements, experiments were conducted with the NTC thermistor using the circuit shown below.

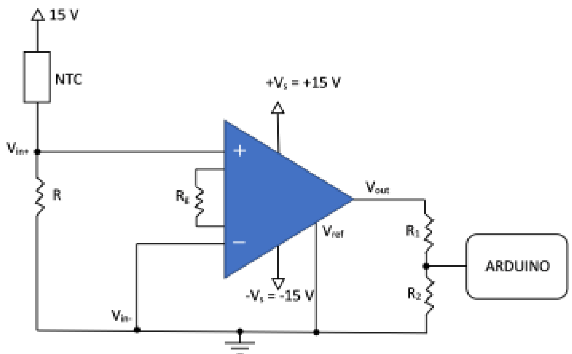

Figure 6: Circuit for testing of NTC

R (kΩ)	Voltage (V)	Current(μA)	Status
1	0.36	420-462	Motor off for about 10mins
1	0.36	380	Motor on for about 2mins at 20V DC supply
10	2.06	199-211	Motor off for about 10mins
10	2.05	202	Motor on for about 2mins at 20V DC supply
100	6.21	63.6-67.2	Motor off for about 10mins
100	6.25	65	Motor on for about 2mins at 20V DC supply

Table 2: Experimental status of a 10KΩ NTC

3. Testing of NTC ND03S00224J (220KΩ)

- The NTC ND03S00224J was inserted into the Copper block and tested in a voltage divider configuration supplied by 10V. A resistor R was placed in series with the NTC and the voltage drop across R was measured, as shown.

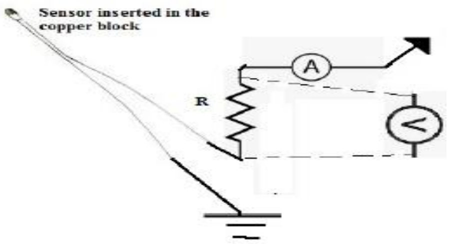

Fig 7: Circuit for testing of the flow sensing through copper block with 10 V supply and R in series

Temperature (T °C)	R (kΩ)	Voltage (V)	Current (μA)	Status
36.8	1	0.06	64.8	NTC after 3mins of flow of motor with DC supply of 20 V
39.5	1	0.02	32.5	NTC after 6mins of flow of motor with DC supply of 20V
37	1	0.02	32.5	NTC after flow of motor with DC supply of 20V, NTC was not kept in air initially but continuously on
37	1	0.03	32.7	NTC after flow of motor with dc supply of 15V, NTC was not kept in air initially but continuously on

Table 3: Experimental Results of the NTC ND03S00224J for Voltage divider

4. Test with NTC B57550G1103F005 immersed in water connected in voltage divider circuit

- The B57550G1103F005 - Thermistor, NTC, 10 kΩ Test was carried out in a voltage divider circuit which is fed to the Instrumentation Amplifier AD8429 to avoid noise interreference.
- The output voltage readings from the AD8429 is given to the Arduino, and captured every second.
- NTC B57550G1103F005 is subjected to air for 5 minutes initially . Thereafter, the pump is turned on to 20V, providing a flow of 14-17 ml/sec for the next 5 minutes. The output voltage VOUT is measured at pin 7 of the AD8429.

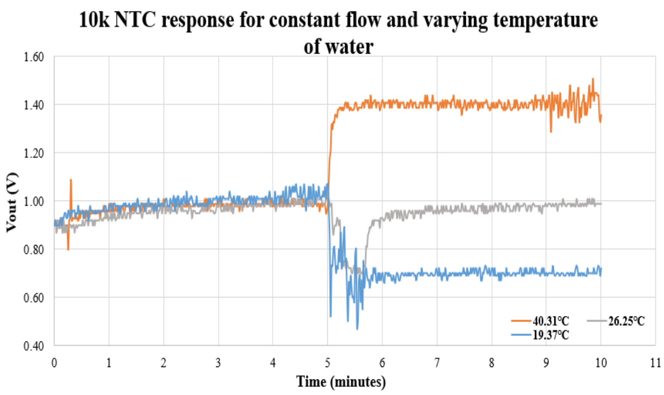

Fig 8: 10K NTC Response graph for different temperatures of water at 40.31°C, 26.25°C and 19.37°C at constant 20V supply pump voltage

5. Test with NTC ND03J00102J

- Due to erratic responses and low operating voltage ranges despite use of an amplifier, the NTC ND03J00102J was selected for its better suited operation. It was also decided to use a fixed resistor in the voltage divide circuit and to obtain the above design, the burning point of the RTD had to be determined.

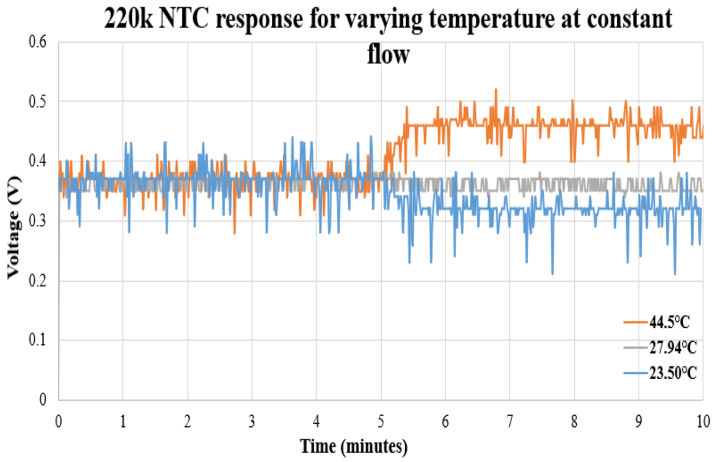

Figure 9: 220k NTC Response graph for different temperatures of water at 44.5°C, 27.94°C and 23.50°C at constant 20V supply pump voltage

6. Test with NTC ND03J00102J immersed in water connected in voltage divider circuit

- The ND03J00102J - Thermistor, NTC, 1kΩ was connected in a voltage divider circuit with supply of 12V and 110Ω resistor in series.
- The instrumentation amplifier AD8429 was not used in this step due to irregular gain.

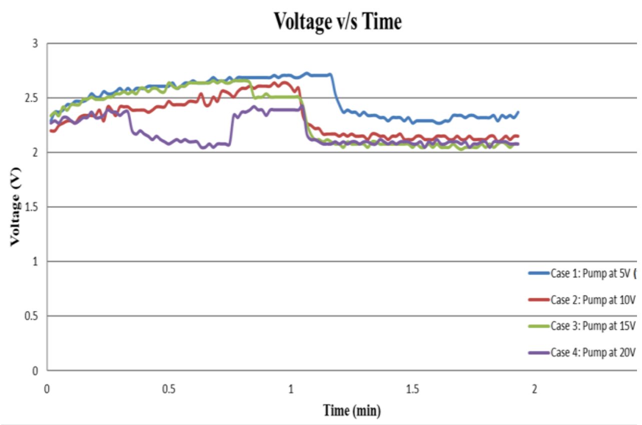

Figure 10: 1k NTC response for different flows at constant temperature for Pump voltages at 5V, 10V, 15V and 20V

7. RESULTS OF TESTING OF NTC ND03J00102J IMMERSED IN WATER CONNECTED IN VOLTAGE DIVIDER CIRCUIT WITH VARYING FLOWRATE

- The NTC sensor is heated for 5 minutes where in the voltage measured across the 110Ω resistor in series with the NTC increases from 1.86V to 2.69V. After this point, the pump is switched on at 7V for a duration of 1 minute, which induces a flow of water of 3.5 ml/min. This brings the measured voltage down to 1.73V.
- Thereafter, the voltage supplied to the pump is increased by 1V every 1 minute, and the corresponding voltage readings noted. This is done until a final point of 18V is supplied to the pump, with a voltage reading of 1.42V.

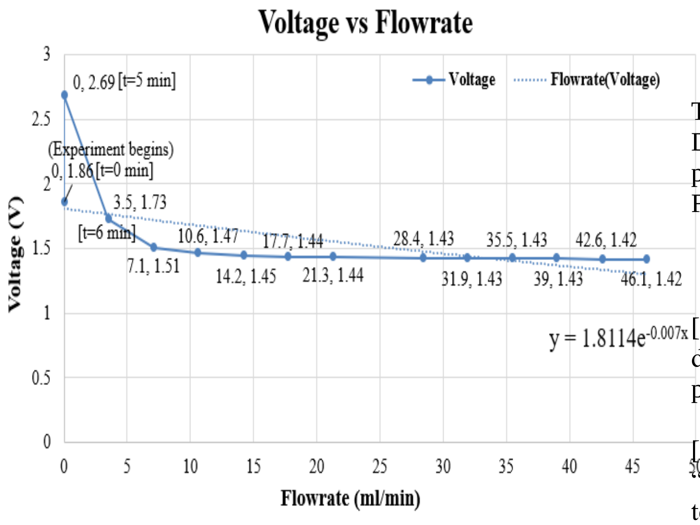

Figure 11: Voltage vs flowrate for a 1K NTC

IV. CONCLUSION

Most Flowmeters used commercially are mechanically operated using moving parts like the turbine rotation type which possesses the disadvantage of clogging when water is dirty or contain ample particles. To eliminate the use of such water flowmeter we worked on designing a Thermal flowmeter which is economically cheaper and efficient to measure flow rates inside the pipe ensuring laminar flow and to calculate and check for any theft or leakage of water in the pipe. The flowmeter designed works on the basic self-heating principle of thermistors in which the resistance changes with the change in heat generated due to the flow of water and the temperature of water.

Through the above tests it was observed and thus determined that the lower resistance NTC, the NTC ND03J00102J (1kW) was the most suitable to obtain faster response with little to no noise. However, due to the instantaneous saturation at higher flowrates, an operational amplifier will be required, wherein the voltage swing will be calibrated to lie between the operating voltages observed from the graph. This in turn, will provide a higher number of data points within the operational range of voltages.
The relation can also be derived for various temperatures of water thus being useful for flowrate measurement in different ambient temperatures

Accurate flow measurement is crucial in these instances, and so precise water meter calibration is vital. The thermal flowmeter is capable of measuring a liquid flow as small as tenths of a milli liter per minute with long-term stability and fast dynamic response.

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