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An Overview of Thermal Mass Flowmeters Applicability in Oil and Gas Industry

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Abstract

Measuring and modeling flow has played a central role in predicting its behavior and its effects on the surroundings. Flow measurement is the basis of trade between producers, transporters, process plants, state and public marketers. To improve transactional operation, thermal flowmeters could provide direct mass flow measurement of gases and vapors over a wide range of process conditions without the need for density corrections based on pressure and temperature.
The flow meters are classified according to the domain in which they are used and their operating principle. The goal of this work is to provide an overview of using thermal flow meter in hydrocarbons industries. The applicability of thermal flow meters is discussed by a simulation using one-dimensional mathematical model of thermal flow sensor.

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Keywords: flow, hot wire anemometer, dispersion flowmeter, thermal flowmeter, CTMF, ITMF.

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1. Introduction

New devices for gas metering such vortex, Coriolis, ultrasonic and thermal mass flowmeters have been emerged. Among them, thermal mass flow meters are very promising, because they present many useful characteristics such as the absence of moving parts, direct mass measurement and digital output [1].

A thermal mass flowmeter measures either the local mass velocity of gas flow gas or the total mass flow rate through a channel or pipe [2].

Basically, the thermal mass flow meters are based on the relationship between the output voltage of sensors and heat transfer rate produced by the sensor itself and the gas flow in the pipe [1, 3]. In fact, the output voltage is influenced by the gas composition through its thermos-physical properties such as thermal conductivity, diffusivity, density, specific heat and dynamic viscosity [1].

The fluid mass flow rate is a measure quantity very important in the control or monitoring of most industrial process. A thermal anemometer is used to measure the mass velocity at a point or small area of fluid flow [4].

There are broadly two concepts of thermal flowmeters available for fluid mass flow measurement: thermal dispersion mass flow meters (ITMF) and capillary thermal mass flow (CTMF). The American Society of Mechanical Engineers (ASME) has published separate standers for each one [3, 5, 6]. Both types measure the flow rate using heat transfer from a heated surface to fluid flow [7].

Thermal dispersion mass flow meters are available as both insertion probe and in-line type. These flowmeters measure the fluid flow mass flowrate through a closed conduit [8]. The fluid flows over a surface of a heated velocity sensor immersed in the flow [3, 7].

Generally, the thermal anemometer is referred to an immiscible thermal mass flow meter because it is immersed in a flow stream or channel in contrast to other thermal mass flow meter systems [4]. Its performance is affected by the internal structure of the thermal flow sensor, the installation conditions and the process conditions [9].

The present work deals with dispersion thermal mass flow meters, their theoretical and practical aspects are discussed.

2. Dispersion thermal flowmeter theory

Dispersion Thermal mass flowmeter are devices in which the associated physical quantity measured by them is the mass flow rate measured by the means of the heat convected from a heated surface to surrounding fluid from an electrically heated sensing element or probe [6, 7, 10]. In response to the large acceptance of thermal dispersion mass flow meters for industrial applications, the American Society of Mechanical Engineers (ASME) has published a new national standard for this kind of flowmeters [11, 12]

The figure 1 illustrates the complete transduction process for thermal flow meter with a voltage output signal. As, it is shown, two transduction processes take place, first, the mechanical signal (mass flow) is converted to a thermal signal (heat transfer), the flow induces a temperature difference which is converted into an electrical output signal (current or voltage). The principle of the gas mass-flow measurement is based on the fact that the output voltage of the sensor element is related to the rate of heat transfer deducted between the sensor and the fluid [13, 14].

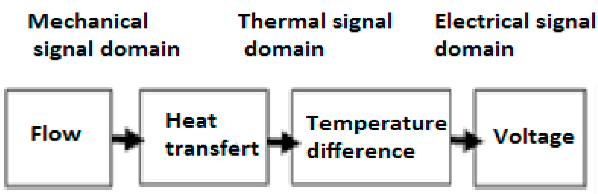

Fig.1. The three signal domains and the signal transfer process of a thermal flow sensor [8].

The composition and the type of the fluid can affect the intensity of the convective heat transfer from the thermal flow sensor to the fluid [7, 13, 15]. The accomplishment of thermal mass flowmeters are attributed to L.V. King [16] who in 1914, published his famous King’s Law revealing how a heated wire immersed in a fluid flow measure locally the mass velocity in the flow. King called his instrument “hot-wire anemometer” [17].

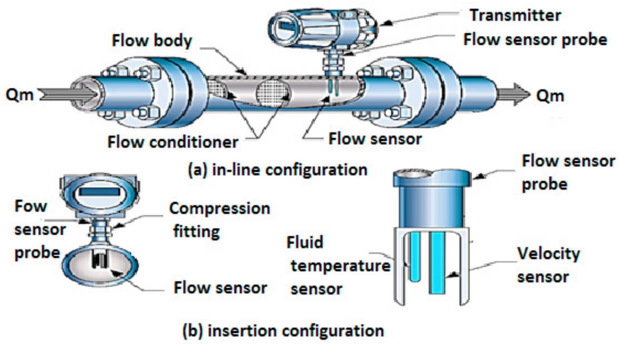

Fig.2. The two configurations of dispersion thermal mass flow meter [8].

The two configurations of dispersion thermal mass flow meter (Insertion meter version for the insertion probe of the meter and In-line flow tube) and its major components are shown in Fig.2. The two configurations have the same major components [17]. The operating principles, construction and applications of industrial thermal dispersion mass flow meters were presented by Olin [2, 5, 7, 8,18]. The structure of the thermal flow sensor, the installation conditions and the process conditions can affect the performance of thermal dispersion mass flow meters.

Baker and Gimson in [19] investigated the sensor structure, the effects of the sensor insertion length and the construction details at the location where the sensor is inserted into the flow pipe.

Industrial thermal mass flowmeters evolved from hot-wire anemometers which are used to measure the local velocity is one of excellent instruments, necessary in flow metrology [20].

A thermal anemometer use sensors to measure total heat loss from some heating elements cooled by the fluid [21].

There are two different principal operating modes for thermal anemometer: constant temperature, and constant current [21]. In our work, we are interested by the constant temperature mode.

3. Theoretical aspect and simulation

Considering a wire that is immersed in a fluid flow, the electrical power input is equal to the power lost to convective heat transfer:

$$w = Q = {I_w}^2 \mathrm{R}_w = h(v).\mathrm{A}_s.(\mathrm{T}_w - T_f) \tag{1}$$

W is the electrical power input, ***Q***, heat converted away from the heated section by the fluid, ***I*** is the input current, $\boldsymbol{R_w}$ the resistance of the wire, $\boldsymbol{T_w}$ and $\boldsymbol{T_f}$ are the temperatures of the wire and fluid respectively, As is wire surface area, and ***h*** is the heat transfer coefficient of the wire [6].

To obtain the heat transfer coefficient ***h(v)***, we employed the Nusselt number:

$$Nu = h(v).d/k_f \tag{2}$$

Where ***d***, is the diameter of the wire, $\boldsymbol{k_f}$ it's the thermal conductivity. Replacing ***h(v)*** by ***Nu.Kf/d*** in equation (1), give:

$${I_w}^2 \mathrm{R}_w = (\mathrm{T}_w - T_f)\, \pi l k_f Nu \tag{3}$$

King's law for general hot wire probes is:

$$Nu = a + b\sqrt{Re}^{n} \quad (4)$$

Where ***Re*** is the Reynolds number, ***a*** and ***b*** are generally dependent on the sensor geometry and the Reynolds number, ***n***, take the value 0.5 for the King Law.

The wire resistance $\boldsymbol{R_w}$ is also a function of temperature:

$$R_w = R_0(1 + \alpha(T_w - T_0)) \quad (5)$$

Replacing $(T_w\text{-}T_0)$ by $(R_w\text{-}R_0)/\alpha R_0$ in equation 1 give:

$$\frac{I_w{}^2 R_w}{(R_w - R_0)} = A + B\sqrt{v} \quad (6)$$

v is the velocity of the fluid, ***A*** and ***B*** are constants depending on geometry of the wire.

The appropriate equation to obtain the flow rate is:

$$q_h = k_g(1 + Kq_m{}^{0.5}\Delta T) \quad (7)$$

Where k_g is the thermal conductivity of the fluid; ***K*** a constant including the area of the duct in which the sensor is inserted, the gas and the heat transfer constants; q_m the mass flow rate; q_h the heat transfer; ΔT the temperature difference between heated and unheated sensors [2, 19].

To validate this theoretical aspect, a simulation work was done with Matlab/Simulink software using industrial data from the gas production field known Gas Tin Fouye Tabankort (**GTFT**) located in the south-east of Algeria.

The natural gas characteristic has the following specifications:

- Humidity: max 50 ppmv ;
- Pressure: 71 bar
- Temperature: 60 ° C [22].

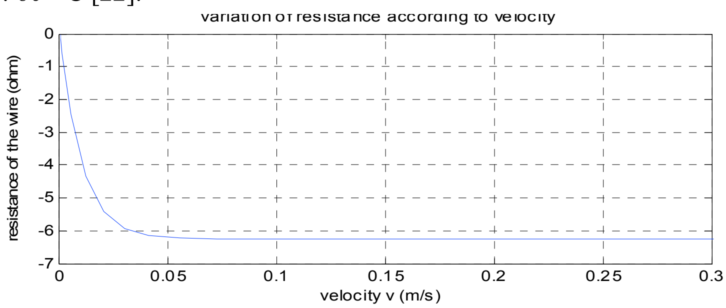

Fig.3. Influence of the velocity v of the fluid on the resistance of the wire.

The flow extracts heat from the wire, which therefore tends to reduce its temperature resistance, the curve declines versus time, and negative (-) values indicate that there is a cooling of the sensor caused by the fluid velocity.

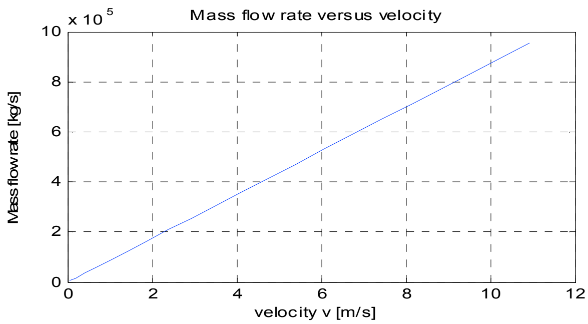

Fig.4. Simulation result of mass flow rate according to velocity v of the fluid.

In figure 4, the mass flow rate increases with the raise of fluid flow velocity input. It has a linear relationship with the speed.

4. Conclusion

Thermal mass flowmeters offer a significant potential in flow rate metering. They are used for precise measurements of fluid (gaseous) flows in many different application areas. Their main advantage is the direct mass flow measurement without the need for additional density corrections as volumetric flow meters, differential pressure, turbine or ultrasonic flow meters.

A description of dispersion thermal mass flowmeters was presented and simulation results were illustrated to show the way how is the variation of velocity according to the voltage and mass flow rate versus the velocity of fluid.

It's still work to be done to investigate the use of this flowmeters in the fields of transactional gas metering process.

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