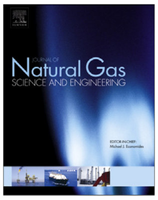
Journal of Natural Gas Science and Engineering 32 (2016) 556–565

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse



Experimental evaluation of thermal mass smart meters influence factors

G. Ficco [a, *], L. Celenza [a], M. Dell'Isola [a], A. Frattolillo [b], P. Vigo [a]

[a] DICEM, Department of Civil and Mechanical Engineering University of Cassino and Southern Lazio, Via G. Di Biasio 43, 03043, Cassino, Italy
[b] DICAAR, Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, 09123, Cagliari, Italy

ARTICLE INFO

Article history:
Received 14 January 2016
Received in revised form
11 March 2016
Accepted 8 April 2016
Available online 11 April 2016

Keywords:
Smart meter
Thermal mass
Gas quality
Capillary flow meter
Insertion flow meter
MEMS

ABSTRACT

New static thermal mass principle is a very promising technology for gas flow-metering since it offers very significant potential such as digital output, absence of moving parts, direct mass measurement. Unfortunately, gas quality is expected to affect metrological performance of thermal mass flow-meters (TMFs), as far as flow disturbances and such conditions often occur in modern networks. In this paper the authors investigate the sensitivity of TMFs with natural gas quality changes and different flow disturbances. To this end, a metrological test campaign has been carried out through specifically designed laboratory test bench and facilities. The results of the tests with gas quality changes show the capillary TMFs are able to recognize the natural gas flowing strictly included in the EN 437 group H and to consequently apply specific correction factors. On the other hand, capillary TMFs have been found sensitive to high contents of CO_2 and N_2, like in biogas and natural gases at the borders of group H. Finally, flow disturbances tests show the accuracy of full bore insertion in line TMFs is affected by the interaction between sensor and piping both for double out-of plane bend and single 90° bend disturbances.

1. Introduction

The spreading of smart metering technologies is expected to effectively integrate different energy home measuring and control devices and to promote energy efficiency through its potential impact on the final-user behaviour. Smart meters, in fact, provide end-users clear and complete information about their energy consumption data over time and allow to perform energy diagnosis of buildings with real actual data. Therefore, a better knowledge of energy flows (by integrating data of different energy sources) should help also to quantify the return on investment of buildings refurbishments for energy efficiency, to reduce energy waste and to achieve the challenging energy efficiency objectives of recent EU directives (European Parliament, 2012). Furthermore, smart meters are indispensable tools for the development of smart homes, smart grids and smart cities (Celenza et al., 2015; Betta et al., 2015) and to this end wide roll-out procedures and incentives to install new smart meters in natural gas distribution networks have been adopted by National Authorities.

In such scenario, innovative static metering principles for gas metering like ultrasonic and thermal mass have been developed. Among new static gas meters, TMFs in distribution networks are very promising since they present many useful characteristics (such as digital output, absence of moving parts, direct mass measurement). To this end, some MID (European Parliament, 2004) approved TMFs are already available specifically for domestic purposes. Unfortunately, due to their recent availability on the market and to their limited diffusion, their reliability in modern city networks characterized by sudden gas quality changes, presence of flow disturbances and pulsating flows, presence of dust and contaminants in the flow, zero flow conditions and/or minimum flow-rates still has to be fully demonstrated. In fact, conventional diaphragm and new static ultrasonic meters are known to be reliable in natural gas distribution networks since they have been deeply studied (Ficco, 2014; Dell'Isola and Cannizzo, 1997). On the other hand, field analysis concerning real metrological and operational performance of thermal mass flow-meters in service (in particular in networks in which gas composition is expected to unpredictably vary, like in Italy) are still not available in scientific literature. In

---

* Corresponding author. Dipartimento di Ingegneria Civile e Meccanica (DICEM), University of Cassino and Southern Lazio, via G.Di Biasio, 43, 03013, Cassino, FR, Italy.

E-mail address: ficco@unicas.it (G. Ficco).

http://dx.doi.org/10.1016/j.jngse.2016.04.025
1875-5100/

fact, nowadays politic and economic scenarios rapidly change and often cause natural gas composition to widely vary in networks as a function of the origin and of the production processes (e.g. Lybian, Algerian, Russian, Northern Europe, National Production, Regasification Plants). This happens particularly in Italy due to the structure of the transmission network with natural gas entering the network from different countries through 5 entry points and 3 LNG plants (Arpino et al., 2014; Ficco et al., 2015; Buonanno et al., 1998). Furthermore, in the near future the injection of Biogas and Biomethane (i.e. gases with high CO_2 content) in networks will become a real possibility (UNI, 2014b) with consequent gas quality issues especially at local level near to the injection plants. As a consequence, TMFs should be potentially affected by not negligible errors in service where, as for example, also flow disturbances often occur.

TMFs are based on the relationship between the output voltage of a sensor and the rate of heat transfer between the sensor itself and the gas flowing in the pipe (de Matos and da Silva Ferreira, 2010). Thus, integrating over time and considering thermophysical properties of the gas, the volume is measured also for domestic applications and billing. Unfortunately, the above mentioned relationship is only the main effect and some other metrological issues are present. In fact, sensor's output is expected to be influenced also by the gas composition through its thermophysical properties (e.g. thermal conductivity, diffusivity, density, specific heat and dynamic viscosity). Therefore, thermal mass flow meters are mainly appropriate for those applications in which the thermal properties of fluid are constant (Farzaneh-Gord et al., 2015) and, to this aim, novel measurement methods for identifying the type of gas in a thermal dispersion mass flow meter have been recently proposed (Rupnik et al., 2014).

Nowadays, only traditional diaphragm gas meters and new ultrasonic are fully described in harmonized technical standards (EN, 2006, 2007) which are used in MID conformity assessment protocols. On the contrary, a specific standard for TMFs type approval is still lacking although some technical groups are working on this task at national (UNI, 2014a) and international level. In fact, ISO 14511 (ISO, 2001) international standard is available only for specification, testing, inspection, installation, operation and calibration of TMFs.

In this paper the authors discuss the results of an experimental campaign conducted on two types of static TMFs: i) capillary TMF, ii) full bore in line insertion TMF. Tests were aimed to assess metrological performance at different flow-rates of: i) capillary TMFs when the gas composition changes and ii) full bore in line insertion TMFs in presence of flow disturbances.

2. Theory

As above described, the output voltage of TMFs, as the main effect, is directly proportional to the gas mass-flow rate. Furthermore, high sensitivity and fast response time are reached thanks to the small size of the sensors. These latter features are particularly relevant in smart metering applications.

According to ISO 14511:2011 (ISO, 2001), TMFs fall into two basic design categories, capillary and full bore insertion and/or in line.

2.1. Capillary thermal mass flowmeter

In a capillary TMF the gas flow is divided into two parts: i) a main flow and ii) a by-pass flow. A defined portion of the total flow is diverted in a capillary pipe specifically designed and provided with a micro electro-mechanical systems (MEMS) sensor able to measure the mass flow-rate. In Fig. 1 the scheme of a capillary TMF is presented. One heater is located in the middle of two temperature sensors and a precision power supply gives constant heat to the flow. At zero flow, the upstream temperature T_1 is equal to the downstream one T_2 and a thermal symmetry is observed. The temperature difference T_2-T_1 is then zeroed. On the other hand, when gas flow-rate increases, heat is carried and transmitted to the flow in a not symmetric way. Thus, T_2 increases and becomes higher than T_1. The amount of the temperature difference is then proportional to the gas flow-rate in the capillary according to the energy conservation law in Equations (1) and (2):

$$P = \left[\dot{m}\, c_p\, \frac{T_2 - T_1}{f}\right] + L \tag{1}$$

$$\dot{m} = \frac{(P - L)\, f}{c_p\, (T_2 - T_1)} \tag{2}$$

where: $\dot{m}$ is the mass flow-rate (kg s^{-1}), c_p is the specific heat (J kg^{-1} K^{-1}), T_2-T_1 is the temperature difference (*K*), *P* is the constant input power (*W*), *L* is the conduction loss (*W*), *f* is the proportionality factor of the meter (*dimensionless*), as described in ISO 14511 (ISO, 2001).

The constant ratio between the main flow and the flow in the capillary allows flow-rate to be measured. In fact, when a laminar and uniform flow is achieved both in the main pipe and in the capillary, the main flow-rate is proportional to the capillary one through a proportional factor dependent from the gas measured. To this aim a flow conditioner in the main pipe is always present.

In fact, according to Hagen-Poiseuille theory, the amount of the flow (necessarily supposed to be laminar) diverted in the capillary pipe is a function of the geometry (i.e. lengths and sections) of the main pipe and of the capillary. Nevertheless, also gas type affects such behaviour through its dynamic viscosity (η) that is a not easily predictable function of the gas temperature. Equations (3) and (4) describe this behaviour:

$$\mathrm{Q} = \frac{\mathrm{S}^2}{8 \cdot \eta \cdot \pi \cdot \mathrm{l}} \Delta \mathrm{p} \tag{3}$$

$$\frac{\mathrm{Q}_1}{\mathrm{Q}_2} = \frac{\eta_2(\mathrm{T})}{\eta_1(\mathrm{T})} \cdot \frac{\mathrm{l}_2}{\mathrm{l}_1} \cdot \frac{\mathrm{S}_1^2}{\mathrm{S}_2^2} = \mathrm{C} \cdot \frac{\eta_2(\mathrm{T})}{\eta_1(\mathrm{T})} \tag{4}$$

where: Δp is the pressure drop (*Pa*), Q_1 and Q_2 are the volumetric flow-rates (m^3 s^{-1}), η is the dynamic viscosity (*Pa s*), l_1 and l_2 are the lenghts (*m*), S_1 and S_2 are the sections of the main pipe and of the capillary (m^2), respectively (ISO, 2001).

Therefore, the ratio Q_1/Q_2 between the flow-rates through the main pipe and the capillary should not be assumed as constant for all gases and this can lead to significant errors. In fact, gas composition strongly influence the viscosity and all other values of the thermodynamic properties. Furthermore, additional pressure losses due to the inlet/outlet flow of the flow conditioner and the not fully developed flow profiles should be responsible for changing ratios between the capillary-pipe flow-rate and the main-pipe flow-rate (especially in case of flow disturbances).

Consequently, accurate measurements require the knowledge of the specific ratio Q_1/Q_2 and to this end gas composition must be constant (or known within fixed limits) in order to not affect meter accuracy above the maximum permissible errors for domestic applications (European Parliament, 2004). In fact, laminar regimes are strongly influenced by dynamic viscosity and by standard density variations (i.e. by the gas composition). However, in modern smart meters, the output signal of capillary TMFs should be corrected with gas quality changes but, to this end, gas composition has to be measured or retrieved from data measured in a homogeneous area and acquired from remote. Finally, the hypothesis of laminar