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STATISTICAL MODELLING OF ERROR MEASUREMENT FOR DIAPHRAGM GAS METERS AT DIFFERENT AMBIENT TEMPERATURES

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ABSTRACT: In this research, a statistical modeling is introduced in order to evaluate measuring error of diaphragm gas meters considering the effects of different ambient temperatures on the usual (0.2Q_{max}) and maximum (Q_{max}) consumption flow rate. In this study, a G4 diaphragm gas meter was used because of its prevalence in Iran. By considering the climate of Iran, average range of experiment's temperature was chosen between 30ºC to 60ºC and 0ºC to -30ºC. For conducting the experiments on these gas meters, a heater-cooler device and a master chamber were utilized. Proposed statistical modeling was able to evaluate the amount of using gas in the form of 0.2Q_{max} and Q_{max}. The obtained results may be used as a correction factor for diaphragm meter operation on different temperature conditions. In other words, the advantages of this research can be used for estimating the proper amount of using gas and calculating the proper fee for the user. According to results, in the countries that the gas consumption is done by diaphragm gas meters, national gas company will be lost for cold cities and will be profited for warm cities and the amount of fee estimation error is significant. As an example, national gas company of Iran lost about 40.7 million dollars for gas consumption measurement error for Tehran city in 2008.
KEYWORDS: Error of gas measurement, Gas consumption, Fee of gas, Diaphragm gas meter

INTRODUCTION

Iran, locating between latitudes 24° and 40° N and longitudes 44° and 64° E has various climates in different regions. Most of these climates have a hot summer and cold winter. It is obvious that the warmth and coldness of the weather have some undesirable influences on working elements of gas meters during the year. Thus, the gas consumption measuring would not be the same in different temperatures. In Iran, depending on the amount of needed flow rate, diaphragm gas meters are used in one of G2.5, G4, G10, G25, G40, G65, and G100 categories.

Some of the parameters that can have effects on the measuring devices are already studied. Nath and Dietrich (1997) analysed the effect of temperature on the measuring accuracy of turbine gas meters. Nilsson (1998) invested the accuracy of gas meters in the weather conditions on Lound city. Kolpatzik et al. (1998) considered the effects of temperature sensor positions in the pipe flows for determining the mean gas temperature.

Petunin (2008) presented an algorithm for indirect measurement of difficult-to-measure GTE parameters on the basis of its mathematical model. In his research, different principles of constructing GTE gas temperature meters based on indirect measurements were considered and simulation results were presented. Douglas (1977) invented a gas meter temperature compensating tangents. The tangent device was able to provide improved accurate deflection due to temperature changes as a result of built-in radial rigidity of the tangent wrist relative to the tangent arm. Cardelius and Skoglund (2004) invented an acoustic gas meter with a temperature probe having an elongated sensor region. In this manner, a temperature measurement can be made which more accurately reflects the temperature of the actual gas through which the emitted acoustic energy propagates. Vanderkamp (1988) studied high pressure test facilities for industrial gas meters in the Netherlands. The calibration procedures and systems were presented in his article. He showed that the gas compressibility effects on calibration and test facility accuracy.

Based on International Organization of Legal Metrology (OIML), for a mechanical gas meter with built-in mechanical temperature conversion device, maximum permissible error is 0.5% in a temperature range of 30°C extending symmetrically around the temperature specified by the manufacturer. The equation that converts the measured volume to a corresponding volume at the base gas temperature is presented as below (MID, 2004).

$$V_b = \frac{T_b}{T} V \qquad (1)$$

where V is the volume at metering conditions, V_b is the volume at base gas temperature, T is the absolute gas temperature at metering conditions and T_b is the base gas temperature specified by the manufacturer. Equation 1 discussed ambient temperature affects on gas and not on the gas meter. Both of Iranian Gas Standard (IGS) and the Gas Meters-Diaphragm Gas Meters-DIN EN 1359 have not considered the effects of temperature on gas flow measuring accuracy in diaphragm gas meters (IGS, 1998; DIN EN 1359, 1993). Massah et al. (2010) studied the effects of ambient temperature on flow rate meters on the medium ($0.2Q_{max}$) and maximum (Q_{max}) flow rate consumption.

The objective of this research was to present statistical models for determining the error of flow rate measurement for diaphragm gas meters considering the effect of ambient temperature at the maximum (Q_{max}) and the medium ($0.2Q_{max}$) flow rate.

MATERIALS AND METHODS

To determine the effects of different ambient temperatures on the accuracy of diaphragm gas meters, the influences of warmth and coldness of the weather on the $0.2Q_{max}$ and Q_{max} were studied. $0.2Q_{max}$ is an index to measure the accuracy of a gas meter in 0.2 of maximum working flow rate (medium flow rate). Q_{max} is an index to measure the accuracy of a gas meter in maximum working flow rate. These two indexes are important parameters in measuring the accuracy of gas meters (IGS, 1998; DIN EN 1359, 1993).

In Iran, temperature of most cities rises up to 45°C in summer and for some colder cities does fall to -25°C in winter. When a gas meter is located directly in the sunlight, its temperature may increase up to 60°C. Thus, the temperature range of experiments was considered 30° to 60°C and 0° to -30°C to determine the accuracy of flow rate measuring for a diaphragm gas meter (IGS, 1998).

The experiments were conducted using a G4 diaphragm gas meter. A heater-cooler and a master chamber (CA12-2232, Camos, Iran) were used to change the temperature of gas meters from -30°C ±0.1°C to 70°C ±0.1°C. Gas meters were located in these chambers. The master chamber had the ability of controlling the temperature at a standard range (19-23°C ±0.1°C) (IGS, 1998). A gas meter was placed in the master chamber as a master gas meter and another gas meter in heater-cooler chamber that its temperature changed at each stage of the experiment. Both chambers were kept next to each other in a way that the outlet gate of master meter was connected to the inlet gate of experimental gas meter, so the amount of passage air from both gas meters would be equal. A blower was used to produce the inlet air with 18 m-bar pressure (Figure 1). To avoid the influence of inlet air temperature on the experiments, both chambers were kept at room temperature (19-23°C ±0.1°C). Therefore, the inlet air to the chambers had standard temperature.

It was necessary to measure the rate of pressure drop, which was caused by the passage of air through the master chamber, concerning that the air first passed through the master chamber and then entered the heater-cooler chamber. Hence, the master chamber was connected to the gas meter in the heater-cooler chamber in series. Then, a volume of 100 Lit of air was passed (IRM3, instrument, Netherlands) through the master and experimental gas meters, which the difference of the value indicated by mechanical counter in the master chamber and experimental gas meters showed the rate of the pressure drop in the master gas meter (Figure 2).

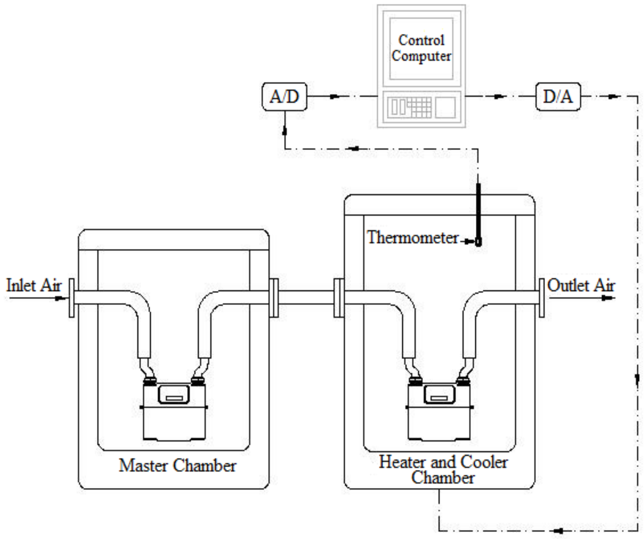

Figure 1. Schematic view of the test chambers

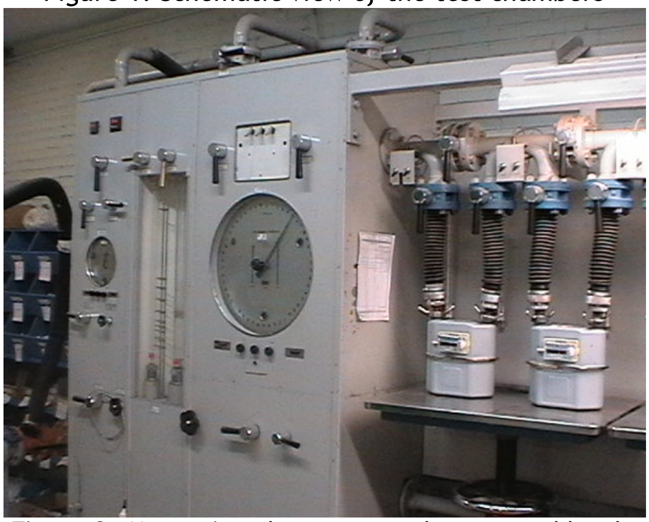

Figure 2. Measuring the pressure drop caused by the air passage from master gas meter

For measuring the effect of warmth and coldness in the form of $0.2Q_{max}$, a 1200 l/h rate of air and in the form of Q_{max}, a 6000 l/h rate of air were passed from master and experimental gas meters. Then, the temperature of passing air from gas meter, which was placed in the heater-cooler chamber, was changed from -30°C to 20°C and from 25°C to 60°C and recorded every 5°C to investigate the effects of warmth and coldness, respectively. The experiment was done with five iterations. Considering obtained results, the linear regression method was used to present the best fit to the data. Then, the percentage of measurement error (E) was calculated as The percentage of measurement error is expressed by equation (2).

$$E\% = \frac{|Q\_Q_m|}{Q_m}.100 \qquad (2)$$

where Q is the measured flow rate of meters in each temperature, and Q_m is the measured flow rate of master meter.

RESULTS AND DISCUSSION

As is illustrated in Figure 3, based on the results of the experiments in form of normal working flow rate ($0.2Q_{max}$) the reduction of temperature from 20°C to -25°C caused the reduction of approximately linear in the measurement error of the gas meter. Nevertheless, the measurement error of meters remained constant between -25°C to -30°C. At temperatures above 25°C to 55°C, the measurement error of gas meters were remained approximately constant, but between 55°C to 60°C this error was risen. As shown in Figure 3, a part of the diagram had more slope and a part of this diagram had less slope. The value of $Q_{0.2Qmax}$ was the same for 20°C to 25°C. Therefore, two equations were determined to measure the gas consumption to determine $Q_{0.2Qmax}$ at different temperatures appropriately by statistical models:

$$Q_{0.2Q_{\max}} = 1089 + 4.95t \qquad -30 \le t \le 20 \qquad (3)$$

$$Q_{0.2Q_{\max}} = 1168.5 + 1.18t \qquad 25 \le t \le 60 \qquad (4)$$

Where t is the ambient temperature (°C), $Q_{0.2Qmax}$ was estimated value of the flow rate in the form of $0.2Q_{max}$ (l/h). Equations 3 and 4 were able to evaluate the gas consumption measurement in the form of $0.2Q_{max}$ between -30°C to 20°C and 25°C to 60°C with a coefficient of determination 0.98 (R=0. 99) and 0.69 (R=0.83), respectively.

Statistical models for estimating the measurement error of gas meters in the form of $0.2Q_{max}$, are presented as below.

$$E_{0.2Q_{\max}} = (1200 - (1089 + 4.95t))/1200 \qquad -30 \le t \le 20 \qquad (5)$$

$$E_{0.2Q_{\max}} = (1200 - (1168.5 + 1.18t))/1200 \qquad 25 \le t \le 60 \qquad (6)$$

where $E_{0.2Qmax}$ represents the measurement error in the form of $0.2Q_{max}$ in l/h. As shown in Figure 3, the stretch line belongs to the obtained data during the experiments and slash line belongs to the fitted line with equations (3) and (4).

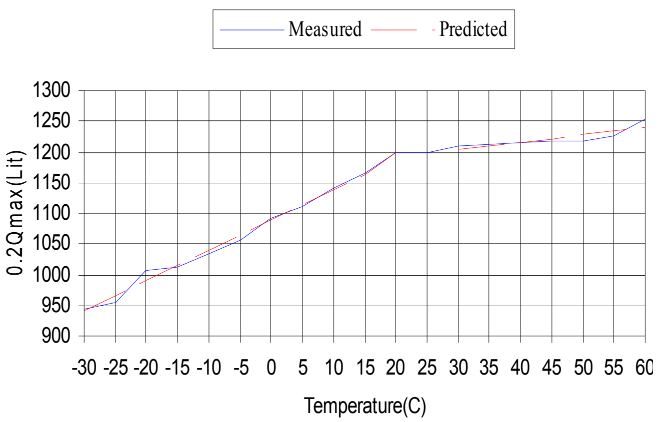

Figure 3. Effect of warm and cold temperature in the form of $0.2Q_{max}$

As is illustrated in Figure 4, based on the results of the experiments in form of maximum working flow rate (Q_{max}) linear reduction of temperature caused the linear reduction of measurement error in gas meter. Thus, it is possible to present the measurement error by a fitted linear equation to determine Q_{max} at temperatures between -30°C to 20°C and 25°C to 60°C. The temperature that used to determine the equations was considered above 25°C and under 20°C because the measured values with the master and experimental gas meters were the same between 20°C to 25°C.

$$Q_{Q_{\max}} = 5844.3 + 9.9t \qquad -30 \le t \le 20 \text{ and } -25 \le t \le 60 \qquad (7)$$

Where t is the ambient temperature (°C), Q_{Qmax} was estimated value of the flow rate in the form of Q_{max} (l/h). Equation 6 was able to evaluate the amount of using gas in the form of Q_{max} between -30°C to 20°C and 25°C to 60°C with a coefficient of determination 0.98 (R=0. 99). A statistical model for estimating the measurement error of gas meters in the form of Q_{max}, is presented as below.

$$E_{Q_{\max}} = (6000 - (5844.3 + 9.9t))/6000 \qquad -30 \le t \le 20 \quad and \quad 25 \le t \le 60 \qquad (8)$$

where E_{Qmax} represents the measurement error in the form of Q_{max} in l/h. As shown in Figure 4, the stretch line belongs to the obtained data during the experiments and slash line belongs to the fitted line with equation 7.

In this research, the effects of ambient temperature on the measured flow rate of meters in $0.2Q_{max}$ and Q_{max} forms and also measurement errors between them have been considered, but Nath and Dietrich (1997) considered the temperature behavior of diaphragm gas meters.

Errors below and above room temperature condition are named positive and negative errors, respectively. Cold temperature caused the meter's measurement show less amount (positive errors), and warm temperature caused the meter's measurement show more amount (negative errors).

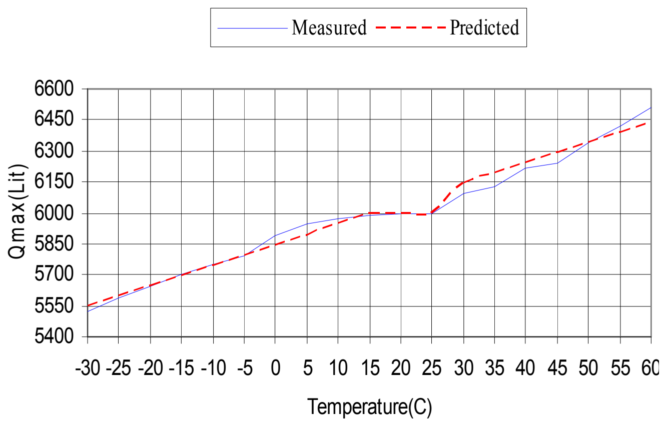

Figure 4. Effect of warm and cold temperature in the form of Q_{max}

To clarify the importance of results that are obtained above, the consumed gas amount of Tehran (The largest city of Iran with a population over 9,000,000 people) is analyzed. This amount in 2008 is presented in table 1. In this table, the average temperature for each month is also shown. The value of $E_{0.2Qmax}$ for each month was calculated using equations (5) and (6) (shown in Figure 5). Considering the gas consumption and the gas measurement error of diaphragm gas meters in each month and considering that each m^3 of gas costs about 0.05$ in Iran, fee estimation error (done by national gas company) was calculated and shown in Figure 6. As it is seen in this figure, national gas company of Iran had a large error and lost about 40.7 million dollars in gas consumption of Tehran in 2008.

Table 1. Consumed gas amount of Tehran during the year 2008

Month	Gas consumption (×1000, 000 m^3)	Average temperature (°C)
January	2877	-1
February	1821	6
March	1543	10
April	997	15
May	886	21
June	896	31
July	835	27
August	874	22
September	837	16
October	1067	13
November	1294	7
December	1921	2
Total	15848	-

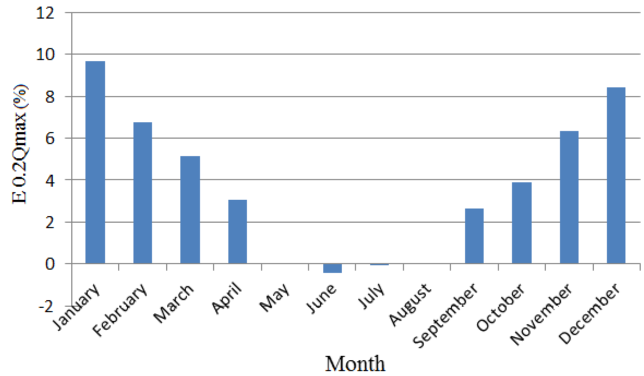

Figure 5. The value of $E_{0.2Qmax}$ (%) for each month

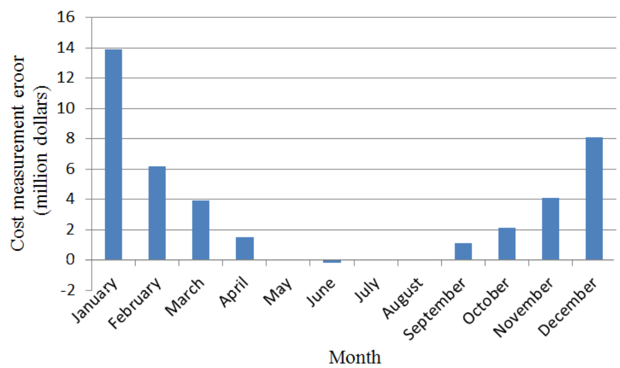

Figure 6. Cost measurement error (done by National Gas Company) for each month

CONCLUSIONS

The following conclusions can be drawn from this study:

1. Presented statistical models were able to evaluate the amount of using gas in the form of $0.2Q_{max}$ between -30°C to 20°C and 25°C to 60°C with a coefficient of determination 0.98 (R=0. 99) and 0.69 (R=0.83), respectively.
2. This model was able to evaluate the amount of using gas in the form of Q_{max} between -30°C to 20°C and 25°C to 60°C with a coefficient of determination 0.98 (R=0. 99).
3. Increasing and decreasing the ambient temperature cause to increase the positive and negative measure error of gas meters, respectively.
4. In the countries that the gas consumption is done by diaphragm gas meters, National Gas Company will be lost for cold cities and will be profited for warm cities and the amount of fee estimation error is significant.

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