Metrological performance of diaphragm gas meters with different use age

Xia Li1, Xiaoyuan Deng2, Song Zhang1, Jiao Zhan1, Li Wu1

1Chongqing Academy of Metrology and Quality Inspection, National Quality Supervision and Inspection Center for Thermal Flow Instruments (Chongqing), No.1 Yangliu North Road, Yubei District, Chongqing, People’s Republic of China
2China Jiliang University, No.258, Xueyuan Street, Higher Education Zone of Xiasha, Hangzhou, People’s Republic of China
E-mail: cmqixia@sina.com

Abstract: According to the current legal metrological regulation of diaphragm gas meter, domestic gas meters in China are required to pass mandatory initial verification at 20°C, and then a 10 years’ legal duration is allowed without any subsequent or in-service verifications. Here, experimental study has been implemented to investigate the metrological performance and temperature adaptability of old diaphragm gas meters with different use age. Through the introduction of weighting factors, weighted mean errors are calculated to analyse the correlation between the indication errors of gas meters and their use age, as well as the relationship between the indication errors and test temperatures. Experimental results indicate that the use age of gas meters has negligible influence on their metrological performance during the 10 years’ legal duration. However, the indication errors worsen as temperature varies.

1 Introduction

Diaphragm gas meter is widely used in natural gas distribution networks [1–4]. Its metrological performance is critical for the trade settlements of natural gas. Therefore, strict legal metrological constraints have been imposed for initial verification of diaphragm gas meters [2–6]. However, according to Chinese national verification regulation of diaphragm gas meter, domestic natural gas meters with maximum flowrate no >10m³/h are not subjected to subsequent or in-service verifications so far, and a legal duration of 10 years is fixed in force [2–4].

In fact, diaphragm gas meter is a kind of mechanical volumetric flowmeter in which the gas volume is measured by means of measuring chambers with deformable walls [1–6]. Its metrological performance often deteriorates due to the abrasion of moving parts and material aging over time and is likely affected by temperature and pressure because of the compressibility and expansibility of the diaphragm [1, 7–9]. However, literatures on the investigation of old gas meters are very limited [10–12], and furthermore, little research has been reported on the temperature adaptability of gas meters in-service. More work is needed to investigate the metrological performance of diaphragm gas meters at varied temperatures and over a period of service.

Here, metrological performance and temperature adaptability of old diaphragm gas meters are studied. For the consideration of the representativeness, >100 diaphragm gas meters of type G2.5, the age of which ranges from 0 to 22 years, are selected to carry out the experiments.

2 Experimental facility

Experimental facility as shown in Fig. 1 is applied to test the measurement performance and temperature adaptability of the diaphragm gas meters. This facility is developed on the basis of master meter principle and negative pressure method [13–15]. The tested gas media is air. A thermostat is applied to control gas temperature, so that the test temperature is adjustable within a range of (∼40–60)°C, and temperature fluctuation < ±0.5°C. A high accuracy roots flowmeter and two wet gas meters are selected as master meters, which could guarantee an uncertainty better than 0.3% (k = 2) of the whole facility with a flowrate range of (0.016–16) m³/h [16].

3 Scheme of test and analysis

3.1 Test principle

In the practical experiment process, the gas temperature and flowrate are first adjusted to the set points stably. Then, the accumulated flowrate, gas pressure, and gas temperature of the diaphragm gas meters and those of the master meters are obtained, respectively. According to the continuity principle and the gas state equation, the following equation could be obtained [1, 2, 4]:

$$\frac{(P_s + P_a)q_s}{T_s + 273.15} - \frac{(P_m + P_a)q_{ms}}{T_m + 273.15} = 0$$  \hspace{1cm} (1)

Then, the actual gas flowrate flowing through the tested diaphragm gas meter can be calculated as

$$q_{ms} = \frac{(P_s + P_a)(T_m + 273.15)}{(P_m + P_a)(T_s + 273.15)} \times q_s$$  \hspace{1cm} (2)

and the relative indication error of the tested diaphragm gas meter is:

$$E = \frac{q_m - q_{ms}}{q_{ms}} \times 100\%$$  \hspace{1cm} (3)

Fig. 1 Structure of the experimental facility
where $q_{a}$ accumulated volume flowrate obtained by the tested diaphragm gas meter, $m^{3}$; $q_{m}$ accumulated volume flowrate obtained by the master meter, $m^{3}$; $q_{max}$ actual accumulated volume flowrate under the conditions at the tested diaphragm gas meter, $m^{3}$; $P_m$ gauge pressure at the tested diaphragm gas meter, Pa; $P_i$ gauge pressure at the master meter, Pa; $P_{atm}$ atmospheric pressure, Pa; $T_m$ temperature at the tested diaphragm gas meter, °C; $T_i$ temperature at the master meter, °C; $E$ indication error of the test diaphragm gas meter.

### 3.2 Test arrangement

Visual check and leak tightness test are conducted first, to guarantee that the tested gas meters have no leakage. Totally, 100 gas meters that pass the leak tightness test are then tested on the facility to obtain their indication errors at different flowrates and varied temperatures. Before the tests of indication error, each gas meter is placed in the laboratory for at least 3 h, and then runs for 30 min beforehand. The arrangement of the indication error tests is as follows:

i. Tested flowrate points: $7q_{min}, 0.2q_{max}, 0.5q_{max}, q_{max}$;
ii. Tested temperature points: $-10, -2, 8, 20, 30, 40\,°C$;
iii. Accumulated flowrate: obtained from a test the duration of which is no <3 min;
iv. Number of measurements: three measurements at each flowrate and temperature point.

### 3.3 Data analysis method

#### 3.3.1 Error of indication

The tested gas meters are grouped by their use age. For each group of the gas meters with the same age, the mean error of indication at each flowrate point and each temperature point is calculated through the following equation:

$$E_{ij} = \frac{\sum_{x=1}^{n} (\sum_{y=1}^{3} (E_{ijxy}))}{3n}$$

where $n$ the quantity of the gas meters with the same age; $(E_{ijy})$, indication error of the $y$th measurement at the $j$th flowrate point and the $i$th temperature point, for the $x$th gas meter, %; $E_{ij}$ the average indication error of the three measurements at the $j$th flowrate point and the $i$th temperature point, for each group of gas meters with the same age, %;

#### 3.3.2 Mean error of indication weighted by flowrate

For the consideration that the working flowrate of a gas meter varies and $0.7q_{max}$ is the most frequently used flowrate, it is necessary to calculate the mean error of indication by using a weighting factor for each flowrate, so that the overall metrological performance of gas meters is evaluated reasonably. The flowrate weighted mean error of indication and the corresponding weighting factors are determined by using (5) [10]:

$$E_i = \frac{\sum_{j=1}^{3} k_j E_{ij}}{\sum_{j=1}^{3} k_j} = \begin{cases} \frac{q_{ij}}{q_{max}}, & q_{ij} \leq 0.7q_{max} \\ 1.4 - \frac{q_{ij}}{q_{max}}, & 0.7q_{max} < q_{ij} \leq q_{max} \end{cases}$$

where $E_i$, the flowrate weighted mean error of indication at the $i$th temperature point, for each group of the gas meters with the same age, %; $k_j$ flowrate weighting factor; $q_{ij}$, the average flowrate of the three measurements at the $j$th flowrate point and the $i$th temperature point, for each group of gas meters with the same age; $q_{max}$ maximum flowrate of gas meters of type G2.5.

Based on (5), the mean error of indication at different temperature points can be obtained for each group of the gas meters with the same age, and then the temperature adaptability of the old gas meters can be investigated.

### 4 Results and discussion

#### 4.1 Metrological performance at reference temperature

Since the verification of gas meters is carried out at a reference temperature of 20°C, the metrological performance of gas meters at 20°C is researched first here. Table 1 lists the specified maximum permissible errors (MPE) of gas meters of type G2.5. Table 2 presents the distribution of the tested gas meters, as well as the number of gas meters, which fail the indication error test of subsequent verification.

| Flowrate $q$ (m$^3$/h) | MPE (%) |
|-------------------------|---------|
| $q_{min} \leq q < q_i$ | ±3%     | ±6%     |
| $q_i \leq q \leq q_{max}$ | ±1.5%   | ±3%     |

Note: The transition flowrate $q_i$ of a diaphragm gas meter is equal to 0.1 $q_{max}$.

### 3.3.3 Mean error of indication weighted by temperature

From the point view of working principle, the metrological performance of gas meters is likely influenced by temperature variation. For a certain city where gas meters are applied, the local temperature changes with seasons. In order to evaluate the actual metrological performance of gas meters under certain geographical temperature conditions, a temperature weighting factor is introduced to calculate the weighted mean error of indication for each group of gas meters with the same age, as shown in (6):

$$\bar{E} = \frac{\sum_{i=1}^{4} n_i k_i E_i}{\sum_{i=1}^{4} n_i k_i}$$

where $\bar{E}$ the weighted mean error of indication for each group of gas meters with the same age, %; $k_i$ temperature weighting factor.

If $\bar{E} < 0$, it is regarded more favourable to gas consumers because the measured gas flowrate is generally smaller than the actual flowrate. On the contrary, if $\bar{E} > 0$, it is regarded more favourable to gas suppliers because the measured gas flowrate is generally greater than the actual flowrate.
satisfactory. It also can be seen from Fig. 2 that the age of the gas meter has negligible influence on its metrological performance.

4.2 Metrological performance at different temperatures

Similar with 4.1, for each group of gas meters with the same age, the mean errors of indication at different temperature points can be obtained according to (5), as shown in Table 4. The corresponding results are illustrated in Fig. 3. The age of the gas meter also shows little influence on its metrological performance, whereas temperature affects the errors of indication of gas meters to some extent. The metrological performance of gas meters deteriorates as the tested temperature deviates from the reference temperature. The more deviations, the worse metrological performance is. It is also found that the maximum indication error for each group of gas meters with the same age is obtained at the highest temperature of 40°C or the lowest temperature of −10°C. Moreover, a trend can be observed that the measured gas flowrate increases as temperature.

4.3 Overall metrological performance in a certain city

In order to evaluate the actual metrological performance of gas meters under certain geographical temperature conditions, two cities, Chongqing which is located in southwestern China, and Harbin which is located in north-eastern China are compared here, in terms of the gas meters’ metrological performance variation with the historical local temperature change through one year. As mentioned in 3.3.3, (6) is adopted to calculate the weighted mean error of indication for a certain group of gas meters with the same age. According to the historical temperature distribution within 1 year in Chongqing city and Harbin city, the temperature weighting factors corresponding to the temperature set [−10, −2, 8, 20, 30, 40°C] are determined as follows:

The temperature weighting factors of Chongqing:

\[
K_{CT} = [0, 0.08, 0.11, 0.45, 0.28, 0.08].
\]

The temperature weighting factors of Harbin:

\[
K_{HT} = [0.27, 0.14, 0.32, 0.14, 0.13, 0].
\]

Based on (6), the weighted mean errors of indication under typical temperature conditions of Chongqing and Harbin are calculated, denoted as \(E_C\) and \(E_H\). Fig. 4 shows the comparison of \(E_C\), \(E_H\) and \(E_{20}\) (which represents the weighted mean errors of indication under reference temperature of 20°C and is calculated in 4.1).

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Table 3 Experimental results under reference temperature of 20°C

| Age of gas meter (years) | \(7q_{\text{min}}\) | \(0.2q_{\text{max}}\) | \(0.5q_{\text{max}}\) | \(q_{\text{max}}\) | \(E_{20}\) (%) |
|-------------------------|----------------|----------------|----------------|----------------|----------------|
| 0                       | -0.22          | -0.03          | 0.19           | -0.50          | -0.10          |
| 2                       | -0.05          | 0.30           | 0.40           | 0.14           | 0.28           |
| 4                       | 1.11           | 1.70           | -0.59          | -1.06          | -0.29          |
| 7                       | 0.65           | 0.53           | -0.68          | -0.92          | -0.50          |
| 8                       | -1.38          | -0.91          | -0.77          | -0.39          | -0.68          |
| 9                       | 1.17           | 1.09           | 1.02           | 0.41           | 0.82           |
| 10                      | 1.21           | 1.29           | 0.76           | 0.51           | 0.78           |
| 11                      | 1.28           | 1.47           | 0.82           | 0.19           | 0.73           |
| 12                      | 1.29           | 1.11           | 0.92           | 0.17           | 0.70           |
| 20                      | 1.23           | 0.67           | 0.69           | 0.62           | 0.72           |
| 22                      | 2.73           | 3.80           | 2.89           | 1.98           | 2.72           |

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Table 4 Experimental results at different temperatures

| Age of gas meter (years) | \(-10°C\) | \(-2°C\) | \(8°C\) | \(20°C\) | \(30°C\) | \(40°C\) | \(E_i\) (%) |
|-------------------------|----------|----------|---------|----------|----------|----------|-------------|
| 0                       | -1.28    | -1.01    | -1.03   | -0.10    | 1.26     | 0.80     |
| 2                       | -1.47    | -0.44    | 0.83    | 0.28     | -1.32    | 2.80     |
| 4                       | -2.77    | -2.55    | -2.05   | -0.29    | -1.39    | -2.46    |
| 7                       | -5.05    | -2.37    | -1.98   | -0.50    | -0.85    | -0.99    |
| 8                       | -2.79    | -2.00    | -1.20   | -0.68    | 0.11     | 1.86     |
| 9                       | -1.88    | -1.22    | -0.28   | 0.82     | 0.93     | 2.94     |
| 10                      | 0.35     | 0.47     | 1.31    | 0.78     | 1.00     | 0.93     |
| 11                      | -1.19    | -0.04    | 0.99    | 0.73     | -0.07    | 0.25     |
| 12                      | -2.46    | -0.79    | 0.11    | 0.70     | 0.59     | -0.02    |
| 20                      | -2.42    | -0.63    | 0.05    | 0.72     | -0.70    | -0.57    |
| 22                      | 0.33     | 0.84     | 2.48    | 2.72     | 1.72     | 1.81     |
Generally, $E_C$, $E_H$, and $E_{E20}$ have similar trends of variation with the age of gas meters. Interestingly, whatever the age of gas meter is, $E_H$ is always the lowest one. A possible reason is that Harbin has lower temperatures than Chongqing, and most of the time, the local temperature is <20°C. Therefore, the measured gas flowrate obtained in Harbin is less than that obtained in Chongqing and that obtained at 20°C. This is in accordance with the analysis in 4.2 that the experimental results indicate an increasing measured gas flowrate with temperature. Since the legal metrology regulation has specified that gas meters are verified at 20°C, the use of gas meters often benefits gas consumers in cold cities such as Harbin.

5 Conclusions

Experimental study has been conducted to investigate the metrological performance and temperature adaptability of old diaphragm gas meters with different use age. Totally, 100 domestic diaphragm gas meters of type G2.5, the age of which ranges from 0 to 22 years, were tested. The tested flowrate points were $7q_{min}$, $0.2q_{max}$, $0.5q_{max}$ and $q_{max}$. The tested temperature points included −10, −2, 8, 20, 30 and 40°C. Results indicate that:

- The indication errors of most of the tested gas meters are within the MPEs of subsequent verification, as long as the gas meters have passed visual check and leak tightness test.
- The use age of gas meter has negligible influence on its metrological performance, during the 10 years’ legal duration.
- The indication errors of gas meters worsen as temperature varies. The maximum indication error for each group of gas meters with the same age is obtained at the highest tested temperature of 40°C or lowest one of −10°C. Moreover, a trend can be observed that the measured gas flowrate increases as temperature.
- The using of gas meters often benefits gas consumers when temperature is low.

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Fig. 3 Mean errors of indication at different temperatures against the age of gas meters

Fig. 4 Comparison of errors of indication under typical temperature conditions