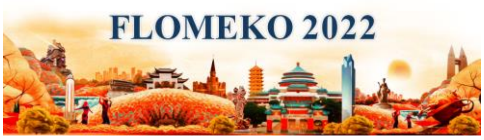

Technical Research and Uncertainty Evaluation of the City Gas Energy Measurement

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Abstract

Based on the specific situation of city gas in Beijing, the technical scheme of city gas energy measurement for different users was proposed in this paper. Combined with the experimental data, the sources of the uncertainty of city gas energy measurement were analyzed from the aspects of volume flow, calorific value per unit volume, integration method and other relevant factors under the measurement reference conditions. Meanwhile, the uncertainty of city gas energy measurement was evaluated. This study puts forward the technical scheme and uncertainty evaluation of natural gas energy measurement for different users, which has certain reference significance for promoting the implementation of city gas energy measurement in China.

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1. Introduction

With the rapid development of the urbanization in China, city gas became one of the most important fields of natural gas consumption. A diversified supply and marketing pattern for natural gas has formed in China. The gross calorific value of different gas sources ranged from 34 MJ/m^3 to 43 MJ/m^3, and the maximum difference of calorific value exceeded 20% [1, 2]. On May, 2019, the National Development and Reform Commission and other three ministries and commissions jointly issued the supervision regulation on the fair access of oil and gas pipeline network facilities, which required that a natural gas energy measurement and pricing system shall be established within 24 months from the implementation data of this regulation. It has kicked off the formal and comprehensive promotion and implementation of natural gas energy measurement in China [3-6].

For city gas, the regulation only requires the gate station of city gas to realize energy measurement. There are no specific requirements for downstream users. However, when the gate station implements energy measurement, the downstream users are bound to transition to energy measurement from the perspective of fairness, but a longer transition period may be required. Therefore, this requires a systematic study of the technical proposal for the implementation of city gas energy measurement, and the planned and phased promotion of the transformation, which is the only way to achieve comprehensive city gas energy measurement.

Beijing has the largest city gas consumption in China, ranking second in the world, which has more than 7million city gas users. In order to give consideration to scientific nature, fairness and economic feasibility, all users can be divided into two types according to the cost of technological transformation and gas consumption. Based on the divided types, different technical proposals were adopted for different users.

2. The first type users

The first type users refers to users with large annual gas consumption, mainly including thermal power plants, large customer heating plants, large chemical plants, wholesale users, etc. The number of such users is small, but the gas consumption of a single user is large. They are suitable to adopt the scheme of "energy measurement and energy settlement".

2.1 Technical proposal

The first type users need to configure various metering equipment, including gas flowmeter, temperature transmitter (thermometer), pressure transmitter (manometer), gas chromatography, and flow integrating equipment. The flow integrating equipment reads the component data of the online gas composition analyser, the volume flow data of the gas flowmeter, the temperature data of the thermometer and the pressure data of the pressure gauge, and recalculates through the collected data. calculate the compression factor and high calorific value according to the natural gas component, temperature and pressure information. According to the instantaneous flow under working conditions and temperature, pressure, compression factor and so on, calculate the instantaneous flow under standard conditions, and then use the calorific value and flow data to accumulate the energy value through the integration method.

2.2 Evaluation of uncertainty

The general calculation formula of natural gas energy measurement was given in GB/T 22723-2008 “determination of natural gas energy”, which can be expressed as,

$$E=\int_{t_0}^{t_n} e_n(t)\,\mathrm{d}t=\int_{t_0}^{t_n} q_n(t)H(t)\,\mathrm{d}t\,. \tag{1}$$

where, q_n is the volume flow under the metering reference condition, m^3/h. H is the calorific value per unit volume of mixed gas, MJ/ m^3. Based on Equation (1), the uncertainty of natural gas energy measurement can be expressed as,

$$u(E)=\sqrt{u(q_n)^2+u(H_n)^2+u(o)^2}\,. \tag{2}$$

where, $u(q_n)$ is the uncertainty introduced by the volume flow under the metering reference condition. $u(H_n)$ is the uncertainty introduced by the calorific value per unit volume of mixed gas. $u(o)$ is the uncertainty introduced by the integration method and other factors.

1) The uncertainty introduced by the volume flow under the metering reference condition.

What the flowmeter directly measured was the volume flow q_f under the working conditions, which need to be converted into the volume flow q_n under the metering reference conditions. The calculation method of conversion was shown in Equation (3).

$$q_n=q_f\frac{p_n}{p_f}\cdot\frac{T_n}{T_f}\cdot\frac{Z_n}{Z_f} \tag{3}$$

Where, T_n is the natural gas temperature under the metering reference conditions, which usually takes 293.15 K. p_n is the natural gas pressure under the metering reference, which usually takes 101.325 kPa. Z_f and Z_n are the compression factor under the working conditions and the metering reference conditions respectively. The uncertainty introduced by the volume flow under the metering reference condition was expressed as,

$$u(q_n)=\sqrt{u(q_f)^2+u(p_f)^2+u(T_f)^2+u(\frac{Z_n}{Z_f})^2} \tag{4}$$

- The uncertainty of flow measurement under the metering conditions.

The accuracy level of the flowmeter configured by the first type user is 1%, which will be calibrated before using.

$$u(q_f)=\frac{1}{\sqrt{3}}\times 100\%=0.6\% \tag{5}$$

- The uncertainty of pressure measurement under the metering conditions.

The accuracy level of the pressure transmitter configured by the first type user is 0.1%, which will be calibrated before using.

$$u(p_f)=\frac{0.1}{\sqrt{3}}\times 100\%=0.06\% \tag{6}$$

- The uncertainty of temperature measurement under the metering conditions.

The accuracy level of the temperature transmitter configured by the first type user is ±0.5 ℃, which will be calibrated before using.

$$u(T_f)=\frac{0.5}{293\times\sqrt{3}}\times 100\%=0.1\% \tag{7}$$

- The uncertainty of compressibility factor.

The influence of the relative uncertainty of physical parameters mainly comes from the uncertainty of analytical data. The uncertainty of compression factor Z_n was to be less than 0.05% under the metering reference conditions, and the maximum uncertainty of compression factor Z_f was 0.1%.

$$u(\frac{Z_n}{Z_f})=\frac{0.1}{2}\times 100\%=0.05\% \tag{8}$$

So, the uncertainty introduced by the volume flow under the metering reference condition was 0.64%.

2) The uncertainty introduced by the calorific value per unit volume of mixed gas.

This part mainly considers the uncertainty of the high calorific value of the ideal volume and the uncertainty introduced by the compression factor.

- The uncertainty of high calorific value of ideal volume.

The uncertainty introduced by the ideal volume high calorific value was equal to the uncertainty introduced by the ideal molar high calorific value, and the latter mainly included two sources, type A uncertainty and type B uncertainty.

When the composition of natural gas in the pipeline was relatively stable, the measurement repeatability of the calorific value reflected the measurement repeatability of instrument, which was the type A uncertainty. During the sampling process, the gas composition was stable, and the fluctuation of calorific value within 24 hours was less than 0.08%. The chromatography stability and the uncertainty introduced by the change was better than 0.08%. According to the literatures, type B uncertainty of the same technical scheme was usually taken as 0.05%. The uncertainty of high calorific value of ideal volume was,

$$u(H_*)=\sqrt{(0.08\%)^2+(0.05\%)^2}=0.095\% \tag{9}$$

- The uncertainty of compressibility factor.

The uncertainty introduced by the compression factor is the same as above, and it was 0.05%.

So, the uncertainty of high calorific value of real volume of natural gas.

$$u(H_0)=\sqrt{u(H_*)^2+u(Z)^2}=0.11\% \tag{10}$$

3) The uncertainty introduced by the integration method and other factors.

- The uncertainty of integration method.

Considering the calculation model of flow integrator, rounding off of reference result, measurement stability and allowable error, the sum of various influencing factors was calculated as 0.05%.

$$u(c_1)=\frac{0.05}{\sqrt{3}}\times 100\%=0.029\% \tag{11}$$

- The uncertainty of flow change.

The energy value of such users was calculated in real time through volume and calorific value. However, the flow change will introduce additional uncertainty in this calculation process. According to literatures, the impact was considered at 0.1%.

$$u(\Delta q) = 0.1\% \quad (12)$$

- The uncertainty of the mismatch between flow and calorific value.

Since the data update frequency of gas chromatography was inconsistent with that of flowmeter, temperature transmitter and pressure transmitter certain uncertainty will be introduced, which will have a certain impact on the flow measurement and energy measurement. The previous data cannot be used for quantitative calculation of this part. It was estimated according to the existing experimental results, and the uncertainty was considered as 0.05%.

So, the uncertainty introduced by the integration method and other factors was,

$$\begin{aligned} u(o) &= \sqrt{u^2(c_1) + u^2(\Delta q) + u^2(\Delta)} \\ &= \sqrt{(0.029\%)^2 + (0.1\%)^2 + (0.05\%)^2} \quad (12) \\ &= 0.12\% \end{aligned}$$

Based on the above, the uncertainty of natural gas energy measurement can be expressed as,

$$\begin{aligned} u(E) &= \sqrt{u^2(q_n) + u^2(H_0) + u^2(o)} \\ &= \sqrt{(0.638\%)^2 + (0.11\%)^2 + (0.12\%)^2} \quad (13) \\ &= 0.659\% \end{aligned}$$

The expansion factor was taken as 2, the expansion uncertainty of natural gas energy measurement for the first type user was,

$$U(E) = k \cdot u(E) = 2 \times 0.659\% = 1.4\% \quad (14)$$

3. The second type users

The second type users refers to users with small annual gas consumption, mainly including small heating users (urban heating deducting large customer heating plants), industrial and commercial users, CNG users, residential users, etc. The number of such users is large, and the annual gas consumption of a single user is small, so the scheme of "volume measurement and energy settlement" is suitable.

3.1 Technical proposal

The second type users are not equipped with online calorific value measurement equipment such as gas chromatography, and the calorific value per unit volume is obtained by means of platform assignment. Most of them are equipped with flowmeters, temperature transmitters (thermometers), pressure transmitters (pressure gauges), correction instruments and other equipment, among which residential users are equipped with gas meters, and the working condition flow is used to replace the standard condition flow for settlement.

3.2 Evaluation of uncertainty

Referring to the section 2.2, take the downstream users of the three gas source ring network as an example to evaluate the uncertainty natural gas energy measurement for the second type users, which can be expressed as,

$$u(E_2) = \sqrt{u(q_2)^2 + u(H_2)^2 + u(o_2)^2}\,. \quad (2)$$

where, $u(q_2)$ is the uncertainty introduced by the volume flow under the metering reference condition. $u(H_2)$ is the uncertainty introduced by the calorific value per unit volume of mixed gas. $u(o_2)$ is the uncertainty introduced by the integration method and other factors.

1) The uncertainty introduced by the volume flow under the metering reference condition.

The accuracy level of the flowmeter configured by the second type user is 1%, and the gas meter is 1.5%. The flowmeters and the gas meters will be calibrated before using.

For gas flowmeter users,

$$u(q_{f2}) = \frac{1}{\sqrt{3}} \times 100\% = 0.6\% \quad (15)$$

For gas meter users,

$$u(q_{f3}) = \frac{1.5}{\sqrt{3}} \times 100\% = 0.87\% \quad (16)$$

- The uncertainty of pressure measurement under the metering conditions.

The accuracy level of the pressure transmitter configured by the second type user is 0.5%, which will be calibrated before using.

$$u(p_{f2}) = \frac{0.5}{\sqrt{3}} \times 100\% = 0.29\% \quad (17)$$

- The uncertainty of temperature measurement under the metering conditions.

The accuracy level of the temperature transmitter configured by the first type user is ±1 ℃, which will be calibrated before using.

$$u(T_{f2}) = \frac{1}{293 \times \sqrt{3}} \times 100\% = 0.2\% \quad (18)$$

- The uncertainty of compressibility factor.

According to the actual, the gas composition of such users will not change significantly in a billing cycle, and the introduced uncertainty was 0.2%.

$$u(Z_{f2}) = 0.2\% \quad (19)$$

So, the uncertainty introduced by the volume flow under the metering reference condition for the second type users is as follows.

For flowmeter users,

$$\begin{aligned} u(q_2) &= \sqrt{u^2(q_{f2}) + u^2(p_{f2}) + u^2(T_{f2}) + u^2(Z_2)} \quad (20) \\ &= 0.724\% \end{aligned}$$

For gas meter users,

$$u(q_3) = u(q_{f3}) = 0.87\% \qquad (20)$$

2) The uncertainty of the calorific value per unit volume under the metering reference conditions.

Such users used the weighted average of the gas volume of calorific value in the settlement period as the calorific value per unit volume for assignment, and settle according to the energy. Taking the small partition of three gas sources as an example, the calculation method is as follows.

$$H_2 = \frac{E_{o1} + E_{o2} + E_{o3}}{\int_{t_0}^{t_n} q_{o1}(t)dt + \int_{t_0}^{t_n} q_{o2}(t)dt + \int_{t_0}^{t_n} q_{o3}(t)dt} \qquad (21)$$

$$u(H_2) = \sqrt{\begin{aligned}&u^2(E_{o1}) + u^2(E_{o2}) + u^2(E_{o3}) \\ &+ u^2(q_{o1}) + u^2(q_{o2}) + u^2(q_{o3})\end{aligned}} \qquad (22)$$

where, $u(E_{o1})$, $u(E_{o2})$ and $u(E_{o3})$ are the uncertainty of the energy supplied by the three gas sources to the partition pipe network in the billing cycle. $u(q_{o1})$, $u(q_{o2})$ and $u(q_{o3})$ are the uncertainty of the flow supplied by the three gas sources to the partition pipe network in the billing cycle. it can be calculated with reference to the section 2.2. So, the uncertainty of the calorific value per unit volume under the metering reference conditions for the second type users was 1.59%.

$$u(H_2) = \sqrt{\begin{aligned}&(0.659\%)^2 + (0.659\%)^2 + (0.659\%)^2 \\ &+ (0.638\%)^2 + (0.638\%)^2 + (0.638\%)^2\end{aligned}} \qquad (23)$$

$$= 1.59\%$$

3) The uncertainty introduced by the integration method and other factors.

- The uncertainty of integration method.

Considering the calculation model of flow integrator, rounding off of reference result, measurement stability and allowable error, the sum of various influencing factors was calculated as 0.05%. The uncertainty of integration method was 0.029%.

- The uncertainty of the mismatch between settlement flow and assigned calorific value.

The flow calculation cycle of this type user cannot match the assigned calorific value cycle completely, which will introduce additional uncertainty. The impact of this part was considered as 0.1%. As the settlement flow cycle of meter reading users is greatly affected by human factors, it was not included in this study.

$$u(\Delta_2) = 0.1\% \qquad (24)$$

- The uncertainty of the mismatch between assigned calorific value and actual calorific value.

There is a mismatch between the assigned calorific value and the actual calorific value, which will introduce a certain degree of uncertainty. The five sampling points in the zone were sampled twice by the cumulative sampler, and the sampled high calorific value was compared with the assigned high calorific value. The current experimental data can not be fully quantitative calculation of this part of the content, and it was estimated according to the existing experimental results. The maximum deviation was 0.29%, which was considered according to the rectangular distribution and the uncertainty introduced by the sampling and detection chromatography (the same as 2.2),

$$u(\Delta H) = \sqrt{\left(\frac{0.29}{\sqrt{3}}\right)^2 + (0.11)^2} \times 100\% = 0.2\% \qquad (25)$$

Table 1, Sampling data.

Sampling times	**1**	**2**
Assigned calorific value	37.24 MJ/m^3	37.96 MJ/m^3
Sampling point A	37.35 MJ/m^3	38.06 MJ/m^3
Sampling point B	37.26 MJ/m^3	38.02 MJ/m^3
Sampling point C	37.24 MJ/m^3	38.06 MJ/m^3
Sampling point D	37.22 MJ/m^3	37.89 MJ/m^3
Sampling point E	37.19 MJ/m^3	37.92 MJ/m^3

So, the uncertainty of the integration method and other factors for the second type users was,

$$u(o_2) = \sqrt{u^2(c_2) + u^2(\Delta_2) + u^2(\Delta H)}$$

$$= \sqrt{(0.029\%)^2 + (0.1\%)^2 + (0.2\%)^2} \qquad (26)$$

$$= 0.225\%$$

Based on the above, the uncertainty of natural gas energy measurement for the flowmeter users of the second type users can be expressed as,

$$u(E_2) = \sqrt{u^2(q_2) + u^2(H_2) + u^2(o_2)}$$

$$= \sqrt{(0.6\%)^2 + (1.59\%)^2 + (0.225\%)^2} \qquad (27)$$

$$= 1.72\%$$

The expansion factor was taken as 2, the expansion uncertainty for the flowmeter users of the second type users was,

$$U(E) = k \cdot u(E) = 2 \times 1.72\% = 3.44\% \qquad (28)$$

Based on the above, the uncertainty of natural gas energy measurement for the gas meter users of the second type users can be expressed as,

$$u(E_2) = \sqrt{u^2(q_2) + u^2(H_2) + u^2(o_2)}$$

$$= \sqrt{(0.87\%)^2 + (1.59\%)^2 + (0.225\%)^2} \qquad (27)$$

$$= 1.83\%$$

The expansion factor was taken as 2, the expansion uncertainty for the gas meter users of the second type users was,

$$U(E) = k \cdot u(E) = 2 \times 1.83\% = 3.66\% \qquad (28)$$

4. Conclusion

Based on the specific situation of city gas in Beijing, the technical scheme of energy measurement for different type city gas users were proposed by the paper. Combined with the experimental data, this paper studied the sources of uncertainty from the aspects of volume flow, calorific value per unit volume, integration method and other related factors under the metering reference conditions, and evaluated the uncertainty for different users. According to the requirements in GB/T 18603-2014, the energy measurement results of the first type users meet the requirements of class B measurement system. The technical scheme of energy measurement for the second type users need to be further optimized, and the evaluation of uncertainty needs to be further discussed.

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