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## Article

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## Research paper

## Energy metering for the urban gas system: A case study in China

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## ABSTRACT

With the continued downturn in global crude oil prices, the natural gas market shows a rapid growth trend. The coordination of natural gas trade is becoming more and more important, and many organizations have put forward natural gas energy metering the schemes. Nowadays, the energy metering schemes for long-distance natural gas pipelines have been approaching maturity, but the energy metering scheme between urban gas gate stations and urban gas users has not yet been proposed. Therefore, this paper takes two different types of cities in China for instance to verify the rationality of urban gas energy metering, and proposes a specific plan for urban gas energy metering. Taking Beijing (China) and Dali (Yunnan Province, China) urban gas systems as examples, by comparing the energy metering method with traditional volumetric metering method, it can be obtained that the use of volumetric metering method in Beijing and Dali will lead to different degrees of extra economic losses to the natural gas companies, and the extra economic losses in winter are the biggest. For some cities with high temperature in summer, the use of volumetric metering will lead extra economic losses in winter and extra economic benefits in summer. Therefore, it is fairer to use the urban gas energy metering method. Furthermore, the method of establishing an urban gas energy metering system and the method of building an Internet plus-based management system are proposed in this paper.

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## 1. Introduction

With the reform of China's economic system, the natural gas market presents a rapid growth trend. In 2018, China's consumed  $2803 \times 10^8 \text{ m}^3$  natural gas, according to BP (British Petroleum, 2019), China's natural gas consumption will occupy 26% of the energy market (Ma et al., 2019a). In order to meet the natural gas demand, the supply pattern of China's natural gas market will be more complicated (Lu et al., 2019a), in addition to domestic gas and imported pipeline gas, LNG will become a major new source, and there will also be coal-bed gas, coal gas, shale gas, and other unconventional natural gas into the pipeline network for sale (Ma et al., 2019b). With the increase in the consumption of civilian natural gas, the Chinese government has also strengthened the construction of supporting facilities (Liu et al., 2019). With the complexity of China's natural gas supply system, three new problems have been derived: (1) Domestic gas and imported gas trade settlement problem; (2) Adaption problem of volumetric metering and valuation to the multiple gas sources, multi-type and multipath gas supply; (3) Distortion of the value of natural

gas caused by volume valuation. These three problems show that the traditional volumetric metering method not only affects the imports of natural gas resources, but also affect its domestic sales, impede the safe supply of natural gas and natural gas industry development. In order to integrate into the world's natural gas trading system, it is imperative to implement energy metering and trade settlement.

Many scholars have conducted research on the energy metering of natural gas and proposed some programs. Jaeschke et al. (2002) introduced a system for measuring natural gas energy and obtained an uncertainty of 0.2% by experiment. Li and Zhou (2011) described the implementation method of natural gas energy metering in long-distance pipeline from the aspects of energy unit and pricing method of natural gas, and put forward relevant measures. Wu (2012) used Fluent software to study the mixing law of natural gas under different gas conditions, which laid a foundation for the energy metering of natural gas under the condition of multiple gas sources. In addition, she also discussed the design and uncertainty analysis of the energy metering system of natural gas. Luo (2014) introduced the related equipment for natural gas energy metering and summarized the relevant measurement standards. The feasibility of natural gas energy metering is proved by field experiments. Wang et al. (2018) summarized how to realize the energy metering of natural gas in

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## Nomenclature

$E$	Energy of natural gas (J)
$Q$	Volume of natural gas ( $m^3$ )
$H$	Calorific value of natural gas ( $J/m^3$ )
$t_1$	Combustion temperature
$p_1$	Combustion pressure
$t_2$	Volumetric measuring temperature
$p_2$	Volumetric measuring and pressure
$R$	Molar gas constant, $R = 8.314510$ ( $J \text{ mol}^{-1} \text{ K}^{-1}$ )
$T_2$	Absolute temperature (K)
$x_j$	Molar fraction of component $j$
$\bar{H}^0 [t_1, V(t_2, p_2)]$	Mix ideal gas of volume calorific value (superior/inferior)
$\bar{H}_j^0(t_1)$	Component $j$ ideal gas volume calorific value (superior/inferior)
$Z_{mix}(t_2, p_2)$	Compression factor in reference condition
$\sqrt{b_j}$	Summation factor for each pure component.
$P_{volume}$	Unit volume price of natural gas (yuan/ $m^3$ )
$H$	Calorific value of natural gas ( $J/m^3$ )
$V_n$	Volume of natural gas under standard reference conditions ( $m^3$ )
$V$	Volume of natural gas under operating conditions ( $m^3$ )
$Z$	Natural gas compression factor under operating conditions
$Z_n$	Natural gas compression factor under standard reference conditions
$T_n$	Standard reference temperature (K)
$T$	Operating temperature (K)
$p_{amb}$	Average atmospheric pressure at meter instrument (kPa)
$p_g$	Operating pressure (gauge pressure) (kPa)
$p_{H2O}$	Pressure of water in natural gas (kPa)
$p_n$	Operating pressure (kPa)
$C_{vc}$	Volume conversion coefficient
$A$	Extra economic loss (%)
$Q_c$	Converted gas volume (under standard reference conditions) ( $m^3$ )
$Q_m$	Natural gas volume displayed on the users' flow meter ( $m^3$ )
$H_0$	Benchmark natural gas calorific value ( $MJ/m^3$ )
$P_0$	Benchmark natural gas price (yuan/MJ)
$q_{it}$	Volume flow of $i$ th gas source and $t$ moment of country (province and city)
$h_{it}$	Unit volume calorific value of $i$ th gas source and $t$ moment of country (province and city)
$N$	Total number of gas sources
$T$	A period of time prior to energy valuation (year, month, week, day)

methods, selection of energy metering units, measurement, and pricing of pipeline transportation. Xu et al. (2018) studied the energy metering method of multi-source natural gas pipeline network, and simulated the pipeline network with TGNET software. The proposed method determined the minimum amount of flow meters needed for state reconstruction of multi-source natural gas pipeline network and the method of instrument layout, and the error was small.

Many enterprises are also carrying out a series of related research. From 2000 to 2003, the Quality Safety and Environmental Protection Department of China National Petroleum Corporation (CNPC) did a research on the integration of oil and gas measurement with international standards, one of which is the energy metering of natural gas. Southwest Oil and Gas Field Company of CNPC carried out a study on energy metering scheme of natural gas in southwest China, this study analyzed the necessity and feasibility of natural gas energy metering, and put forward the method of determining the pricing rules and pricing conversion coefficient of natural gas in southwest China. In 2005 and 2006, CNPC organized a research about natural gas energy metering supporting technology. This research analyzed five aspects: flow measurement equipment, natural gas composition analysis equipment, natural gas physical parameter measurement, flow standardization, and analytical standardization. In 2007 and 2008, Southwest Oil and Gas Field Company of CNPC organized a "Gas energy metering and gas prices" study. This study made a comprehensive and in-depth analysis of the metering methods and technical level, instrument and equipment, standards and criterions, and development trend of natural gas metering in China. Furthermore, this study put forward the technical scheme of energy metering. Four kinds of natural gas energy metering price scheme were proposed, through the simulation and economic analysis of the technical scheme, the results show that there is no technical problem in the natural gas energy metering, the demand for equipment investment is small, and monthly trade settlement is feasible. In 2008, CNPC organized a project about the application of natural gas metering in the long-distance pipeline, the project is based on WEPPII (The second west to east gas pipeline project) and put forward two kinds of implementation schemes. The project provided technical support for the construction of the WEPPII, the temperament management and implementation of energy metering. From then on, natural gas energy measurement began to apply to the long-distance pipeline. In 2010 and 2011, Southwest Oil and Gas Field Company of CNPC conducted a field test of natural gas energy metering. The test selected three natural gas metering stations and collected one year's energy data. According to the results of the analysis, the best transit time of the test site is obtained (PetroChina Southwest Oil & Gasfield Company, 2010).

As can be seen from the above research survey, on the one hand, natural gas energy metering is focused on long-distance pipelines, the situation of long-distance pipeline is single, the gas source is usually stable, and the implementation of energy metering is simpler. On the other hand, natural gas energy metering has not been applied to urban gas because urban gas has the characteristics of the unstable gas source, complex pipe network, and multiple gas sources, it is more challenging to implement. Consequently, this paper studied the implementation of urban gas energy metering. The rest of this paper is organized as follows:

Section 2 briefly introduces the relevant theory of natural gas energy metering. Section 3 takes the urban gas system of Beijing and Dali as an example to analyze the influence of energy metering on traditional metering methods. Section 4 puts forward two energy metering schemes and recommended equipment according to the scale of urban gas system. Section 5 proposes an energy metering management system architecture based on "Internet plus".

China, and elaborated on the details of implementing the energy metering of natural gas from the aspects of energy metering

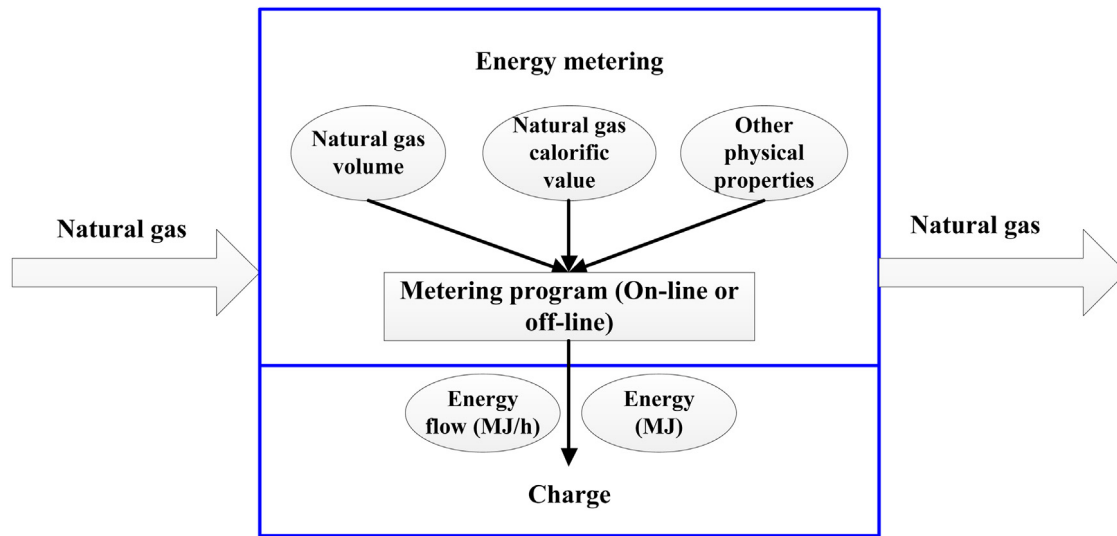


Fig. 1. Indirect determination of natural gas energy principle.

## 2. Theory

The energy of natural gas is the product of volume and calorific value. It can be expressed by Eq. (1):

$$E = Q \times H \tag{1}$$

The determination of natural gas energy can be divided into direct measurement and indirect determination. Direct measurement is to fully burn the natural gas and determine the heat released by the combustion. Indirect measurement is to determine the composition of natural gas by the chromatograph, and then calculate the energy of natural gas according to the calorific value of each component. Although the results of the direct measurement are more accurate, the experimental conditions are complex, and the applicability of the engineering is poor. Therefore, the sampling interval of the direct measurement is longer, and it is recommended to be one month. Thus, the indirect measurement method is usually used in engineering, in addition to its simple application, also enables online measurement (GB/T 22723, 2008).

### 2.1. Natural gas energy metering principle

Fig. 1 is a schematic diagram of the indirect determination of the natural gas energy principle. Indirect measurements can be divided into on-line analysis and off-line analysis. The off-line analysis method is through regular sampling, uses the off-line gas chromatograph to complete the analysis in the laboratory. It is characterized by high accuracy and poor real-time performance. On-line analysis refers to using online autosampler, online gas chromatograph and other instruments to automatically complete the natural gas sampling, component analysis, calculate the natural gas relative density, compression factor, calorific value and other parameters within the specified time interval. These parameters are passed to the database of the host system to participate in energy metering.

If the components of natural gas are known, the volume heat can be calculated according to Eqs. (2) and (3).

$$\bar{H}[t_1, V(t_2, p_2)] = \frac{\bar{H}^0[t_1, V(t_2, p_2)]}{Z_{mix}(t_2, p_2)} = \frac{\sum_{j=1}^n x_j \cdot \bar{H}_j^0(t_1)}{Z_{mix}(t_2, p_2)} \times \frac{p_2}{RT_2} \tag{2}$$

$$Z_{mix}(t_2, p_2) = 1 - \left[ \sum_{j=1}^N x_j \sqrt{b_j} \right] \tag{3}$$

### 2.2. Standard reference conditions

Standard reference conditions have three factors: pressure, temperature, and humidity. All countries in the world have adopted 101.325 kPa as the standard reference pressure. The standard reference temperature is related to the geographical position and the traditional history. There are four kinds: 0 °C, 15 °C, 20 °C, 25 °C, Table 1 lists the standard reference temperatures used in some major countries and regions. There are two kinds of standard reference humidity: dry gas and gas containing saturated water [1].

### 2.3. Natural gas energy valuation

Natural gas valuation using the “energy metering, energy settlement” approach, which is based on the average calorific value of natural gas measured during the settlement period and is settled at unit energy prices. The unit energy price of natural gas can be calculated by Eq. (4).

$$P_{energy} = P_{volume}/H \tag{4}$$

## 3. Case study

The paper takes Beijing (China) and Dali (Yunnan Province, China) urban gas systems for instance, the economics of urban gas metering are analyzed. The choice of Beijing and Dali is because they belong to different types of cities (See Table 2), so the results are more convincing. This paper compares the natural gas consumption income of two cities using volume valuation system and energy valuation system, thus proves the rationality and fairness of using the energy valuation method.

### 3.1. Analysis on the effect of urban gas energy metering in Dali

From January 1, 2016 onwards, Dali urban gas valuation began to use tiered pricing (Three grades) method and the volumetric metering method. The concrete valuation method of Dali urban gas can be seen in Table 3.

**Table 1**

Standard reference temperature for major countries and regions (PetroChina Southwest Oil & Gasfield Company, 2010).

Country or region	Combustion temperature (°C)	Volumetric metering temperature (°C)	Country or region	Combustion temperature (°C)	Volumetric metering temperature (°C)
China	20	20	United States	15	15
Canada	15	15	Russia	25	25 and 0
United Kingdom	15	15	France	0	0

**Table 2**

The main difference between Beijing and Dali on the urban gas system.

City	Pipeline network scale	Natural gas consumption in 2020 (m <sup>3</sup> )	Gas source	Summer average temperature (°C)	Winter average temperature (°C)	Average annual temperature (°C)
Beijing, China	Large	280 × 10 <sup>8</sup>	Multi-gas source	24.1	0.2	12.9
Dali, China	Small	8674 × 10 <sup>4</sup>	Single gas source	19.6	9.2	14.8

Note: The other consumption and pipeline network loss are ignored in the calculation of predict natural gas consumption in 2020.

**Table 3**

The volume valuation method of Dali urban gas.

User type	Natural gas prices					
	First grade		Second grade		Third grade	
	Consumption x (m <sup>3</sup> /a)	Price (yuan/m <sup>3</sup> )	Consumption x (m <sup>3</sup> /a)	Price (yuan/m <sup>3</sup> )	Consumption x (m <sup>3</sup> /a)	Price (yuan/m <sup>3</sup> )
Ordinary residents (No more than 4 people)	0 < x ≤ 360	3.31	360 < x ≤ 540	3.97	540 < x	4.97
Multiperson household (More than 4 people, the number is z)	0 < x ≤ 90z	3.31	90z < x ≤ 90z + 180	3.97	90z + 180 < x	4.97
The residents who enjoy the minimum living guarantee	0 < x ≤ 120	2	120 < x ≤ 360	3.31	360 < x ≤ 540	3.97
Industry and commerce				3.42		

According to the 2020 forecast of natural gas consumption in Dali, the consumption of residents is 2989 × 10<sup>4</sup> m<sup>3</sup>, the consumption of industrial and commercial users is 5685 × 10<sup>4</sup> m<sup>3</sup>. Assume the natural gas consumption of all the residents belongs to the first grade, and then the natural gas companies should charge 293,362,900 yuan (based on volumetric metering). In fact, the volume of natural gas at the point of the user is different from the volume at the urban gas gate station because of the change of temperature and pressure during the transportation process. The total amount of natural gas consumed on the user's meter can be calculated according to Eq. (5).

$$V = \frac{V_n}{\frac{T_n}{T} \frac{p_{amb} + p_g - p_{H_2O}}{p_n} \frac{Z_n}{Z}} \quad (5)$$

If calculated according to the annual average temperature of 14.8 °C in Dali, and the user's operating pressure is 5 kPa (Gauge pressure), the amount of natural gas consumed at the user meter is:  $V = \frac{V_n}{\frac{T_n}{T} \frac{p_{amb} + p_g - p_{H_2O}}{p_n} \frac{Z_n}{Z}} = \frac{86740000}{\frac{293}{287.8} \frac{101.325 + 5}{101.325} \frac{1}{0.99789}} \approx 81\,022\,657$  m<sup>3</sup>. It means that the urban gas gate station will transport 8674 × 10<sup>4</sup> m<sup>3</sup> natural gas, only charge the fee of 81 022 657 m<sup>3</sup> natural gas, natural gas companies will have 6.6% extra economic losses in 2020. The same method can be used to calculate the extra economic losses per month, as shown in Table 4.

### 3.2. Analysis on the effect of urban gas energy metering in Beijing

From January 1, 2016 onwards, Beijing urban gas valuation also began to use tiered pricing (Three grades) method and the volumetric metering method. The concrete valuation method of Beijing urban gas can be seen in Table 5.

**Table 4**

Extra economic losses per month of natural gas companies in Dali.

Month	Average temperature (°C)	Extra economic losses (%)
1	8.2	8.75
2	10.2	8.10
3	13.1	7.15
4	15.8	6.26
5	18.7	5.32
6	20.2	4.83
7	19.9	4.92
8	19.2	5.15
9	17.8	5.61
10	15.4	6.40
11	11.4	7.70
12	8.1	8.78

Similarly, in accordance with the method of Section 3.1, natural gas companies in Beijing will have 7.0% extra economic losses in 2020. The extra profit and loss situation of Beijing urban gas companies can be seen in Table 6.

### 3.3. Results and discussion

#### 3.3.1. Energy metering effect of urban gas

According to the calculation results of Sections 3.1 and 3.2, it can be obtained that Beijing and Dali urban gas companies have different economic losses in different months which caused by the difference in temperature and pressure. Fig. 2 shows that, with the increase of the temperature, the economic loss decreased. The difference in the extra economic losses in different months in Beijing is larger because of the large temperature difference in Beijing. It should be noted that Fig. 2 shows that the



**Table 5**  
The volume valuation method of Beijing urban gas.

User type	Natural gas prices					
	First grade		Second grad		Third grade	
	Consumption $x$ ( $m^3/a$ )	Price (yuan/ $m^3$ )	Consumption $x$ ( $m^3/a$ )	Price (yuan/ $m^3$ )	Consumption $x$ ( $m^3/a$ )	Price (yuan/ $m^3$ )
Ordinary resident (No more than 5 people)	$0 < x \leq 350$	2.28	$350 < x \leq 500$	2.5	$500 < x$	3.9
Multiperson household (More than 5 people)	$0 < x \leq 500$	2.28	$500 < x \leq 650$	2.5	$650 < x$	3.9
Hanged heating stove users	$0 < x \leq 1500$	2.28	$1500 < x \leq 2500$	2.5	$2500 < x$	3.9
Industry and commerce				3.78		
Electric power generation (Heating, refrigeration)				3.22		
CNG primary station	For residents			2.23		
	For non-residents			3.17		

**Table 6**  
Extra economic losses per month of natural gas companies in Beijing.

Month	Average temperature ( $^{\circ}C$ )	Extra economic losses (%)
1	-3.1	12.22
2	0.2	11.14
3	6.7	9.03
4	14.8	6.39
5	20.8	4.44
6	24.9	3.11
7	26.7	2.52
8	25.5	2.91
9	20.7	4.47
10	13.7	6.75
11	4.9	9.61
12	-1.1	11.57

natural gas company will have extra losses because it is calculated on the basis of the monthly average temperature. However, a more detailed analysis will show that if the temperature is higher, the natural gas company will gain additional profit. For example, Beijing’s highest temperature in July can reach  $39^{\circ}C$ , according to the calculation of this temperature, natural gas companies will earn an additional 1.32% profit. Therefore, urban gas energy metering is a fairer method.

3.3.2. The economic impact of urban gas energy valuation

It is necessary to analyze the influence of energy valuation on the economy after the determination of energy metering is more reasonable. Assuming that the volumetric metering and energy metering are under the same reference conditions, the analysis model can be seen in Table 8.

The following conclusions can be drawn from Table 7:

(1) When  $H > H_0$ , we can get  $(H/H_0 - 1) \times Pp \times Q > 0$ ,  $(H/H_0 - 1) \times Ps \times Q > 0$ ,  $(H/H_0 - 1) \times (Ps - Pp) \times Q > 0$ ,  $(H/H_0 - 1) \times Ps \times Q > 0$ . In other words, if using the energy valuation, when average calorific value of natural gas greater than the benchmark natural gas calorific value, the gas purchase cost, gas sales income and profit of natural gas companies will be greater than the use of volume valuation, in the meantime, the user payments will be increased.

(2) Regardless of the natural gas companies or users, the main economic impact of energy valuation is derived from the difference between the actual calorific value of natural gas and the benchmark natural gas calorific value, and the greater the difference, the greater the economic impact.

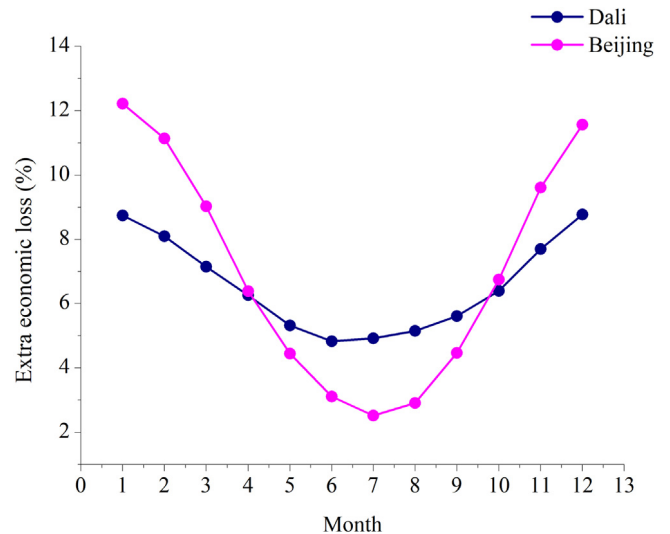


Fig. 2. The economic losses of Beijing and Dali urban gas companies in different months.

4. Establishment of urban gas energy metering system

The establishment of an urban gas energy metering system includes three parts: (1) Energy metering scheme; (2) Supporting equipment and (3) Energy valuation system. According to the scale of urban gas, gas source and other factors, energy metering scheme and supporting equipment have two different standards, such as Beijing and Dali.

4.1. Energy metering scheme

4.1.1. Scheme 1 (For cities with smaller urban gas scale)

For some cities with a smaller urban gas scale such as Dali city, because of its gas source is single and stable, taking the economy of energy metering system establishment into consideration, the scheme as shown in Fig. 3.

Fig. 3 shows an energy metering scheme for remote (or local) off-line calorific value measurement, for some cities with single and stable gas source, regular sampling can be done in urban gas gate station (such as sampling fourth a month), then send the natural gas sample to the test center and measure the calorific

**Table 7**  
Economic analysis model of the influence of natural gas energy valuation (PetroChina Southwest Oil & Gasfield Company, 2010).

Item	Valuation method	Gas consumption (volume flow)	Average calorific value of natural gas	Benchmark natural gas calorific value	Natural gas company					User payments
					Gas purchase link		Gas selling link		Profit	
					Gas purchase price	Gas purchase cost	Gas sale price	Gas sales income		
I	Energy valuation	$Q$	$H$	$H_0$	$Pp/H_0$	$Pp/H_0 \times H \times Q$	$Ps/H_0$	$Ps/H_0 \times H \times Q$	$(Ps-Pp) \times H \times Q/H_0$	$Ps/H_0 \times H \times Q$
II	Volume valuation	$Q$	$H$	$H_0$	$Pp$	$Pp \times Q$	$Ps$	$Ps \times Q$	$(Ps-Pp) \times Q$	$Ps \times Q$
I-II	-	-	-	-	-	$(H/H_0-1) \times Pp \times Q$	-	$(H/H_0-1) \times Ps \times Q$	$(H/H_0-1) \times (Ps-Pp) \times Q$	$(H/H_0-1) \times Ps \times Q$

Note: According to the temperment conditions of various gas sources in China, it is suggested that  $H_0$  take 36 MJ/m<sup>3</sup>.

**Table 8**  
Volume conversion coefficient of urban gas in Dali.

Month	Extra economic losses (%)	Volume conversion coefficient $C_{vc}$
1	8.75	1.10
2	8.10	1.09
3	7.15	1.08
4	6.26	1.07
5	5.32	1.06
6	4.83	1.05
7	4.92	1.05
8	5.15	1.05
9	5.61	1.06
10	6.40	1.07
11	7.70	1.08
12	8.78	1.10

value, the sample not only can be measured at a faraway place through traffic tools, but also can be local measured in the laboratory of urban gas gate station. The energy metering center can meter the natural gas energy after the volume conversion. Volume conversion can be achieved by defining a volume conversion coefficient, so that energy and volume can under the same reference conditions. The volume conversion coefficient can be expressed as Eq. (6).

$$C_{vc} = \frac{1}{1 - \alpha} \quad (6)$$

Take Dali city for instance, the volume conversion coefficient of each month is shown in Table 8. The volume conversion coefficient is used to multiply the amount displayed on the user's flow meter, the results obtained is the parameter  $Q$  in the energy calculation. So, the energy of natural gas can be calculated by Eq. (7).

$$E = H \times Q_c = H \times C_{vc} \times Q_m \quad (7)$$

#### 4.1.2. Scheme 2 (For cities with larger urban gas scale)

For some cities with larger urban gas scale such as Beijing city, because of its gas source is multiple, using the local on-line measurement is more reasonable, the scheme as shown in Fig. 4.

Fig. 4 shows an energy metering scheme for local on-line measurement, for some cities with multiple and unstable gas sources, regular sampling measurement cannot meet the accuracy requirement. Therefore, using on-line equipment to measure the calorific value is more rational. If a city has several urban gas gate stations, it is necessary to measure the calorific value at different stations and calculate the average calorific value of this city. Concrete calculation method is shown in GB/T 22723 (2008). Moreover, the sampling period needs to be judged based on whether the gas source of the natural gas is stable. In the implementation process, the measurement can be performed at a short time interval (for example, 10–15 min). By observing, if the measurement result of the calorific value is found to be stable, the sampling interval can be appropriately increased. Gaz de France uses a combination of off-line analysis and on-line analysis. The sampling analysis period is usually 1 h, and for large flow export station, the sampling period is 20 min. Because Beijing is a mega city, it has the characteristics of wide gas source. Such many gas sources will inevitably increase the fluctuation of natural gas calorific value in urban gate stations. Therefore, for such megacities, the sampling frequency period should be shorter. The recommended sampling period is 4–15 min.

#### 4.2. Supporting equipment

Different energy metering schemes have different supporting equipment, still in accordance with the city type, specific equipment scheme as shown in Table 9.

**Table 9**  
Supporting equipment of natural gas energy metering.

Equipment	Scheme 1 (Small scale)	Scheme 2 (Large scale)
Integrated temperature transmitter	R	R
Pressure transmitter	R	R
Differential pressure transmitter	R	R
Bimetallic thermometer	R	R
Pressure gauge	R	R
Natural gas quality analysis room	N	R
Gas chromatograph	R	N
Online composition analyzer	N	R
Flowmeter	R	R
Large flow computer	N	R

Note: R represents that the equipment is recommended to configure; N represents that the equipment is not recommended to configure.

#### 4.3. Energy valuation system

The key to natural gas energy valuation is to determine the benchmark calorific value price. In order to maintain the overall level of current natural gas volume price as far as possible, the easiest way is to convert the current natural gas volume prices to natural gas energy prices. The natural gas benchmark price can be calculated using Eq. (8).

$$P_0 = P_{volume}/H_0 \quad (8)$$

$$H_0 = \frac{\sum_{t=1}^T \sum_{i=1}^N q_{it} h_{it}}{\sum_{t=1}^T \sum_{i=1}^N q_{it}} \quad (9)$$

According to this method, take Dali as an example to establish the urban gas valuation system. Dali urban gas only has one gas source of Sino-Burmese gas pipeline, and according to the field data, the Sino-Burmese pipeline temperament component is very stable, the inferior calorific value is 33322 kJ/m<sup>3</sup> (20 °C, 101.325 kPa). Therefore, the energy valuation method is shown in Table 10.

### 5. Internet plus-based management system

In recent years, China is vigorously carried out the “Internet plus traditional industries”, it refers to using information communication technology and the Internet platform, so that the Internet and traditional industries can be deeply integrated, to create a new ecological development. It can significantly improve people's lives and improve the management efficiency of enterprises. At the same time, the framework can also promote the use of blockchain technology in urban energy management (Lu et al., 2019b). Therefore, this paper puts forward the conception of “Internet+MUGMV (Management of Urban Gas about Metering and Valuation)”.

The function of “Internet+MUGMV” mainly includes payment management services, convenience inquiry services, prepaid services, and enterprise management. The specific contents of each module are as follows (Zhang, 2015):

#### (1) Payment management service

A payment management service is the basic functional requirements of “Internet+MUGMV”. Its function mainly includes: I. Pay the cost of natural gas; II. Make a supplementary payment.

#### (2) Convenience inquiry service

Mainly includes: I. Natural gas energy valuation standard query; II. Natural gas energy consumption query; III. Natural gas volume consumption query.

#### (3) Prepaid service

Prepaid service can be used for some cities' users who using the gas card, it can online prepaid and stored fees.



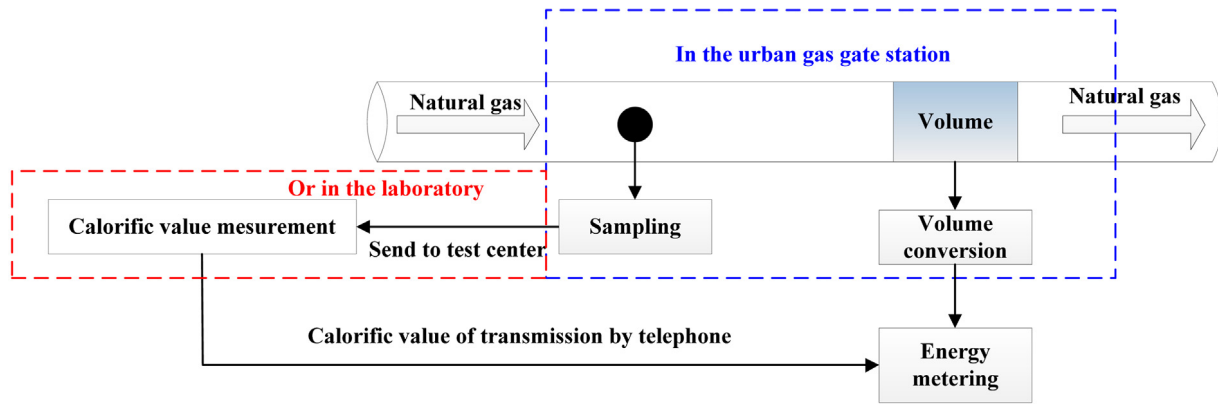


Fig. 3. Energy metering scheme for remote (or local) off-line calorific value measurement.

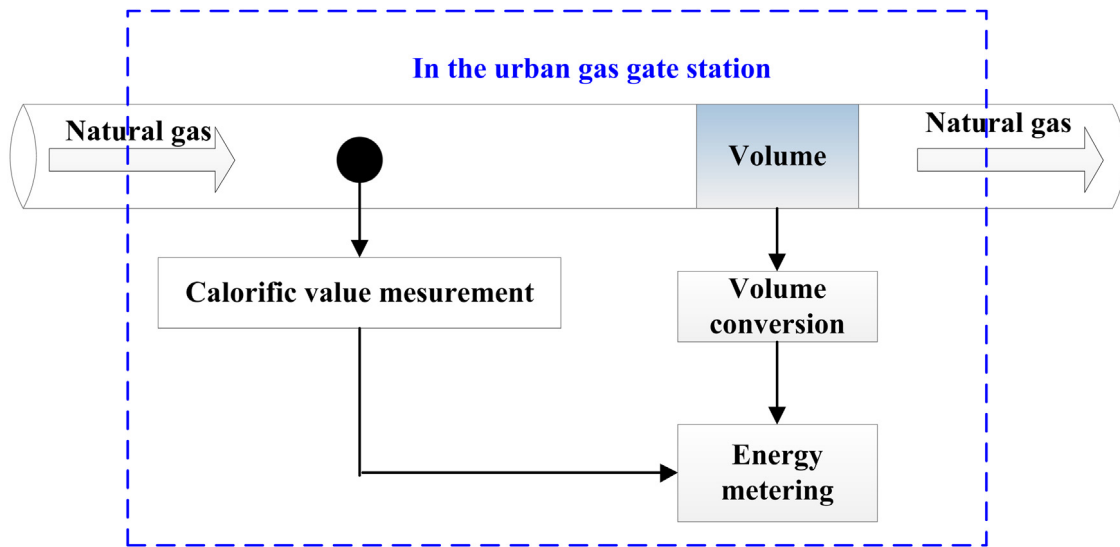


Fig. 4. Energy metering scheme for local on-line calorific value measurement.

Table 10  
The energy valuation method of Dali urban gas.

User type	Natural gas prices							
	First grade		Second grad		Third grade			
	Consumption y (MJ/a)	Price (yuan/MJ)	Consumption y (MJ/a)	Price (yuan/MJ)	Consumption y (MJ/a)	Price (yuan/MJ)		
Ordinary residents (No more than 4 people)	$0 < y \leq 11995.92$	0.09933	$11995.92 < y \leq 17993.88$	0.11914	$17993.88 < x$	0.14915		
Multiperson household (More than 4 people, the number is z)	$0 < y \leq 2998.98z$	0.09933	$2998.98z < y \leq 2998.98z + 5997.96$	0.11914	$2998.98z < y < 2998.98z + 5997.96$	0.14915		
The residents who enjoy the minimum living guarantee	$0 < x \leq 3998.64$	0.06002	$3998.64 < x \leq 11995.92$	0.09933	$11995.92 < x \leq 17993.88$	0.11914	$17993.88 < x$	0.14915
Industry and commerce	0.10264							

(4) Enterprise management

The enterprise can analyze the historical operation data according to the data on the management platform.

In order to achieve these functions, the establishment of the “Internet+MUGMV” model is needed, its system architecture can be expressed by Fig. 5.

6. Conclusions

This paper takes Dali and Beijing urban gas for instance, compared the difference between volumetric metering and energy metering, analyzed the economic impact of energy metering valuation. The main conclusions are as follows:

(1) The use of the volumetric metering method will lead to different degrees of extra economic losses or extra profit to the

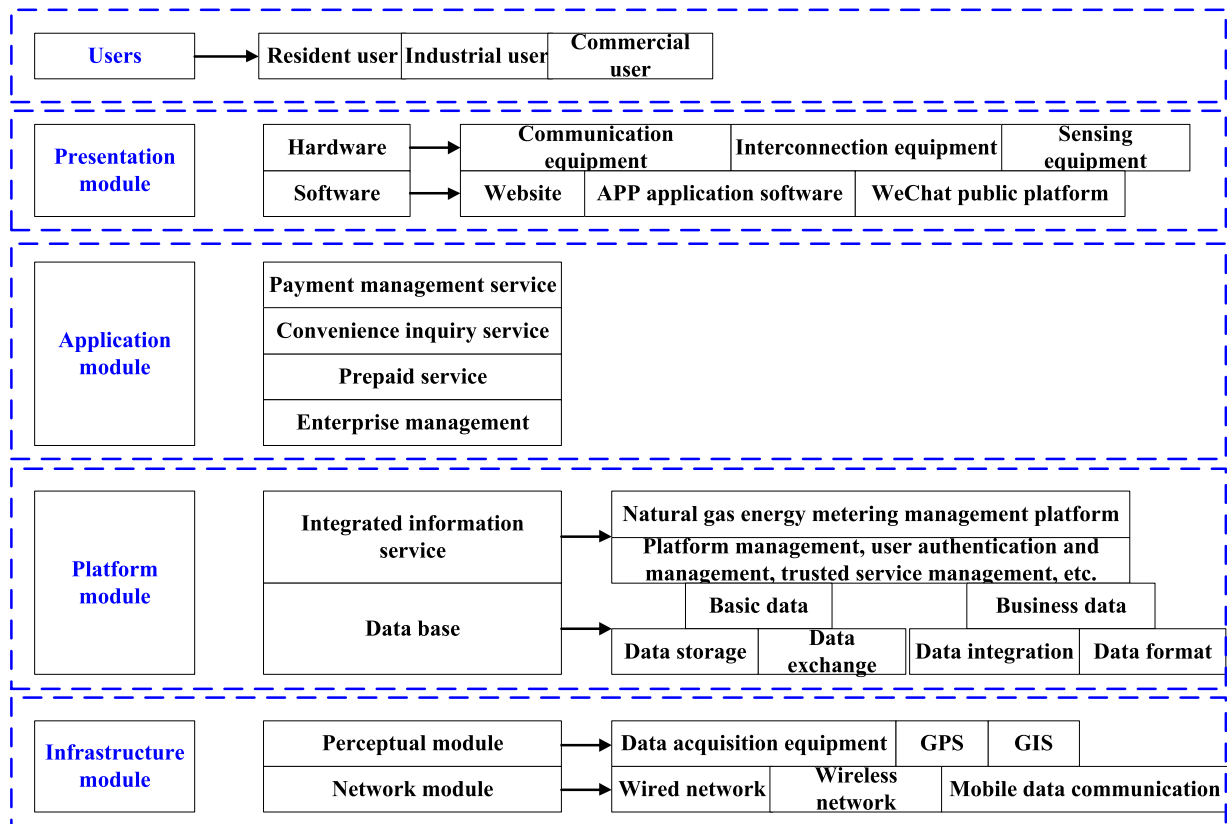


Fig. 5. System architecture of "Internet+MUGMV".

natural gas companies. The lower the temperature, the higher the extra loss. Therefore, energy metering is a fairer trade mode;

(2) The main economic impact of energy valuation is derived from the difference between the actual calorific value of natural gas and the benchmark natural gas calorific value.

In addition, the paper proposes the method of establishing an urban gas energy metering system, two different energy metering schemes are proposed for two types of cities. Finally, in order to apply the energy metering management of natural gas into the smart city, the paper put forward the "Internet+MUGMV" model, if the model can be achieved in the future, there is a problem need to pay attention to, in the early stages of the construction of "Internet+MUGMV" system, in order to avoid the problem of information sharing difficulties, the government needs to make detailed plan.

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