Research Progress on Calculation and Control of Unaccounted for Gas of Natural Gas Pipeline Network

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Abstract. At present, volume measurement is still used in transfer measurement of natural gas in China, so the calculation and management of Unaccounted for Gas are based on volume measurement. With the change of natural gas measurement method from volume measurement to energy measurement, the calculation and management of Unaccounted for Gas based on energy measurement will be paid more and more attention. This paper investigates the calculation methods and management measures of Unaccounted for Gas based on volume measurement in China and Unaccounted for Gas based on energy measurement in other countries, and compares the research progress. The results show that: the general principles of Unaccounted for Gas calculation in China and other countries are basically the same, but the calculation formulas are not completely the same. All countries consider the input gas, output gas, line pack variation and self-consumption gas. On this basis, Italy considers the known leakage, and Britain considers the known leakage and the daily calorific value shrinkage caused by its settlement rules. In order to reduce Unaccounted for Gas, the UK regularly verifies meter, carries out the research on Unaccounted for Gas baseline, and actively participates in the global Unaccounted for Gas benchmarking. Australia replaces the old main line and reduces the operation pressure of pipeline, which significantly reduces Unaccounted for Gas. The calculation methods and control measures of Unaccounted for Gas based on energy measurement in Italy, Britain and Australia can be used for reference in China.

1. Introduction

Unaccounted for Gas refers to the deviation determined by gas balance calculation of natural gas pipeline network within a certain time period. In some countries, Unaccounted for Gas can be abbreviated as UAG, UFG, UAFG, etc. In the process of natural gas pipeline transmission, UAG will be caused by measurement error, line pack calculation error and pipeline leakage. The existence of UAG affects the fairness of trade handover and is directly related to the economic benefits of enterprises. How to calculate UAG and control it within a reasonable range is an important problem faced by pipeline transmission enterprises.
2. Calculation methods of Unaccounted for Gas

2.1 the UK
Energy measurement is adopted for natural gas in the UK. The gas day in the UK is defined in line with EU standards as between 5 a.m. and 5 a.m. [1]. National Grid takes a gas day as the Unaccounted for Gas calculation cycle. The unit of Unaccounted for Gas is kWh, which is calculated as follows:

\[ U_t = \sum_{i=1}^{n} v_{i,t} - \sum_{i=n+1}^{m} v_{i,t} - (\lambda_t - \lambda_{t-1}) - (c_t + s_t + a_t) \]  

(1)

Where \( U_t \) is Unaccounted for Gas; \( n \) and \( m \) are the number of input and output nodes across the transmission system; \( v_{i,t} \) is the flow of the node \( i \) on day \( t \); \( \lambda_t \) and \( \lambda_{t-1} \) are the line pack on day \( t \) and \( t-1 \); \( c_t \) is the total daily compressor fuel usage; \( s_t \) is the daily calorific value shrinkage; \( a_t \) is network specific losses such as leakage.

The UK stipulated in The gas (calculation of thermal energy) (amendment) regulations 1997 that the daily calorific value in megajoules per cubic meter shall be rounded to the first decimal place [2,3] at the time of daily settlement. Due to this provision, there will be the calorific value shrinkage every day.

Because the volume of natural gas transported changes with time, the absolute UAG cannot represent the fluctuation of UAG, so it is necessary to introduce the concept of relative Unaccounted for Gas. The relative Unaccounted for Gas is usually expressed as the percentage of the UAG in the total gas transported across the system [1].

2.2 Italy
Italy uses equation (2) to calculate Unaccounted for Gas based on energy measurement and volume measurement, and the Unaccounted for Gas is in J or m\(^3\) [4,5]:

\[ E + S = D + SC + L + \Delta LP + UAG \]  

(2)

Where \( UAG \) is the Unaccounted for Gas; \( E \) is the natural gas entering the network from the entry; \( S \) is the natural gas extracted from (positive) and injected to (negative) the storage facilities; \( D \) is the network off-takes; \( SC \) is the self-consumption gas (i.e. gas used for compressor operation, preheating, sampling, etc.); \( L \) is natural gas losses from the network (i.e. the non-voluntary emission to atmosphere, the losses due to pipelines maintenance, emergencies, faults and leaks); \( \Delta LP \) is the variation of line pack gas.

The calculation of relative Unaccounted for Gas is the same as that in the UK, that is, the UAG accounts for the percentage of the transported (\( E \)) natural gas [4,5].

2.3 China
At present, there is no national standard for the calculation method of Unaccounted for Gas of natural gas pipeline network in China, but the calculation methods have been stipulated in the petroleum industry standards and enterprise standards.

(1) The Operation Regulation of Gas Pipeline (SY/T 5922-2012)
According to the requirements of The Operation Regulation of Gas Pipeline (SY/T 5922-2012), the calculation formula of Unaccounted for Gas is equation (3), and Unaccounted for Gas is in m\(^3\) [6]:

\[ Q_{UAG} = (V_1 + Q_1) - (Q_2 + Q_3 + Q_4 + V_2) \]  

(3)

Where \( Q_{UAG} \) is the Unaccounted for Gas in a certain period of time; \( Q_1 \) is the input gas in the same period; \( Q_2 \) is the output gas in the same period; \( Q_3 \) is the production and domestic gas consumption of gas transmission station in the same period; \( Q_4 \) is the natural gas vented in the same period; \( V_1 \) is the stored gas (line pack) of the pipeline at the beginning of the calculation time; \( V_2 \) is the stored gas (line pack) of the pipeline at the end of the calculation time.

Relative Unaccounted for Gas is calculated as follows:

\[ \eta = \frac{Q_{UAG}}{V_1 + V_2} \times 100\% \]  

(4)

(2) Calculation Methods for Transmission Loss of Oil and Gas Pipeline (Q/SY 197-2012)
According to the requirements of *Calculation Methods for Transmission Loss of Oil and Gas Pipeline (Q/SY 197-2012)*, the calculation formula of Unaccounted for Gas is equation (5), and the Unaccounted for Gas is in $m^3$. The result is positive for loss and negative for surplus.\(^7\)

$$\Delta m_h = (m_a + m_{p1} + m_{s1}) - (m_b + m_{p2} + m_{s2}) - m_c - m_f$$

Where $\Delta m_h$ is the transmission loss (Unaccounted for Gas); $m_a$ is the gas entering the pipeline; $m_{p1}$ is the line pack at the beginning of the period; $m_{s1}$ is the inventory of the gas storage tank at the beginning of the period; $m_b$ is the gas sold; $m_{p2}$ is the line pack at the end of the period; $m_{s2}$ is the inventory of gas storage tank at the end of the period; $m_c$ is self-consumption; $m_f$ is the gas vented in normal operation.

Pipeline transmission enterprises usually use the transmission loss rate (relative Unaccounted for Gas) to measure the loss. The calculation formula is as follows:

$$\eta = \frac{\Delta m_h}{m_a + m_{p1} + m_{s1}} \times 100\%$$

### 2.4 Comparison of calculation methods in different countries

In order to facilitate settlement, the UK stipulates that the calorific value in megajoules per cubic meter of natural gas is rounded to the first decimal place, which increases the complexity of Unaccounted for Gas calculation, but it is of great significance for natural gas trade settlement and is worthy of reference for China. For the self-consumption gas, the UK only includes the consumption of compressor fuel gas, while Italy includes the gas used for compressor operation, preheating and sampling. The self-consumption gas in China includes not only production gas, but also domestic gas, which is more comprehensive. However, compared with the other two countries, China's Unaccounted for Gas calculation formula does not consider the known leakage. Since the natural gas transmission volume changes with time, the Unaccounted for Gas management level should be reflected by the relative Unaccounted for Gas. The denominator of China's relative Unaccounted for Gas calculation formula includes not only the input gas, but also the line pack (and the inventory of the gas storage tank) at the beginning of the period. Therefore, it is meaningless to directly compare the relative Unaccounted for Gas data calculated by China and the other two countries. We should first unify the denominator and then compare them.

### 3. Control of Unaccounted for Gas

#### 3.1 the UK

National Grid has carried out the following measures to analyze and manage Unaccounted for Gas.\(^8\)

1. **Meter validation report reviews**

   Meter owners are obliged to undertake meter validations for each metering installations at least once a year to confirm whether the metering equipment is functioning correctly. The results are recorded in the validation reports and provided to the National Grid. National Grid can evaluate the health status and measurement accuracy of assets related to the report, which is helpful to better understand the impact of meter error on Unaccounted for Gas.

2. **Meter witnessing**

   National Grid plans and undertakes an annual meter witnessing programme. The personnel of the National Grid observe and document the testing taking place throughout the UK during meter validations. The location of the meter witnessing is selected by National Grid based on the assessment of the previous validation report or if the site has current measurement issues.

3. **Baseline UAG analysis**

   National Grid currently uses the baseline values of $\pm20$ GWh. Once this baseline values are exceeded, it will investigate potentially high levels of positive or negative UAG. Due to the variation of natural gas transmission volume, the dynamic baseline value can better help to manage UAG. The
Department of mathematics at the University of Manchester is evaluating the baseline values to provide dynamic baseline quantity.

(4) Tableau analysis
National Grid has been using Tableau software to visualize and analyze its data, which can enable the staff to identify and minimize data errors.

(5) Global UAG benchmarking
National Grid is participating in a global UAG benchmarking exercise, which is being coordinated by the Italian Network Operator. The participating Networks share methodologies and bring together techniques for managing UAG.

3.2 Australia
Australian Gas Networks (AGN) has been implementing a scheme to replace the old mains of the distribution network in recent years. From June 2010 to June 2014, Unaccounted for Gas decreased from 2182 TJ to 1426 TJ. The obvious reduction is largely due to the mains replacement program, and partly due to the reduction of the operating pressure of the pipeline. Both of these two reasons reduce the leakage rate of the pipeline [9].

In addition to mains replacement, AGN also has a number of management measures for Unaccounted for Gas distribution network, such as formulating meter management policy to ensure that all meters can be removed from the field and regularly tested for accuracy, have a comprehensive leak survey and leakage response/repair strategy to ensure that all detected and reported leaks are handled in time, promote Dial Before You Dig (DBYD) service and claim compensation from the third party causing pipeline damage in order to reduce the incidence of third party damage, replacement and refurbishment of custody transfer meter, etc [9, 10].

3.3 China
(1) Analysis methods of Unaccounted for Gas
When Unaccounted for Gas exceeds the reasonable range, the causes shall be analyzed. There are several analysis methods in China as follows.

Metering instrument first. Metering instrument first, that is, when there is Unaccounted for Gas, the metering instrument is analyzed first. Compared with leakage, the metering instrument is more likely to cause Unaccounted for Gas, and it is easier to repair the metering instrument than to patrol the line due to leakage. Therefore, in case of Unaccounted for Gas, adhere to the principle of ‘As soon as Unaccounted for Gas occurs, metering instrument shall be analyzed first’ [11].

Curve comparison. Unaccounted for Gas of the whole network and each region are made into Unaccounted for Gas curves and compared them. It is more likely that there is an Unaccounted for Gas problem in the region with a similar trend to the curve of the whole network, then we can focus on this region [12]. This method can reduce the work scope and improve the work efficiency.

Traceability. When the error of the metering instrument itself is large, the metering medium, pressure, temperature and other factors involved shall be connected through an uninterrupted comparison chain with uncertainty to connect the measurement results with higher standard instruments, so as to trace the error source [11].

Shortening period. Unaccounted for Gas analysis in China is mostly carried out in days. When there is an Unaccounted for Gas problem in the region with a similar trend to the curve of the whole network, then we can focus on this region [12]. This method can reduce the work scope and improve the work efficiency.

(2) Control measures
The control measures of Unaccounted for Gas can be summarized into two aspects: technology and management.

At the technical level, in order to improve the accuracy of measurement, the metering instrument shall be selected, used and maintained in accordance with relevant standards or regulations. During model selection, whether the selected flowmeter, pressure and temperature instrument or transmitter is
appropriate shall be determined according to the pressure, measured flow range, flow fluctuation range and gas quality of trade measurement\cite{13}. The flowmeter with high environmental requirements during installation, use and maintenance shall try to meet its conditions (temperature, humidity, etc.). Establishing an on-line flowmeter verification system or setting up a certain process to realize the online mutual inspection of flowmeter will help to find the faults of metering equipment in time\cite{14}. For stations without chromatographs, attention should be paid to sampling and analyzing gas quality in time, and relevant parameters of metering instruments should be updated in time according to the analysis results\cite{15}. In addition, in order to enhance the accuracy of line pack calculation, the enterprise should select a reasonable handover time to avoid large calculation error of line pack due to the large variation range of pipeline operating pressure and temperature at the handover time.

At the management level, we must insist on pre job training and regular skill training for metering employees to ensure that they have basic knowledge of metering equipment use and maintenance\cite{14}, and minimize the loss caused by metering error. Moreover, the natural gas pipeline network has a long distance and spans many provinces and regions. The natural gas pipeline network company shall establish a line patrol team, establish a daily line patrol system and conduct line patrol regularly, so as to find corrosion, leakage and other problems in time. Last but not least, formulate a perfect Unaccounted for Gas analysis system. Unaccounted for Gas shall be calculated and analyzed regularly. If Unaccounted for Gas fluctuates greatly, the problem shall be reported in time and effective solutions shall be taken as soon as possible. Shaanxi Natural Gas Company implements the daily Unaccounted for Gas analysis system. At 8 a.m. every day, the SCADA system calls out the temperature, pressure and flow equivalents of relevant points to calculate Unaccounted for Gas and analyzes the calculation results\cite{16}.

4. Conclusion

At present, the energy measurement of natural gas has not been implemented in China, so the research of Unaccounted for Gas is mostly based on volume measurement. The research on Unaccounted for Gas in the UK, Italy and Australia is based on energy measurement. Through the research on the calculation methods and control measures of Unaccounted for Gas in these countries, the following conclusions are drawn:

1) The general principles of calculation are basically the same regardless of Unaccounted for Gas based on volume or energy, but the formulas are not exactly the same. All countries have considered the input gas, output gas, line pack variation and self-consumption gas. On this basis, Italy has considered the known leakage, and the UK has considered the known leakage and the daily calorific value shrinkage caused by its settlement rules. It is suggested that China should formulate the national standard for Unaccounted for Gas based on energy measurement calculation as soon as possible and unify the calculation methods on the basis of comprehensively considering various factors affecting Unaccounted for Gas and drawing lessons from other countries’ calculation methods.

2) Britain rounds the calorific value in megajoules per cubic meter of natural gas to the first decimal place during trade settlement. Although this provision increases the complexity of calculation of Unaccounted for Gas, it is convenient for trade settlement and has a certain reference significance for energy measurement and pricing in China.

3) In terms of Unaccounted for Gas control and management, based on the current control measures, it is suggested that China should carry out the research on baseline of Unaccounted for Gas, actively participate in the global benchmarking activities of Unaccounted for Gas, and discuss the experience of Unaccounted for Gas management with other countries, so as to carry out Unaccounted for Gas control and management more efficiently.

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