An online sulfur monitoring system can improve process balance sheets

A Canadian gas processor used this technology to meet environmental regulations

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Sulfur emissions from sour gas processing facilities are a serious concern to the environment and personal health. Governments have implemented strict guidelines for monitoring and reporting emissions created by such processing facilities. In Alberta, Canada, the Energy Utilities Board (EUB) requires gas producers to provide a report that clearly indicates how much sulfur is brought into a plant and how much is either converted to elemental sulfur or injected as acid gas. The report is known as the S-30 Sulfur Balance Report. Producers are required to produce a balance from the inlet to outlet on sulfur tonnage with a 10% uncertainty. This is equal to ±5% of the total balance for a monthly average.

Many gas processing plants suffer imprecision in evaluating sulfur imbalance over a period of time due to the difficulties in accurately measuring and calculating the sulfur balance. A real-time online sulfur monitoring system (RTOSMS) was developed for acid gas processing plants to assist operations and management by providing real-time monitoring and reporting of sulfur imbalances.

Sulfur monitoring before RTOSMS.
A grab sample from necessary streams was taken once a month and its composition would then be used until the next sampling period. Daily sulfur imbalances for that month were then evaluated using these gas compositions, as well as the streams' average daily standard volumetric flowrates. This method, however, produced unsatisfactory results and created errors in managing sulfur balance.

The main reason this practice is insufficient is due to one or more factors:
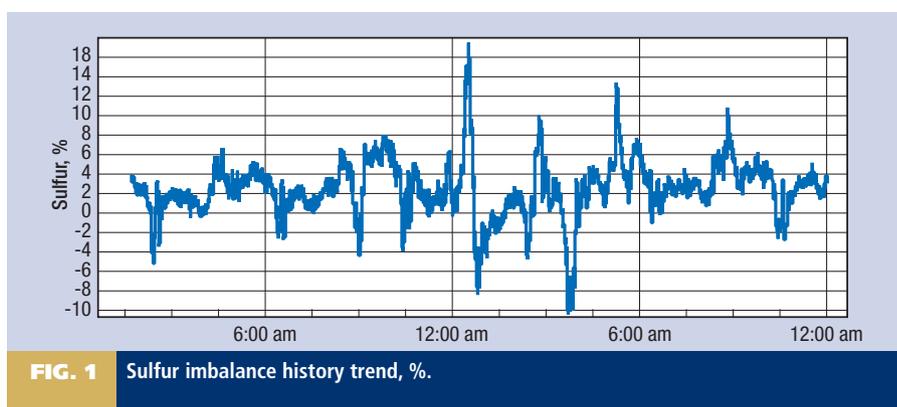• Inlet and outlet stream flow changes and its measurements

FIG. 1 Sulfur imbalance history trend, %.
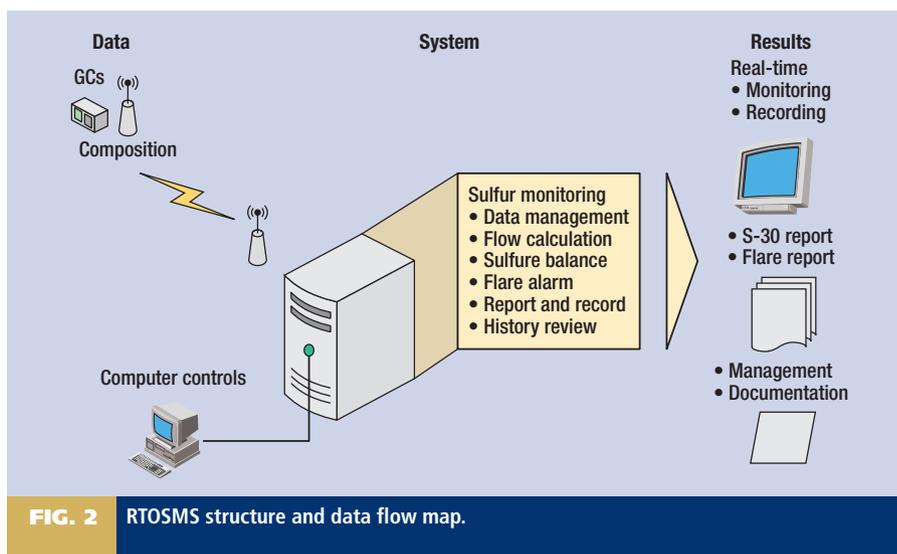

FIG. 2 RTOSMS structure and data flow map.

• Changes in each stream's gas composition and its measurements
• Changes in stream flow conditions and its measurements
• Sour gas plant processing cycle time.

Fig. 1 shows the historical sulfur imbalance trend for a 24-hr period (Pouce Coupe gas plant, February 4, 2005). Although the daily average imbalance is 2.5386%, instantaneous measurements varied between 10% and 17%. Thus, taking a grab sample anytime that day would produce different results. Also, taking grab samples at periodic times have shown errors of ±20% or more from real-time sampling.

Errors associated with grab samples are:
1. The time between sampling and analysis. Most sour gas production plants are
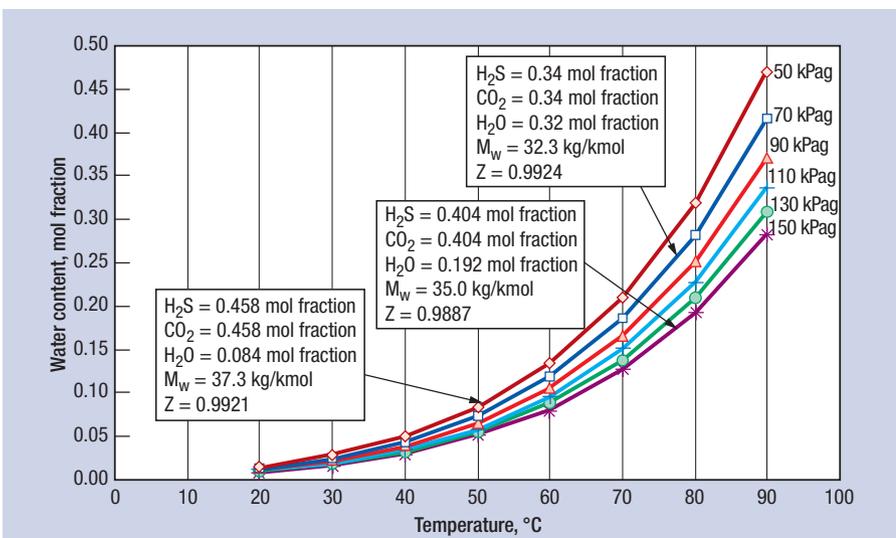
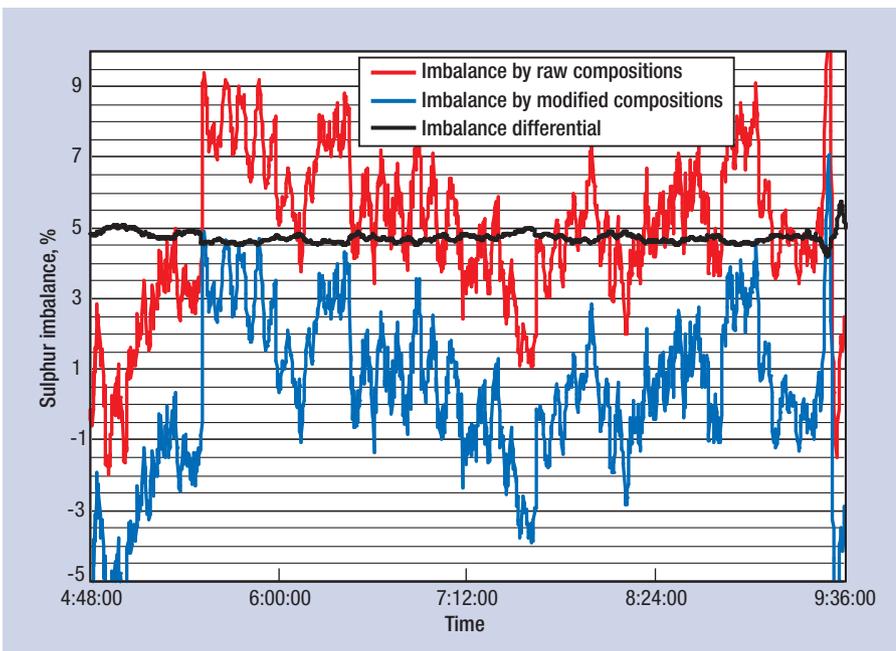**FIG. 3**   H$_2$O content (dry basis) of 50% H$_2$S and 50% CO$_2$.

FIG. 4   Sulfur imbalance correction by modified gases.

and gas compositions for all involved streams. The plant operating system provides the raw data used by the RTOSMS for process streams measurements. Gas chromatographs (GCs) are installed and can either be connected to the plant computer or directly linked to the RTOSMS engineering computer (Fig. 2).

For the Pouce Coupe project, wireless communication was used to transmit gas compositions from each installed GC. This technology was chosen because it is relatively easy to install, made the system transportable, and provided cost effectiveness since there was an installed computer control system. The RTOSMS engineering station was then connected to the plant loop to obtain raw data from the process measuring devices.

GCs can be set up to analyze one stream or multiple streams. The RTOSMS utilized one GC for the inlets and one for the outlets. This provided a workable system and prevented the high-concentration hydrogen sulfide (H$_2$S) stream from contaminating the lower-concentration H$_2$S stream.

Process data analysis sequence. Data collected from the GCs and plant computer are organized on a database platform. For the Pouce Coupe gas plant, a 10-sec. scan rate was chosen. A smaller scan rate can be used but results in needing more database storage. The 10-sec. scan rate was also sufficient in obtaining correct flow measurements. For a valid scan, the system follows this sequence to verify and calculate results:

1. Gas composition modification
2. Calculation of the standard volumetric orifice flowrate
3. Sulfur imbalance calculation and alarm monitoring
4. Flare event monitoring
5. Data reporting, recording and management

In the event that the process causes an incorrect result from either a process flow condition or disturbance, the RTOSMS automatically reports this condition and ignores the value. This is very important for analyzing streams that are very heavily saturated with water (H$_2$O), because most acid gas streams operate near or in a two-phase region. Not being able to calculate when the acid gas stream is near or on the verge of becoming a two-phase stream will result in erroneous readings.

Gas composition modification. Both the GC and grab samples only give gas composition results on a dry basis, which means that the H$_2$O in the gas stream is not included. Neglecting stream

located in rural areas and analysis labs are located in major cities. In some cases, the samples can be stored in a vehicle for more than three days before analysis.

2. Samples are taken in areas where, in case of leakage, the technician can safely evacuate away from the sample point. Because of this, sample lines are usually installed with long runs of tubing. This tubing is usually not heat traced and produces a cooling effect on process samples (30°C). This results in liquid condensation and sample distortion.

3. Process compositions can vary from hour-to-hour and day-to-day. In the event

of a plant upset, it can take as long as an hour before the plant is balanced again. Taking grab samples at the inlets and outlets when there is a production upset can result in large differences in mass balance.

To eliminate errors that are associated with grab samples, a real-time approach is required utilizing technology that helps improve accuracy and protect the workers and environment from mishaps.

RTOSMS structure. Online monitoring of sulfur imbalance and sour gas emissions is realized by continuously watching and analyzing flow, its related measurements

TABLE 1. Gas composition modification

Streams	Inlet		Outlet 1		Outlet 2	
Temperature, °C	18.8		29.8		25.4	
Pressure, kPag	3,977.6		57.2		56.9	
Gas component	**Mol %**		**Mol %**		**Mol %**	
	Raw	**Modified**	**Raw**	**Modified**	**Raw**	**Modified**
H_2O		0.0647		2.8489		2.2133
H_2S	0.8462	0.8456	48.2347	46.8606	43.5511	42.5872
CO_2	1.8299	1.8287	51.2617	49.8013	55.9694	54.7307
Methane	90.4801	90.4216	0.4664	0.4531	0.4314	0.4219
Ethane	4.5467	4.5438				
Propane	1.4092	1.4084				
i-butane	0.2189	0.2188	0.0052	0.005	0.0043	0.0042
n-Butane	0.3767	0.3764			0.0142	0.0139
i-pentane	0.0863	0.0862	0.0292	0.0284		
n-Pentane	0.1033	0.1032	0.0028	0.0027	0.0295	0.0289
Hexane+	0.1026	0.1026				
The streams calculated flowrate and sulfur production						
Flowrate, e^3m^3/d	1167.483	1162.8100	10.2261	10.2194	11.8376	11.8125
Sulfur, ton per day (tpd)	13.3401	13.3324	6.6881	6.4933	6.9903	6.8211
Sulfur imbalance	2.4738	−0.1348				

H_2O content results in calculation discrepancies of the flowrates, sulfur content and plant sulfur imbalance (Table 1). Fig. 3 shows how the saturated H_2O content of a 50% H_2S and 50% carbon dioxide (CO_2) mixture is changed due to these conditions.

A quick calculation of the sulfur content (dry basis) at 50°C would result in the difference shown in Table 2.

A method developed especially for H_2O and acid gas equilibrium was introduced to adjust the stream's gas composition according to its flowing condition (pressure and temperature) and original mol% of gas components from the GCs.[1,2,3] A complex algorithm is used to calculate the H_2O content and produce a stream mixture that is a more accurate representation of the process stream being used.

Table 1 illustrates the results of flowrates and sulfur in the streams with and without modifications. The modification performances on different streams vary. Gener-

FIG. 5   Online monitoring page.

ally, the calculated sulfur imbalance will decrease by gas composition modification because there is actually less sulfur being produced than what is expected.

The method's contribution to correcting sulfur imbalance varies from time-to-time due to the flowing conditions and gas compositions (Fig. 4). It also adds about a 5% decrease in the sulfur imbalance for this case.

From both theories and practice, a better and more reasonable calculation of flow

measurements and evaluating sulfur imbalance can be derived by gas modification and the RTOSMS. This is done by taking the H_2O content into account for gas compositions.

Sulfur imbalance calculations. The sulfur imbalance for a sour gas plant is calculated as:

$$S_\% = \left(\frac{\sum_{out} \dot{m}_s - \sum_{in} \dot{m}_s}{\sum_{out} \dot{m}_s} \right) 100 \qquad (1)$$

For each gas stream, the mass flowrate of sulfur is computed from the stream gas flowrate and the mol fraction of the H_2S in the stream.[4]

$$\overset{\infty}{m}_s = 1.35592 Q\ y_{H_2S} \qquad (2)$$

H_2O content. The H_2O mass flowrate can be calculated by:

$$\overset{\infty}{m}_{water} = \overset{\infty}{m}_{gas}\ \frac{MW_{water}}{MW_{gas}}\ y_{water} \qquad (3)$$

Flow meters and flow measurements. Careful selection of measuring devices and installation must be considered when measuring streams with high acid gas concentrations. The reason for this is not only H_2O content but also flow conditions. Due to the low pressure and viscosity of the acid gas streams, it is important that correct flow measurements are taken. It requires that the measuring devices produce very low-pressure restrictions and also prevents H_2O from obstructing or interfering with the flow measurement device.

Both vortex and senior orifice meter runs were used for the plant. However, before they could be used, installation corrections were required. Common errors found in measurements were noticed and changes made.

For a vortex meter, the standard volumetric flowrate is:

$$Q = Q_{P,T}\ \frac{\rho_{P,T}}{\rho} \qquad (4)$$

For the orifice measurement, the API Natural Gas Fluids Measurement Standard[5] is followed exactly to calculate the mass flowrate:
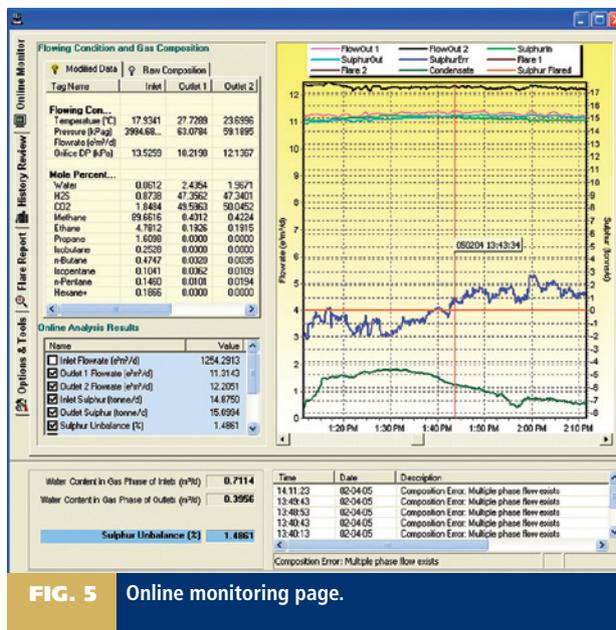
TABLE 2. H₂O content calculation for a single stream

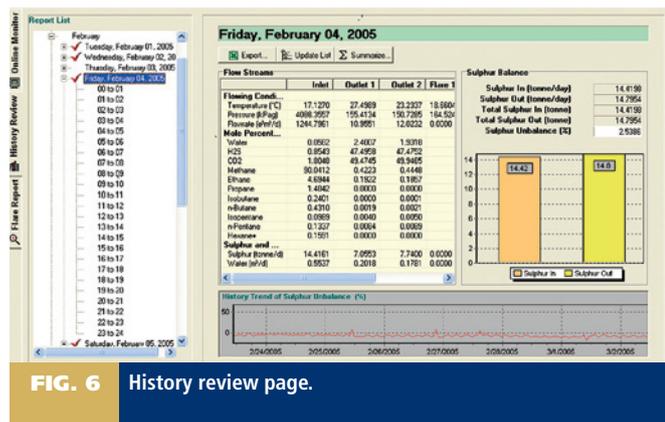| Stream composition, mol %	Flowrate, e^3m^3/day	Sulfur produced, tons	% error
50% H_2S with no H_2O content at 50°C and 50 kPag (dry basis)	10	6.78	8.4
45.8% H_2S with H_2O content at 50°C and 50 kPag	10	6.21	

FIG. 6   History review page.

$$q_m = N_1 C_d E_v Y \times d^2 \sqrt{\rho_{P,T} \times \; P} \quad (5)$$

Eq. 4 is used to convert the mass flowrate to the standard volumetric flowrate required by Eq. 2 for sulfur mass flowrate.

Gas density estimation has a great impact on equation accuracy. The American Gas Association detail characteristic method[6] is used here and can generally be expressed as:

$$\rho_{P,T} = f \; \left(P,T,(x_i) \right) \quad (6)$$

Real-time monitoring. Continuous online monitoring for the plant study included these streams:

• The inlet stream flow combines with one inlet stream off the inlet separator and a stream generated from the stabilizer overhead.

• The outlet stream flow consists of parallel acid gas streams that are generated from two processing plants. Each acid gas stream is equipped with one acid gas flare stream.

To measure stream composition, one GC is used to measure the inlets and one GC is used to measure the outlet streams. Analysis time for each stream varies from 3 min. to 5 min. depending on GC configuration.

The RTOSMS scans the online run-time data from the database every 10 seconds.

The data status check is performed first to see if there is any error in the data acquisition system. If successful, the data status checks this scan's data which will be saved to database history for later detailed analysis. This works exactly the same as the online monitoring; otherwise, this scan will be discarded and the program will wait for the next update.

For each gas stream, the calculation is applied to the GC gas composition at the measured flow temperature and pressure making the H_2O content adjustment to gas composition. The proper flow calculation procedure will be initiated according to the flowmeter and its installations. Finally, the stream's sulfur and H_2O mass flowrate will be calculated using Eqs. 2 and 3.

After finishing the calculations for all streams, the sulfur imbalance can be finalized with Eq. 1. After each scan, the data and results will be sent to the online monitor report page (Fig. 5). The sulfur imbalance will be shown in alarm color if its absolute value is larger than 5%. A trend chart, capable of various time periods, is provided to show historical results. The error-message window on the computer screen shows any error message found during processing. The most common error message is the two-phase flow error.

In addition to instant results, the hourly, daily and monthly analysis summaries will be generated and saved and automatically added to the database. The results can be downloaded to other computers and reviewed, or reports can be generated from this computer.

Historical review. The hourly, daily and monthly summaries saved in the database are managed by the time tree in the history review page (Fig. 6). This facilitates easy access to existing reports or summaries.

The RTOSMS automatically checks to ensure data has been collected for a 24-hr period. This is indicated by a red check mark beside each day. In the event that data is lost or not reported, the program treats this as lost emission monitor time which is reported monthly. This tool was added for properly managing emission control devices and it prevents any emissions devices from incorrectly recording false inputs.

An existing summary and report item can be overwritten or a new item can be added for a specified day or month manually. The selected daily or monthly report (S-30) can be exported to a spreadsheet and then printed or E-mailed depending on requirements. Fig. 7 shows the automatically filled S-30 form for the Pouce Coupe gas plant, which was generated at the beginning of the month from the monitoring software.

Flare event monitoring. It has become more important, in the past few years, that producers manage and record flaring incidents. The RTOSMS can accurately measure and record acid gas flare events.

Once a flare event happens, the start- and end-time, maximum and average standard volumetric flare flowrate and sulfur flared will be calculated and recorded to the database.

All flares are listed on the flare report page with the latest at the top, as shown in Fig. 7. The operator can navigate in the record table and attach notes to the flares. This information can then be viewed by the operators and used to fill out the required flaring report.

The flare report can be generated at any time for the selected events and is capable of daily, monthly or yearly reporting. The reports will total the duration and volumes to help manage flare events (Fig. 8).

What has been learned? The RTOSMS has been working at two Duke Energy Midstream Services gas plants for more than one year. The system's performance demonstrates that this is the right solution to help assist in the daily operation of a sour gas processing plant. System benefits include:

1. RTOSMS provides a reliable and accurate way to evaluate the sulfur imbalance for a sour gas processing plant by continuously analyzing sulfur imbalance with the latest technologies.

2. This system records all the detailed operation information about the plant electronically. It also automatically generates daily and monthly (S-30) reports for operations and management.
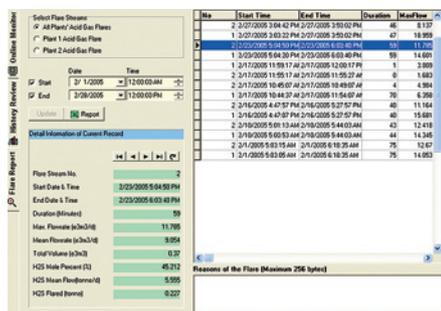
FIG. 7 Flare report page.

3. RTOSMS also provides an accurate method for measuring and recording acid gas flare events. This will help operators find out why flaring events occurred and hopefully help reduce such events by correcting the problem.

4. RTOSMS can be set up to monitor multiple plants. Data can be stored on the plant site and retrieved a distance away. For this study, the sour gas plants were located in Canada's Grand Prairie region and the data was sent to Calgary where the reports were generated. **HP**

NOMENCLATURE

Symbols:

$S_\%$	Gas plant sulfur imbalance, %
$\overset{\infty}{m}_{s_{in}}$	Gas plant inlet streams total sulfur rate, ton/day (tpd)
$\overset{\infty}{m}_{s_{out}}$	Gas plant outlet streams total sulfur rate, tpd
$\overset{\infty}{m}_s$	Sulfur stream mass flowrate, tpd
Q	Standard (@101.325 kPa, 15°C) volumetric flowrate of the gas, 1,000 standard cubic meters/day (Sm³/d)
y_{H_2S}	H_2S mol fraction in gas
$\overset{\infty}{m}_{water}$	H_2O mass flowrate, tpd
$\overset{\infty}{m}_{gas}$	Gas stream mass flowrate, tpd
MW_{water}	Mol weight of H_2O, kg/kmol
MW_{gas}	Mol weight of gas, kg/kmol
y_{water}	Mol fraction of H_2O in gas
$Q_{P,T}$	Actual volumetric flowrate of gas measured by vortex meter, 1,000 Sm³/d
P	Flow pressure, kPa
T	Flow temperature, °C
q_m	Orifice mass flowrate measurement, kg/s
N_1	Unit conversion factor, 1.11072 for SI units
C_d	Discharge orifice plate coefficient
E_v	Velocity of approach factor
Y	Expansion factor
d	Orifice plate bore diameter calculated at flowing temperature, m
ΔP	Orifice differential pressure, Pa
x_i	Gas composition modified by the RTOSMS.

Greek letters:

$\rho_{P,T}$	Gas density at flow condition, kg/m³
ρ	Gas density at standard condition (101.325kPa, 15°C), kg/m³

Subscripts:

s	Sulfur
in	Inlet streams
out	Outlet streams
H_2S	Hydrogen sulfide
H_2O	H_2O
gas	Gas
P,T	At flow pressure and temperature
m	Mass flowrate

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[5] "Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases," *AGA Transmission Measurement Committee Report No. 8,* American Petroleum Institute MPMS Chapter 14.2, Gas Research Institute, November 2003.
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Shouxi Wang has over 15 years of combined experience in engineering and software development for oil and gas handling, and transportation. He holds a PhD in petroleum engineering and a BS degree in oil and gas storage and transportation from Southwest Petroleum Institute, China. Dr. Wang has extensive expertise and experience in the software development of pipeline network simulation, pipeline leak detection and engineering applications.

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