American Journal of Mechanical and Industrial Engineering
2025, Vol. 10, No. 2, pp. 46-51
https://doi.org/10.11648/j.ajmie.20251002.12

SciencePG
Science Publishing Group

Research Article

Analyses of Technological Processes of Automobile Compressed Natural Gas Stations and Development of Methods for Loss Reduction

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Abstract

This article is dedicated to the detection and calculation of unavoidable gas losses due to the measuring devices and technological processes of auto-gasification pressure stations (CNGs), which are conditioned by the productivity of CNGs. The productivity of CNG stations operating in the territory of RA differs according to their daily charging capabilities, i.e. according to the number of existing gas pressure stations. The need of analysis and development of such methodology stems from new approaches in flow measurements, which are of high importance in ensuring uniformity of measurements in gas transportation and distribution systems. The accurate determination of CH4 emissions is of high necessity in the scope of environmental management systems, which already function according to the international requirements prescribed by ISO 14001 as well. In the territory of the Republic of Armenia the development of such a methodology result from the implementation of Article 150 of the Government Decision No. 1101-N of August 28, 2008 "On approving the technical regulation of the minimum requirements for the construction and operation of gas filling stations" of the Republic of Armenia.

Keywords

Auto-gasification Pressure Station (CNGs), Gas Loss, Error of a Gas Measuring Device, Source of Uncertainty, Standard Conditions, Working Conditions

1. Introduction

In this article, the unavoidable gas losses due to measuring devices and technological processes will be considered based on the example of a CNG station with three pressure stations and five gas station dispensers [2], paying great attention to the type and capabilities of the measuring device at the entrance, since the accuracy of the amount of gas entering the CNG station is of great importance for the calculation of losses, as well as in the gas supplier's commercial calculations. Currently, the measuring devices at the entrance of CNG stations operating in the territory of the Republic of Armenia are mainly flowmeters working with flow restrictors (orifice plates), or turbine or rotary meters working with electronic correctors. The technical and metrological characteristics of the mentioned flowmeters do not meet the working conditions in the pipeline caused by

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Received: 20 March 2025; **Accepted:** 1 April 2025; **Published:** 28 April 2025

the operating modes of the compressor stations. Therefore, a flowmeter with a different working principle will be considered in the article, which with its technical and metrological capabilities responds to the working conditions caused by CNGs working modes. By correctly determining the volume of entering and sold gas, it is possible to determine the actual volumes of gas spent on the needs and lost due to technological processes, also to control the balance between entered and sold gas volumes by CNG station, as well as to contribute to the uniformity of measurements in the gas system and increase the commercial efficiency of each CNG station.

2. Materials and Methods

The technological losses of gas and the gas spent on the needs in CNG consist of the following factors:

1) undercounting of gas caused by the error of gas measuring devices (V_m),
2) gas losses due to technological processes (V_{tp}),
3) heating of production premises and buildings (V_h).

$$V_{CNG} = V_m + V_{tp} + V_h \quad (1)$$

2.1. Gas Losses Due to the Undercounting of Gas Measuring Devices

Undercounting of gas volume caused by the error of gas measuring devices for CNG stations' is calculated by formula (2).

$$V_m = \Delta_m^{ed} + \Delta_m^{gd} \quad (2)$$

where:

Δ_m^{ed} - the error of entrance measuring device, %,

Δ_m^{gd} - the error of a gas station dispenser, %:

The gas undercount caused by the error of the natural gas input measuring device is calculated according to the error given in the verification certificate of the input measuring device. However, considering that the measurement error is only one of the sources of uncertainty in the measurement, it is necessary to study the other quantities that have a significant effect on the measurements made by the CNG input measuring device in order to perform an accurate calculation of the natural gas loss. It should be noted that the dynamic processes occurring in the CNG pipeline are very different from the processes occurring in the pipelines of the gas transportation system, because one or more gas pressure stations are installed at a certain distance after the measuring device, depending on the productivity of the CNG. Back in 2015-2016 in Russia referred to the measuring devices for determining the volume of gas working under special conditions caused by dynamic processes in the pipeline depending on the condition and working modes of CNG equipment. The operation of gas pressure stations causes noises in the pipeline, as well as when the gas pressure station stops working, gas is pushed back to the measuring device, which is a hydraulic shock to the measuring device [10]. Although back pressure valves are widely used in RA, their resistance to hydraulic shocks and gas pressure in pipelines has not been tested, so it is not possible to talk about the effectiveness of these valves. In addition to hydraulic shock, which damages measuring devices equipped with mechanical parts and causes an unregulated and unrecorded error, gas backflow is not metered by current measuring devices, as the current measuring devices used in the territory of the Republic of Armenia are single-way flow meters.

Based on the above-mentioned studies carried out at Gazprom Transgas Moscow Ryazan-1 CNG Plant in Russia, we can note that the difference between the results of the two-way recording 4-beam reflective flow meter and the results of the single-way flow meter is 0.46%-0.56%.

In addition to the accuracy of the above-mentioned measurements the measurement result in working condition is brought to standard conditions, for checking the balance of gas purchased and sold by CNG. Bringing the results measured under working conditions to standard conditions in the territory of the Republic of Armenia is carried out by temperature and pressure conversion devices or electronic correctors installed on industrial flowmeters, which convert the volume of gas in dependence of gas density (ρ), which is not measured at the moment due to the absence of a density meter in the given measuring pipeline, but is mostly adopted as a conditional constant value (ρ = 0.7100, average value of gas density), which in turn is a source of unregulated uncertainty. The RA National Metrology Body posts the average daily values of gas density imported into Armenia for a month. Therefore, using these values, we can compare graphically (Figure 1) the density adopted as a conventional constant value and the density values of gas imported during November [11], which in turn is a source of uncertainty in the gas volume measurement result.

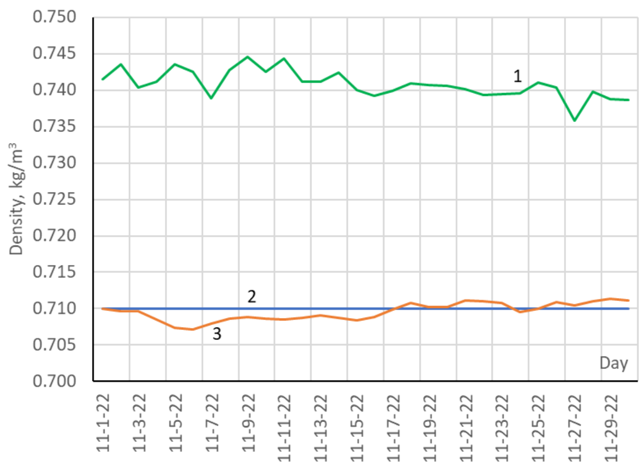

Figure 1. *The comparison of values of ρ of natural gas 1) imported from Islamic Republic of Iran, 2) adopted as a conventional constant value and 3) imported from Russian Federation.*

Therefore, in order to exclude at least one source of uncertainty, it is recommended to consider and use such measurement devices or flowmeter complexes, the bringing to standard conditions of which does not depend on the averaged density of the gas, but at least on the component composition of the natural gas, which has a minor effect on recalculations and bringing to standard conditions. One of that type of measuring instruments are flowmeters working on the ultrasonic principle, whose conversion factors are temperature and pressure, which are measured at the given moment.

Undercounting of gas volume due to the error of the gas station dispenser is calculated by the following formula:

$$\Delta_m^{gd} = \pm\sqrt{\Delta_1^2 + \Delta_2^2 + \ldots + \Delta_n^2} \quad (3)$$

where:

Δ_n - the error of n^{th} measuring instrument, %,

n - the number of the measuring instrument.

2.2. Gas Losses Due to Technological Processes in CNGs

The sources of technological losses in CNG stations are:

1) the accumulator testing (performed once two years in RA),
2) the gas volume consumed on blowdowns of technological equipment,
3) the gas losses conditioned by the tightness of accumulators' shut-off valves,
4) the gas losses conditioned by the tightness in gas pipelines,
5) the gas losses conditioned by the tightness of shut-off valves,
6) the gas losses conditioned by the emissions of vent stacks of technological equipment [6].

Losses of natural gas caused by the emptying of technological equipment during planned-preventive repair works or tests according to [8] are calculated by the following formula:

$$V_{at} = (VPT_{st})/(P_{st}TZ) \quad (4)$$

where:

V - the geometric volume of technological equipment to be emptied before repair or testing, m^3,

P_{st} , T_{st} - the pressure and temperature under standard conditions, MPa, ℃,

P , T - the operating pressure and temperature before emptying, MPa, ℃,

Z - the gas compressibility coefficient under operating conditions.

The losses of natural gas caused by the blowdowns in the oil-water separators of the compressor station (CS) and the pipeline according to [8] are calculated by the following formula:

$$V_{bd} = N(V_1 P_1 T_{st1})/(P_{st1} T_1 Z_1) \quad (5)$$

where:

N - the number of oil-water separators, pcs,

V_1 - the geometrical volume of a technological equipment to be blowdowned, m^3,

P_{st1} , T_{st1} - the pressure and temperature under standard conditions, MPa, ℃,

P_1 , T_1 - the operating pressure and temperature, MPa, ℃,

Z_1 - the gas compressibility coefficient under operating conditions.

Losses of natural gas conditioned by the tightness of CNG accumulators' shut-off valves and accumulator according to [3] are calculated by the following formula:

$$V_a = V_t^L K_P K_O t\, n^v 10^{-3} \quad (6)$$

where:

V_t^L - the permissible amount of gas losses from one gas well in 1 day, which according to [9], under conditions of average pressure (7.5 MPa) is equal to 70.4m^3.

K_P - the coefficient that take into account the deviation of the actual average gas pressure in the pipeline from the gas pressure during the test,

K_O - the coefficient taking into account the actual conditions of operation,

t - the calculation period, day.

n^v - number of accumulators, pcs,

The natural gas losses conditioned by the tightness of pipelines according to [3] are determined by the following formula:

$$V_{tp} = 3.14\sum_{i=1}^{n}\left(D_i^P L_i^P\right) V_l^t K_P K_T K_D K_O \tau \quad (7)$$

where:

D_i^P - the inner diameter of the i-th gas pipeline segment, m,

L_i^P - the length of the i-th gas pipeline segment, m,

V_l^t - the amount of permissible gas losses during the tightness test of the gas pipeline, from 1m^2 of surface per day, m^3,

K_P, K_T, K_D - coefficients that take into account the deviation of the actual average gas pressure, average temperature, and average internal diameter of the gas pipeline respectively, from the gas pressure, temperature, and internal diameter of the gas pipeline during the test,

τ - the calculation period, day,

n - the number of gas pipelines, pcs.

The natural gas losses conditioned by the tightness of shut-off valves according to [3] are determined by the following formula:

$$V_{tv} = V_0 K_P K_T K_O t 10^{-3} f_i \quad (8)$$

where:

f_i - the surface of i-th shut-off valve, m^2,

V_0 - the amount of permissible gas losses during the hermeticity test of the gas pipeline, from $1m^2$ of surface per day, $V_0 = 0.3548$ $m^3/m^2 \cdot$day,

K_P, K_T - the coefficients that take into account the deviation of the actual average gas pressure and average temperature, respectively, from the gas pressure and temperature during the test.

Technological unavoidable losses of natural gas due to the emissions of vent stacks of technological equipment according to [4] are determined by the following formula:

$$V_{vs} = A_\Phi \sum_{i}^{n=1} \left(D_{\Phi i}^2 P_{\Phi i}^{ave} t_{\Phi i} N_{\Phi i} \right) \quad (9)$$

where:

A_Φ - the constant coefficient, which takes into account the critical mode of gas leakage and is equal to 2.37 m/MPa s,

$D_{\Phi i}^2$ - the inner diameter of the vent stack (pipe), m,

$P_{\Phi i}^{ave}$ - the average gas pressure before the flow cut, MPa,

$t_{\Phi i}$ - the duration of the emission, s,

$N_{\Phi i}$ - the number of emissions in the calculation period, times,

n - the number of vent stacks in the calculation period, pcs.

2.3. Gas Consumed for CNGs Needs

The gas consumed for the CNGs needs is the gas consumption for heating of production premises and buildings.

The volume of the gas consumed for heating of production premises and buildings according to [4] and to [5] is determined by the following formula:

$$V_h = 3.6 Q_H^S / q_{lsh} \eta_h \quad (10)$$

where:

Q_H^S - the seasonal heat demand of the heating system, kWh,

q_{lsh} - the lower specific heat of gas, kJ/m^3,

η_h - the average useful efficiency coefficient of heating boilers.

3. Results

Calculating the technological losses of the CNG station with three pressure stations and five gas dispensers using the above formulae and comparing it with the volume of incoming gas, we have the following result (Table 1):

Table 1. *Calculation of November technological losses of a CNG plant with three compressor stations and five gas station dispensers.*

The volume (529240 m3) of entered gas in calculation period (31 days)			
The source of gas loss	**Symbol**	**Estimated value (m^3)**	**Estimated value in comparison with incoming gas (%)**
Error of measuring device	V_m	0.000	3.736
Accumulator testing	V_{at}	0.000	0.000
Tightness of accumulator	V_a	344.557	0.065
Blowdowns	V_{bd}	13.032	0.002
Tightness of shut-off valves	V_{tv}	0.133	0.000025
Tightness in gas pipelines	V_{tp}	64.200	0.012131
Heating	V_h	63.414	0.011982
Total		485.337	0.092

Based on the above calculations, we can note that the technological loss in the CNG station is about 4.541% depending on the equipment used and the processes implemented. As well, taking into account the capabilities of the measuring device at the entrance, i.e., in the absence of the possibility of measuring the return flow, to the above value will be added the average of the 0.46%-0.56% (0.51%) the undercount caused by the measurement uncertainty. As a result, it turns out that the unavoidable monthly natural gas loss of CNG stations is 5.051%, though not taking into account the source of uncertainty arising from the difference between ρ of natural gas and ρ, which is taken as a conventional constant quantity for bringing the measured result to standard conditions.

4. Discussion

The implementation of above-described methodology for calculating the gas volume lost by technological processes [1] and used for own needs with its patented program for each CNG plant in order to perform monthly calculations will contribute to:

1) the correct determination of the actual volumes of natural gas,
2) ensuring the uniformity in gas measurements,
3) accurate estimation of emissions of CH_4 to the environment [7]
4) increasing the commercial efficiency of each CNG plant.

5. Conclusions

Currently, the measuring devices at the entrance of CNG stations operating not only in the territory of the Republic of Armenia, but worldwide are mainly flowmeters working with flow restrictors (orifice plates), or turbine or rotary meters working with electronic correctors, whose technical and metrological characteristics sometimes are worn out and do not meet the working conditions in the pipeline caused by the operating modes of the compressor stations, it is recommended to study and if possible, replace with flowmeters working on a different state-to-the-art working principle, which with their technical and metrological capabilities respond to the working conditions caused by CNGs working modes for example the above mentioned the two-way recording 4-beam reflective flow meter. Still there is a need in further studies of working principles of industrial flow meters and corresponding modifications.

Abbreviations

CJSC	Closed Joint Stock Company
NUACA	National University of Architecture and Construction of Armenia
HGSV	Heat and Gas Supply and Ventilation
CNGs	Compressed Natural Gas Station
CNG	Compressed Natural Gas
RA	Republic of Armenia

Author Contributions

Anna Sahakyan: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft

Siranush Egnatosyan: Formal Analysis, Methodology, Resources, Software, Visualization, Writing – original draft

Funding

This work is not supported by any external funding.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Anna Sahakyan: Development of quality and metrology systems in gas transportation and distribution systems, development and production of new or modified flow metering systems, production of natural gas detection devices, production of natural gas analyzers, investigation of calculation in natural gas losses in state-to-the-art technological processes and accidents.

Siranush Egnatosyan – Associate Professor of HGSV Chair. In 2011 participated in and completed advanced training courses "Energy Audit and Audit Equipment", "ESCO Establishment and Basic Business", organized by USAID. In 2022 took second place in the innovation technology competition and received the "Look into the Future" medal. Currently is a researcher in the program "Maintenance and development of the Construction and Urban Economics Research Laboratory". The main research fields are energy efficiency of building using heat pumps systems and renewable energy sources.

Research Field

Anna Sahakyan: Metrology, heat and gas supply, energy efficiency, energy saving, system management.
Siranush Egnatosyan: Thermal-energy, heat and gas supply, heating, ventilation, energy efficiency, energy saving, heat pump.