



Unaccounted for gas in natural gas transmission networks: Prediction model and analysis of the solutions



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ABSTRACT

One of the main issues in the management and control of Natural Gas (NG) transmission networks is represented by Unaccounted-for-Gas (UAG), that is the quantity to be necessarily considered in the network balancing equation to take into account the unavoidable measuring errors.

Even though this aspect has been continuously investigated in the scientific literature, few studies are available concerning UAG sources and related uncertainty estimation by considering pipelines typology, operative and environmental conditions, metrological performance of the installed measuring systems, procedures used to perform the network balancing and to estimate each term of the balancing equation including the losses and line-packs terms.

In this paper the authors investigate the UAG sources and evaluate the criticalities related to UAG estimation—prediction, besides the possible actions aimed at reducing UAG quantity in different NG transmission networks. To this purpose, the authors investigate the UAG in some relevant NG transmission networks, statistically analyzing annual and monthly trends of UAG and evidence UAG sources, with particular reference to the influence of the uncertainty of the measuring plants. In fact, inaccurate measurements can be responsible of large UAG, with potentially significant economic losses for all players in the system. Finally, the authors point out that the main UAG sources are related to some systematic measurement errors associated to climatic conditions and propose a simplified model to predict UAG value.

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1. Introduction

Nowadays, modern markets for energy fluids through pipeline networks, such as fuels, natural gas (NG), heat and water, require complex technologies for their management, together with adequate measuring systems and devices for the monitoring of the fluxes. As a consequence, the balancing of each network represents a fundamental tool for its management from several points of view: i) economic, in order to correctly allocate costs among the users (Feldmann et al., 2000; Filho, 2000), ii) operational, in order to guarantee a safe operation of the network (Bell, 2013), and iii) environmental to reduce greenhouse gases emissions (Barroso et al., 2009).

In the case of NG, the balancing potentially involves extraction and production, treatment, regasification, storage, transmission and distribution. As a consequence, the network balancing

involves a large number of users and applies to a wide geographical area. Furthermore, in modern networks, and especially in the Italian one, gases from different origins are continuously transported (i.e. LNG, biomethane, shale gas) and mixed. Chemical and physical properties of NG mixtures for the Italian transmission network are available in Table 1, evidencing that a significant variation of the resulting NG mixture is registered. Even though the network balancing in the considered interval of time (generally one month or one year) should be performed in terms of mass or energy (that are conservative quantities), today's technologies only allow direct measurements of NG volumes. Measurements are then converted to volumes at base conditions (15 °C and 101,325 Pa) by measuring the NG operative temperature and pressure and employing auxiliary volume conversion devices. Unfortunately, this could not be sufficient because NG present a wide variability of its composition and does not obey to ideal gas model. Since different NG densities can be measured at the same base conditions, the volume conversion to base condition does not guarantee the closure of the network balancing equation. Such data can be obtained by measuring the NG

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Table 1

Chemical and physical properties of NG mixture at Italian transmission network inlets (data from SNAM Rete Gas).

Composition	Unit	Imports Tarvisio (Russian NG)	Imports Passo Gries (North European NG)	Imports Mazara del Vallo (Algerian NG)	Imports Gela (Libyan NG)	Imports Panigaglia (LNG)	Inlets Ravenna Terra (Italian NG)	Inlets Falconara (Italian NG)	Interconnection LNG Edison Minerbio
Methane (CH ₄)	% mol	97.078	90.461	88.027	85.454	89.954	99.610	99.436	92.750
Ethane (C ₂ H ₆)	% mol	1.368	4.695	7.186	6.671	7.730	0.067	0.017	6.159
Propane (C ₃ H ₈)	% mol	0.415	0.983	1.270	1.842	1.188	0.014	0.002	0.319
Isobutane (C ₄ H ₁₀)	% mol	0.063	0.151	0.119	0.283	0.135	0.006	0.008	0.038
n-Butane (C ₄ H ₁₀)	% mol	0.067	0.157	0.168	0.446	0.124	0.001	0.001	0.053
Iso Pentane (C ₅ H ₁₂)	% mol	0.015	0.040	0.030	0.112	0.001	0.004	0.003	0.013
n-Pentane (C ₅ H ₁₂)	% mol	0.012	0.031	0.027	0.076	0.001	0.003	0.003	0.009
Esani +	% mol	0.007	0.046	0.031	0.016	0.000	0.002	0.000	0.002
Nitrogen (N ₂)	% mol	0.794	2.159	1.751	3.558	0.806	0.278	0.448	0.521
Carbon dioxide (CO ₂)	% mol	0.169	1.243	1.292	1.438	0.000	0.015	0.080	0.111
Helium (He)	% mol	0.012	0.034	0.099	0.104	0.000	0.000	0.002	0.025
Oxygen (O ₂)	% mol	—	—	—	—	0.061	—	—	—
Higher Heat Value (H _S)	kJ m ⁻³	38.189	38.787	39.720	39.656	40.559	37.714	37.601	39.579
Lower Heat Value (H _L)	kJ m ⁻³	34.408	34.997	35.864	35.828	36.619	33.957	33.854	35.702
Density (ρ)	kg m ⁻³	0.702	0.754	0.769	0.794	0.749	0.682	0.683	0.727
Compressibility factor (Z _b)	—	0.99790	0.99767	0.99753	0.99747	0.99754	0.99800	0.99801	0.99770
Wobbe Index	kJ m ⁻³	50.451	49.456	50.136	49.254	51.863	50.541	50.347	51.403
Relative density	—	0.573	0.615	0.628	0.648	0.612	0.557	0.558	0.593
Molecular weight	kg kmol ⁻¹	16.57	17.78	18.14	18.73	17.68	16.10	16.13	17.14

chemical composition by means of process gas chromatographs (GC) or of NG analyzers, that have been recently developed for the on-field analysis. Alternatively, it is possible to associate remotely measured values to the terms of the network balancing equation by means of the so-called Homogeneous Areas (HA) system (i.e. geographical areas of the network characterized by a constant NG quality within a prescribed approximation range).

Thus, for a safe and efficient network management, it is necessary to guarantee high-quality and effective NG flow-rate measurements, together with related thermodynamic and chemical–physical properties, such as pressure, temperature, density and heat value (H_S). Nevertheless, because of the unavoidable measuring errors and of the statistic evaluation of some terms, the closure of the network balancing equation is not achievable in practice. As a consequence, it is crucial to understand the nature of the errors affecting the UAG estimation (i.e. the difference between left-hand side and right-hand side of the balancing equation) and, in particular, if these errors are physiologic or if they are related to the unavoidable decay of the measuring systems and components of networks (Belyaev and Patrikeev, 2002; Nilsson, 1998; Upp, 2013).

Even though UAG has been investigated in several transmission networks – such as the British (National Grid, 2009), United State's (Grady, 2013), Canadian (Alberta Utilities Commission, 2009), New Zealand (Wabnitz and Hughson, 2007), Californian (Meshkati et al., 1993), Italian (Dell'Isola et al., 2010) – just few studies are available in the scientific literature concerning the UAG sources (National Grid, 2009) and the related uncertainty estimation. Furthermore, the available studies not always take into account: i) the effects on UAG of the different pipelines typologies; ii) the operative and environmental conditions; iii) the metrological performance of the measuring systems; iv) the procedures used to perform the network balancing and to estimate each term of the balancing equation included losses and line-packs.

In this paper the authors analyze UAG sources and evaluate the criticalities related to UAG estimation–prediction, together with the potential actions aimed at reducing UAG amount in different natural gas transport networks. To this aim, the authors:

- i) investigate UAG in some relevant NG transmission networks (with particular reference to the Italian one and to networks of different size);

- ii) present a statistical analysis of annual and monthly trends of UAG aimed at evaluate the correlation between the UAG and the climatic and network process parameters (NG pressure, temperature and flow-rate);
- iii) analyze the different approaches for the network balancing with reference to a short (month) and a long (year) interval of time;
- iv) investigate UAG sources, with particular reference to the measuring plants metrological performance (in fact, inaccurate measurements can be responsible of large UAG, with potentially large economic losses for all players in the system).

From the proposed investigations, the authors evidenced that the main UAG sources are generated by some systematic measurement errors, that are strongly related to climatic conditions. Finally in this paper a simplified model is proposed to predict UAG value.

2. Natural gas transmission network balancing

The physical and commercial balancing of a NG transmission network consists of managing the NG from the network entry points (i.e. importation, production and storage) to the delivery points.

In theory, the network balancing equation (1) can be written in terms of:

- mass (in this case the measured volumes must be converted to the equivalent mass; nevertheless, it must be underlined that the same mass of different gases can generate different energy as a consequence of their different H_S);
- energy (in this case the balancing equation refers only to the potential NG energy, neglecting contributions due to work, and both sensible and latent components of thermal energy of the entering and leaving NG; besides, it is always required to convert NG to the equivalent potential energy);
- volumes referred to base conditions, which cannot be strictly considered to be a conservative quantity, because of the non linear behavior of the compressibility factor with the NG composition which is extremely variable in some networks, such as in the Italian one as shown in Table 1.

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