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Experimental Study on the Effects of Hydrogen in Gas Distribution Customer Service Lines: Stratification in Risers and Meter Aging

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Abstract

Introduction: The injection of hydrogen into the existing gas networks, known as hydrogen blending, has been widely proposed as a transitional solution to reduce carbon emissions while rapidly facilitating the integration of hydrogen-based technologies. The current natural gas infrastructure can accommodate modest hydrogen volume concentrations ($c_{v,H2} < 10\%$) without significant alterations to thermo-fluid dynamic properties or natural gas quality. Nonetheless, several studies have reported functional limitations on components and equipment in high and medium-pressure infrastructure. Conversely, detailed research on the operational impact of hydrogen blending on low-pressure distribution network equipment, particularly in customer service lines, remains limited. This lack is particularly relevant not only due to potential safety risks but also because of the fiscal implications related to legal metrology in domestic gas meters (GMs). In light of this context, two key aspects must be addressed across different hydrogen blends: the stability of the mixture in gas risers and the metrological integrity of gas meters. In gas risers, stratification effects due to hydrogen's lower density must be analyzed to prevent localized hydrogen enrichment when gas is withdrawn. Existing studies offer conflicting results on hydrogen stratification, with some reporting significant separation in stagnant conditions, while others suggest the effect does not persist over long periods [1] [2]. These discrepancies highlight the need for further experimental studies to clarify hydrogen behavior in real-world distribution networks. Meanwhile, GMs must ensure accurate billing measurements: since natural gas is metered volumetrically rather than based on energy content that is not inherently conserved, measurement errors can become significant when gas meters operate with gas mixtures they were not originally calibrated for. This issue is particularly pronounced with a high presence of hydrogen in the mixture, as certain metering technologies may exhibit accuracy drift over time when exposed to varying gas compositions [3] [4].

Objectives: This study aims to expand the available dataset and validate it under real operational conditions, testing various blending levels up to $c_{v,H2}$=10%. Accordingly, this work:

- Investigates hydrogen stratification phenomena in vertical gas risers, under stagnation conditions, measuring the difference in concentration of hydrogen from the highest and lower point in a vertical column over daily and weekly timescales.
- Assessing the accuracy drift of domestic GMs under prolonged exposure to several hydrogen blends, determining the average volumetric flow measurement error.

Material and methods: The experimental activity was carried out at CENTRIA S.r.l test facility, which included two main modular, separately instrumented operational sections: the vertical riser section and the GMs Section. The experimental setup for the gas riser section consists of an isolated vertical steel gas riser, 4 meters high (h_{max}), with a 40 mm pipeline nominal diameter. Pressure and temperature sensors and gas sampling ports for chromatographic composition analysis are positioned at three sampling points: Pt.1, Pt.2, and Pt.3 (respectively at $h/h_{max}=0.05$, $h/h_{max}=0.5$, and $h/h_{max}=0.95$). Two tests were performed: a high-resolution daily short-term analysis with hourly measurements and a weekly long-term stability test with a 12-hour resolution. Gas composition analysis was performed using an on-site gas chromatograph, which sampled gas at different heights using pure Helium and Argon as carrier gases. Instead, the meters under test (MUT) included two ultrasonic meters (US), one thermal mass meter (TM), and one diaphragm meter (D). Each meter applied temperature-compensated conversions in compliance with MID Directive 2014/32/EU [5]. The tests were conducted using natural gas along with hydrogen blends containing 2%, 5%, and 10% hydrogen by volume. To simulate real-world usage, a domestic boiler operated for two weeks under continuous and intermittent (3-hour cycle) conditions. Before and after this extended operational period, metrological drift was further evaluated through laboratory tests conducted in an accredited facility in pure methane gas: involving meter removal, acclimatization, methane testing, and subsequent reinstallation in the test facility.

Results: The results for gas risers confirm the long-term stability of the hydrogen-natural gas mixture. The daily test recorded a maximum concentration difference of less than 0.2% between the highest (Pt.3) and lowest (Pt.1) sampling points, while the weekly test showed even average smaller variations, with differences ranging from -0.03% to 0.34%. The Spearman correlation coefficient (ρ_{sp}= 0.924 - 0.989, p-value < 0.05) indicates a strong positive monotonic relationship, demonstrating that concentration values remain stable over time without divergence. The experimental results from field tests indicate that the Thermal-Mass Gas Meter (TM-G4) exhibits a consistently negative measurement error across all hydrogen–natural gas mixtures, with a clear drift increasing with hydrogen concentration, reaching a maximum underestimation of -22.55% for the $c_{v,H2}$=10%, resulting in severe billing inaccuracies. In contrast, ultrasonic and diaphragm gas meters show significantly lower measurement deviations, remaining within ±1.5% and well within regulatory limits [5].

Laboratory tests before and after hydrogen exposure reveal distinct responses among different metering technologies. Specifically, the MUT-4 diaphragm meter exhibits higher drift errors at low flow rates, while the MUT-2 thermal-mass meter maintains errors within the Maximum Permissible Error (MPE) limit. The MUT-(1,3) ultrasonic meters show a positive drift, with measurement errors decreasing as the hydrogen concentration increases. These long-term deviations do not significantly alter the considerations of the fiscal impact.

Conclusions: This study suggests that hydrogen-natural gas mixtures remain stable in vertical risers, with no clear evidence of stratification under stagnant conditions. Minimal concentration differences and strong monotonic correlation indicate negligible separation effects over time, supporting the feasibility of hydrogen blending in low-pressure networks. On the other hand, metrological assessments highlight technology-dependent accuracy variations. Thermal mass meters progressively underestimate flow as hydrogen content increases, raising concerns over billing accuracy. In contrast, ultrasonic and diaphragm meters show lower deviations, remaining within ±1.5% and regulatory thresholds. Laboratory tests further suggest distinct metrological drifts due to hydrogen exposure, though these variations appear insufficient to significantly impact fiscal accuracy. The adoption of next-generation meters with integrated hydrogen detection would enhance metering reliability, while, in the absence of stratification, optimized mixing strategies at injection points are sufficient to ensure uniform hydrogen distribution within the gas risers.

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