Optimal Gas Flow Model for Evaluating the Fluid Dynamic Feasibility of Transporting Hydrogen-Natural Gas Blends in Gas Networks

Guzzo Gabriele[1]*, Carcasci Carlo[1]
* corresponding author: gabriele.guzzo@unifi.it
[1] University of Florence via Santa Marta, 3 50139 Florence (IT) Phone: +39 055 275 8783

Keywords: Hydrogen; Linepack; Natural Gas Pipeline; Optimal Gas Flow;

Abstract

Blending hydrogen in gas networks has the potential to support the development of the hydrogen economy and facilitate decarbonisation in the gas sector. However, due to the different properties of natural gas and hydrogen, fluid-dynamic models are needed to assess transport feasibility. This work introduces an optimal transient gas flow model for homogeneous NG-H_2 blends, incorporating linepack management to ensure system flexibility. A topologically simple case study highlights the main features of the model. A second case study, based on a real gas transmission network, evaluates the feasibility of transporting NG-H_2 blends with 20% mol H_2. The results confirm the robustness of the model and its effectiveness in conducting fluid dynamic feasibility studies to support the decarbonization of gas networks.

Introduction: Natural Gas (NG) is regarded as a transition fuel due to its comparatively lower carbon intensity in comparison with coal and oil. A significant number of countries have developed extensive NG infrastructure, including transmission pipelines and distribution networks [1]. Nevertheless, despite its advantages, NG is still a fossil fuel and is not considered a long-term sustainable solution to climate change. In the context of the ongoing energy transition, a shift towards electrification wherever feasible is being explored, complemented by the idea of repurposing existing gas infrastructure for H_2 transport. In fact, green H_2 is a clean energy vector that retains the advantage of being transported in gas form [2]. Consequently, the development of dedicated analytical tools to evaluate the fluid-dynamic feasibility of NG-H_2 transportation via large-scale gas networks is necessary [3].

Objectives: The work presents an optimization framework embedding a transient gas flow model for homogeneous NG-H_2 mixtures that also considers linepack constraints in the planning problem. The goal is to use the optimal gas flow (OGF) model developed to study the feasibility of transporting homogeneous NG-H_2 blends in a large-scale gas transmission network considering a multi-day planning horizon.

Material and methods: The analysis includes two case studies. The first one is a simple but representative pipeline system with a demand node at the end of the pipeline and a compressor station at the supply point. The second case study is a real national gas transmission network. The length of the network is 7560 km network (including loops and laterals) containing 11 NG sources and 21 compressor stations.

A gas network can be modelled as a graph where elements such as nodes, pipes, and compressors are connected. The fluid-dynamic model adopted for the pipe is a 1-dimensional unsteady state isothermal model. The numerical scheme used to discretize the partial differential equations, namely the continuity and the momentum equation is the first-order backward discretization scheme in time and the first-order forward difference scheme in space. The unsteady state model is initialized with the fluid-dynamic solution obtained through a steady-state model. The gas properties are modelled by the SRK equation of state. The optimization function minimizes resource usage (gas supplied) while incorporating a penalty term for linepack consumption [4]. The resulting problem is a non-linear, non-convex problem implemented in an optimization framework and solved through an interior point optimizer named Ipopt [5].

Results: The first case study is used to demonstrate that by omitting the penalty term on linepack usage in the optimization function, the gas supply is interrupted for several hours. This phenomenon can be attributed to the fact that the model interprets linepack as a zero-cost NG source. This solution, although feasible, is not representative of real gas pipeline operation. The second case study is used to demonstrate the model capacity on a large-scale national gas network. The results demonstrate the fluid-dynamic feasibility of transporting blends of NG and H_2 containing 20% mol H_2. The pressure losses increase by up to 20% for blends containing 20% mol H_2 compared to pure NG and compressors offset these losses by operating with higher pressure ratios.

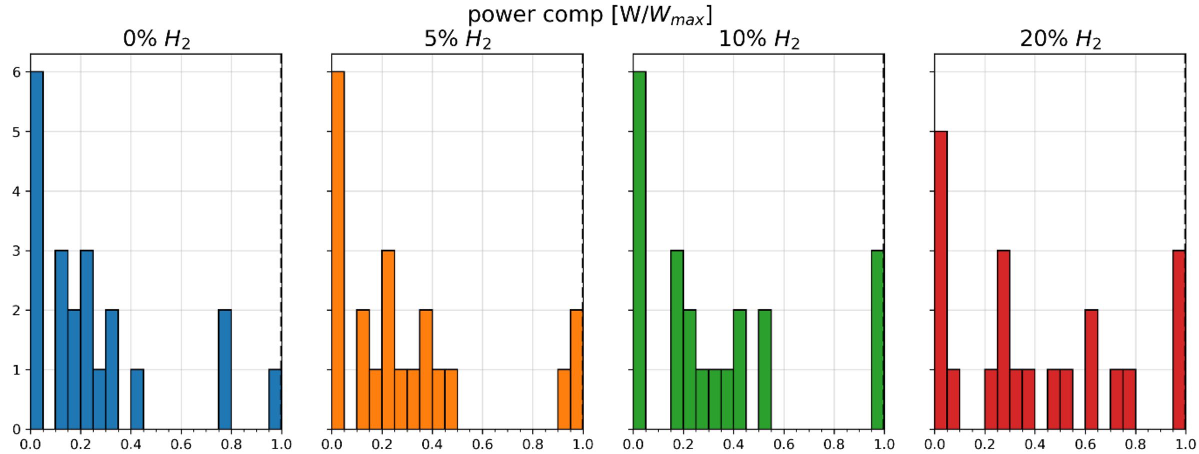

Figure 1 Distributions of compressors' power consumption (relative to the maximum compressor power), at peak demand, for several NG-H2 blends

Conclusions: The OGF presented can effectively assess the fluid-dynamic feasibility of transporting NG-H_2 blends in large-scale networks.

Moreover, it was demonstrated that not including a linepack usage penalty term in the OGF formulation can yield misleading optimal solutions characterized by unacceptable progressive linepack reduction. OGF models must incorporate linepack management, as solutions showing a decrease in linepack indirectly diminish the pipeline's safety margin, thereby compromising the network's ability to manage unforeseen events. The model demonstrates the fluid-dynamic feasibility of transporting 20% mol H_2, decarbonizing 7.80% of the energy transported by the network.

Acknowledgment

References

[1] Guzzo G, Cheli L, Carcasci C. Hydrogen blending in the Italian scenario: Effects on a real distribution network considering natural gas origin. Journal of Cleaner Production 2022;379:134682. https://doi.org/10.1016/j.jclepro.2022.134682.

[2] Cavana M, Leone P. Solar hydrogen from North Africa to Europe through greenstream: A simulation-based analysis of blending scenarios and production plant sizing. International Journal of Hydrogen Energy 2021;46:22618–37. https://doi.org/10.1016/j.ijhydene.2021.04.065.

[3] Arya AK, Katiyar R, Senthil Kumar P, Kapoor A, Pal DB, Rangasamy G. A multi-objective model for optimizing hydrogen injected-high pressure natural gas pipeline networks. International Journal of Hydrogen Energy 2023;48:29699–723. https://doi.org/10.1016/j.ijhydene.2023.04.133.

[4] Tran TH, French S, Ashman R, Kent E. Linepack planning models for gas transmission network under uncertainty. European Journal of Operational Research 2018;268:688–702. https://doi.org/10.1016/j.ejor.2018.01.033.

[5] Wächter A, Biegler LT. On the implementation of an interior-point filter line-search algorithm for large-scale nonlinear programming. Math Program 2006;106:25–57. https://doi.org/10.1007/s10107-004-0559-y.

COPYRIGHT FORM

In submitting and article, I grant ATENA scarl to publish the abstract.

I certify that:

- I'm authorized by my co-author to enter into this arrangements.
- I warrant, on behalf of myself and my co-authors, that:
  - the document is original, has not been formally published in any other journal, is not under consideration by any other journal.
  - I am/we are the sole author(s) of the article and have full authority to enter into this agreement and in granting rights to the Publisher that are not in breach of any other obligation.

I/we declare that corresponding author or one of the co-authors register, pay any applicable registration fees for that conference, attend, and present the work.

Title of the abstract

……Optimal Gas Flow Model for Evaluating the Fluid Dynamic Feasibility of Transporting

Hydrogen-Natural Gas Blends in National Networks……………………

Authors

………Gabriele Guzzo, Carlo Carcasci ………………………………………………………………

Author's signature　　　　　　　　　　　　　　　　　　　Date

………………………………　　　　　　　　　　　　　　…………………………

Should you have any questions about the new process or about adding your co-authors, either now or once the process has started, please contact info@europeanfuelcells.com