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Review

Optimization problems in natural gas transportation systems: A state-of-the-art review

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HIGHLIGHTS

- A review on optimization of natural gas transportation systems is presented.
- Gathering, transmission, and distribution systems are reviewed.
- Steady-state and transient models are analyzed.
- The most promising research challenges are highlighted.

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ABSTRACT

This paper provides a review on the most relevant research works conducted to solve natural gas transportation problems via pipeline systems. The literature reveals three major groups of gas pipeline systems, namely gathering, transmission, and distribution systems. In this work, we aim at presenting a detailed discussion of the efforts made in optimizing natural gas transmission lines.

There is certainly a vast amount of research done over the past few years on many decision-making problems in the natural gas industry and, specifically, in pipeline network optimization. In this work, we present a state-of-the-art survey focusing on specific categories that include short-term basis storage (line-packing problems), gas quality satisfaction (pooling problems), and compressor station modeling (fuel cost minimization problems). We discuss both steady-state and transient optimization models highlighting the modeling aspects and the most relevant solution approaches known to date.

Although the literature on natural gas transmission system problems is quite extensive, this is, to the best of our knowledge, the first comprehensive review or survey covering this specific research area on natural gas transmission from an operations research perspective. The paper includes a discussion of the most important and promising research areas in this field. Hence, this paper can serve as a useful tool to gain insight into the evolution of the many real-life applications and most recent advances in solution methodologies arising from this exciting and challenging research area of decision-making problems.

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1. Introduction

Natural gas [1] is an essential energy source for the future. Its manifold benefits include low greenhouse gas emissions and relatively reduced capital costs, which make its position competitive in most of the sectors among other energy sources, particularly for new power generation facilities. Global projections in natural gas reserve levels are also a clear indication of the increasingly important role that natural gas will play to support growth in markets through 2035. Fig. 1 shows global projections in natural gas reserves by geographic regions, where the largest concentrations are observed in Eurasia and the Middle East.

The performance of natural gas as a primary energy source is highly representative within three specific natural gas end-use consumption sectors, namely, (a) the residential/commercial, (b) industrial and (c) electric generation sectors. Fig. 2 shows world projections of energy consumption by end-use sector and fuel through 2035. Electric power sector projections are shown separately in Fig. 3, with the addition of nuclear power projections. These figures reveal that most of natural gas consumption is concentrated in the (b)- and (c)-sectors, accounting for 87% of the total world natural gas consumption, with an average growth of 1.7% and 2.0% per year, respectively, through 2035.

Natural gas consumption can significantly be affected by short term factors, such as weather, fuel switching and price/market variability. However, it is the long term demand factors that reflect the basic trends for natural gas use into the future. For example, the most likely important long term driver of natural gas demand in the (a)-sector is heating applications (see Fig. 4). The percentage increase in the number of new households using natural gas for heating over the next 20 years is expected to provide a strong driver for residential natural gas demand.

In the (b)-sector, two long-term driving forces may be observed due to the movement away from energy-intensive manufacturing processes, namely: the increased energy efficiency of equipment and processes, and the shift to the manufacture of goods that require less energy input. Although these factors lead to modest increases in energy demand, the trend is expected to hold into the future.

In the (c)-sector, the long-term factor is primarily attributable to natural gas-fired combined cycle generation plants, which require relatively low capital investments and provide emission reductions from using natural gas as opposed to other fossil fuels. The U.S. Energy Information Administration (EIA) expects 60% of new electric generation capacity built by 2035 will be natural gas combined-cycle or combustion turbine generation. Readers

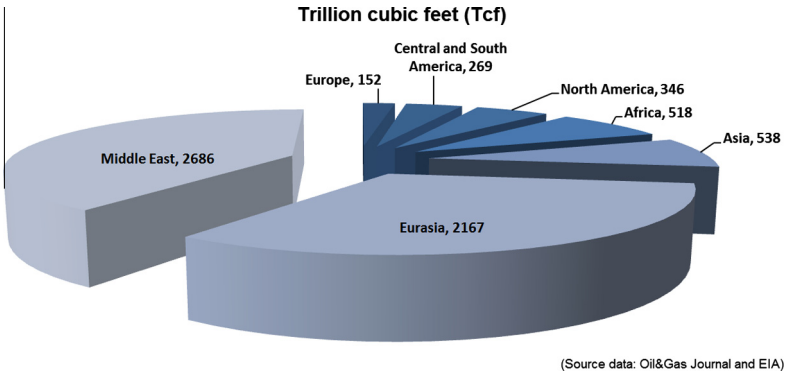

Fig. 1. Projected world natural gas reserves by geographic region.

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