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Review on Gas Leakage from Pipeline Structure

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Abstract: The transportation of gas through pipelines is complex process and possess risks of leakage. The design and supply chain of gas pipelines should be properly done in order to meet demands and reduce risks. The current research reviews various works conducted in the field of pipeline design and supply chain. The standards defining pipeline materials and cross sections used for transporting different types of fluids is presented. The analytical equation of gas flow and pipeline network system is developed by various researchers is also presented in the paper.

Key Words: Pipeline distribution, safety, gas leakage

1. INTRODUCTION

Pipeline systems are divided in three major categories based on the type of fluid transported: oil pipelines (both crude and refined petroleum), natural gas pipelines and others (water, chemical, slurry, etc.) [1]. When compared with other methods of transportation, such as tankers, railroad, trucks, etc., it has been stated that the transportation of oil, gas and their products through pipelines is still safe and economically efficient [2]. Although most pipes are made from steel, some oil pipelines and distribution lines can be also made from plastic materials. Pipe diameters vary from 4 to 48 inches (102-1219 mm) for oil pipelines and 2 to 60 inches (51-1524 mm) for gas pipelines, where small diameters are used for gathering and distribution lines Several standards, issued jointly by the American National Standards Institute (ANSI) and American Society of Mechanical Engineers (ASME), are used to design pipelines in the United States.

The standards are:

- ANSI/ASME Standard B31.1, Power Piping [4]
- ANSI/ASME Standard B31.3, Chemical Plant and Petroleum Refinery Piping [5], which is applied to main onshore and offshore facilities worldwide.
-ANSI/ASME Standard B31.4, Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia, and Alcohols [6].
-ANSI/ASME Standard B31.8, Gas Transmission and Distribution Piping Systems [7].

The first step in the design of a new pipeline is projecting the route based on the original and destination points, so that topography of the pipeline route can be determined. Subsequent major steps in piping design require input parameters, such as [8]:

- Volumetric flow rate of the fluid carried by pipe
- Fluid type, temperature and quality
- Maximum operating pressure for the pipeline
- Minimum pressure required at the destination points
- Ambient temperature

2. LITERATURE REVIEW

Welch et al. [9], for example, proposed to deal with this problem by using other fuels and optimizing a number of scheduled interruptions whenever the gas flow broke down. In addition, they showed that the availability of large industrial contracts was an important factor in containing the peak demand.

More recently, Contesse, Ferrer, and Maturana [10] conduct a study on the natural gas supply chain, in which they infer that the changes in the gas industry regulatory system have lead to several alternatives for absorbing demand fluctuations based on contractual strategies of, for example, the use of storage facilities. They mainly refer to two types of contracts: (a) a sale customer contract on a supply interruptible basis in which customers have their gas supply shortened during periods of peak demands in exchange for a lower price; and (b) the firm transportation contract, which allows shippers to reserve a portion of the pipeline's total delivery capacity for their own use.

From the mathematical programming perspective, some attempts, although few, have been made in the direction of mathematical planning models for the line-packing problem [11, 12, 13, 14, 15]. For instance, de Nevers and Day [11] examine the natural gas pipeline inventory from a mathematical perspective to match time-varying demands with supplies in an unsteady-state pipeline network system. Their study is based on two dimensionless parameters for the packing and drafting behavior. As a result, their model is capable of showing the limits of the line-pack line-drafting for a single pipeline segment.

Carter and Rachford [12] discuss several control strategies to operate pipeline network systems through periods of fluctuating loads. Their study aims at finding an optimal schedule for the line-pack under uncertain demand assumptions. As a result, they provide a number of possible scenarios with specific schedules for modifying the set-point values of compressor stations.

Krishnaswami, Chapman, and Abbaspour [13] present a simulation approach for optimizing pressure units of compressor stations to meet a specific line-packing along transient, non-isothermal pipeline network systems. They first formulate an implicit finite difference model to provide a flow capacity analysis, and then propose a nonlinear programming model to minimize the average fuel consumption rate of each compressor station over a given planning horizon. The model is solved by applying a sequential unconstrained minimization technique based on a directed grid search method that solves the unconstrained subproblems. Due to the complexity of problem, their study is, however, limited to a linear (gun-barrel) pipeline network system with two compressor stations composed of three compressor units each.

Frimannslund and Haugland [14] follow the ideas presented in the work of Carter and Rachford [12], and propose a mathematical formulation to cope with line-packing levels for a pipeline network system in steady-state conditions. Their study is based on homogeneous gas batches, a concept introduced in [28]. The concept refers to the creation of a number of batches (gas packages) inside the pipelines for their future scheduled withdrawal. The "homogeneous" term in turn establishes that all gas batches are made of the same gas composition no matter when they are constructed, thus implying the assumption that all gas sources in the network provide gas of the same quality. Due to this assumption, no quality constraints on the transported and delivered gas was required. According to [14], a blending process between the batches inside the pipeline seems to be unrealistic unless a long lasting shortfall in downstream capacity takes place.

Borraz-S´anchez [15], motivated by the work of Frimannslund and Haugland [14], proposes and implements a mixed-integer nonlinear programming (MINLP) model and a global optimizer-based mathematical programming algorithm for solving large-scale natural gas transmission networks problems under steady-state assumptions. Unlike Frimannslund and Haugland's work, the key idea behind Borraz-S´anchez's MINLP model is to build up 'heterogeneous' batches (i.e., gas packages of possibly different composition) for a multiple-time period planning horizon. This strategy basically allows the model to account for gas sources that may provide gas of different quality, thus resulting in a more sophisticated model.

An essential assumption of Borraz-S´anchez's work is to consider that no blending process among the batches takes place inside the pipelines [14], which is a rather common practice in the gas industry. Moreover, a fundamental part of Borraz-S´anchez's model is also its capability to keep track of energy content and gas quality to ensure that contract terms are met. The model assumes a specific gas quality at the sources (which may be determined by producers), and satisfies the gas quality imposed at the terminals. Here, several gas streams of different composition may be blend at junction points of the network in order to meet the quality requirements. The inherent problem in satisfying natural gas quality requirements, which directly introduces an NP-hard problem known as the pooling problem [16, 17].

More recently, Zavala [18] presents a stochastic model to solve the line-packing problem. The model also captures the network dynamics by discretizing the governing partial differential equations in time and space. Zavala considers a gas network with links comprising long pipelines and nodes consisting of junction points and compressors. The proposed model is a representation of a stochastic optimal control model that considers conservation and momentum equations, typical operational constrains, and uncertainty in demands. The author performs a degrees-of-freedom (DOF) analysis to verify the consistency of the model and uses the underlying results to derive consistent initial conditions and non-anticipativity constraints. In addition, the author also incorporates a risk metric into the objective function to mitigate cost variance and system volatility. The computational study demonstrates the benefits obtained with the stochastic formulation against the deterministic and robust counterparts. Darcy's law, and equations of state [19]. Basically, the bigger, shorter, and colder the pipeline containing lighter gasses is, the more flow is permitted.

Menon [19] establishes that the pipeline resistance, also referred to as the maximum flow capacity in a pipeline, is strongly dependent on the physical properties of pipelines and the composition of the gas. Thus, during the last century several equations were proposed to simulate compressible gas flow in long pipelines, including the Weymouth equation (developed in 1912), the Panhandle A equation (developed in 1940), and the Panhandle B equation (developed in 1956). The equations were developed from the fundamental energy equation for compressible flow, but each has a special representation of the friction factor to allow the equations be solved analytically. In addition, they differ from each other by the method used to create them and the number of parameters used to define them. For low pressures and short pipeline, they may not be applicable. The works of Osiadacz [20], Crane [21], and Modisette [22] provide complete details of these equations.

Katz et al. [23] a graphical correlation for the z-factor as a function of pseudo-reduced temperature and pressure based on experimental data is presented. As a result, the Standing-Katz z-factor chart has been used to obtain natural gas compressibility factors for more than 40 years.

Dranchuk and Abou-Kassem [24] used the equation of the state to fit the Standing-Katz data and extrapolated to higher reduced pressure. This was accomplished by a simple mathematical description of the Standing-Katz z-factor chart. The CNGA method [25] was developed by the California Natural Gas Association (CNGA) to compute the z-factor based on the gas specific gravity, temperature and pressure values. This method has been in use since the last century. One of its first applications is reported by Davisson [25], who makes use of the method in a computer program for precise flow calculations.

More recently, Borraz-S´anchez and Haugland [26] make use of the CNGA method to compute gas compressibility values in pipelines along natural gas transmission systems. The AGA-NX19 method is used to compute z-factor values based on the gas specific gravity and the average temperature and pressure conditions. The method was developed in a research project supported by the American Gas Association (AGA) between 1956 and 1962 .

3. CONCLUSION

The distribution network of natural gas is continuously evolving process and demands higher flexibility. The analytical and numerical methods can be used to predict the natural gas distribution network to meet specific demands of a region. From the optimization perspective, there are still quite a few areas that pose a wide range of challenges to the scientific community.

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