PIPELINE ENGINEERING

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Contents

Summary

Pipelines are lifelines of the global oil/gas industry, providing economic, reliable means to transport oil and natural gas from upstream production to downstream refineries, power stations and markets, crossing nations, oceans and continents. This theme introduces the key topics contained in the discipline of pipeline engineering, such as pipeline design and construction, operation, instrumentation, maintenance, integrity management, corrosion and its control, etc., with the anticipation of imparting a fundamental, comprehensive understanding of pipeline engineering.

1. Introduction

Pipelines have provided economic, reliable means to transport oil and natural gas from upstream production, often very remote regions, to downstream refineries, power stations and markets, crossing nations, oceans and continents. The pipelines could be very large in diameter, e.g., a Russian pipeline system has diameter up to 1422 millimeters, and can be over several thousands of kilometers in length (Hopkins, 2007). Most of pipelines are underground and undersea, while some operate above ground.

Pipelines are lifelines of the global oil/gas industry, contributing to strong national economies to most countries. For example, in Canada, a total length of over 580,000 kilometers of pipeline network transports 97% of crude oil and natural gas production from the producing regions to markets throughout Canada and the United States. Statistics show [Canadian Energy Pipeline Association, 2007] that Canadian pipelines transport approximately 2.65 million barrels of crude oil and equivalent and 17.1 billion cubic feet of natural gas daily. Moreover, virtually all oil and gas exports – worth $38 billion in 2005 – are carried by pipelines. With an asset value of approximately US$20 billion, the Canadian pipelines are anticipated to double in size by 2015 to meet the forecasted oil/gas production increases.

Transportation of liquids and gases by pipelines has been used for thousands of years. Ancient Chinese and Egyptian used pipes to transport water, hydrocarbons and even natural gases (Hopkins, 2007). Today's pipeline industry was originated from the oil business that brought considerable amount of profits to the energy producers and pipeline operators. Nowadays, pipeline development has been driving by the expanding energy demands. In addition to be one of the most environment-friendly and the safest means for oil and natural gas transportation, pipelines have been integrated into the components of national security in most countries.

Pipeline Engineering as a specific subject of major has been enriched significantly its connotation with the development of pipeline industry. Understanding pipeline engineering needs a comprehensive knowledge ranging from pipeline design, construction, instrumentation and control to maintenance, inspection, integrity management and corrosion and stress corrosion cracking prevention. A complete review of Pipeline Engineering on both engineering application and scientific knowledge is contained in this theme. It is anticipated that a fundamental, comprehensive understanding about pipeline engineering will be developed to provide insights into the essence of pipeline engineering to oil/gas transportation, economic development, environmental sustainability and the community and society as a whole.

2. Pipeline Engineering as a Discipline

There are many similarities and differences between Pipeline Engineering and other engineering discipline, such as Chemical Engineering, Mechanical Engineering, Civil Engineering, etc. Compared to these conventional Engineering subjects, Pipeline Engineering is still in infancy in terms of its short history. The first major exploitation and commercialization using pipelines started 150 years ago, and the building of long distance, large diameter pipelines was pioneered in the 1940s (Hopkins, 2007). With the continuously increasing energy demands and rapid expansion of the worldwide pipeline network, Pipeline Engineering emerges as a specific discipline in the 1970s (Hopkins, 2007). Like the conventional Engineering disciplines, Pipeline Engineering envisions a considerable number of sub-majors, each of which focuses on its essential target area and also often inter-connects each other, constitutes a diverse and evolving engineering discipline with substantive contents.

Broadly speaking, Pipeline Engineering is a discipline specializing at pipeline design, construction, operation, inspection, maintenance and integrity management, with the purpose of providing safe, reliable transportation of oil and natural gas while realizing hige economic savings. Pipeline Engineering deals with not only energy transportation by pipeline operation, but also environmental conservation, climate change and national security.

While the great economic, safety and environmental values of pipelines have been realized, and the great technological advancements made in the pipeline engineering area in the past decades, a significant number of engineers, oil/gas distributors and pipeline operators have inadequate knowledge in pipelines and pipeline engineering (Liu and Marrero, 1998). As a new discipline with a relatively short period of development as well as the associated, intrinsic complexity, pipeline engineering has been considerable space to get improved in both educational and research areas. To date, there have been three Centers for Pipeline Engineering Education and Research in the worldwide range, which are hosted by the University of Calgary, Canada (http://www.eng.ucalgary.ca/PEC/), University of Newcastle Upon Tyne, UK (http://www.ncl.ac.uk/marine/pipelineeng/), and Federal University of Rio de Janeiro, Brazil (http://www.poli.ufrj.br/), respectively, providing engineering education at both undergraduate and graduate levels and conducting research in the pipeline area.

Generally, pipeline engineering as a discipline contains more than a number of essential topics such as pipeline design and construction, pipeline operations, instrumentation, environmental conservation, maintenance, integrity management, corrosion control, etc. Pipeline engineering could develop its own major, and could also be associated with engineering departments such as Mechanical, Materials, Environmental, Civil, Chemical and Electrical Engineering to develop specialization in pipeline engineering. Nowadays, pipeline engineering is developing a multi-majored discipline.

3. Understand the Pipeline Engineering

Pipeline engineering constitutes one of the most complex systems. A description and analysis of the individual topics included in the area of pipeline engineering is critical to understand the essence of this system.

3.1. Pipeline Design and Construction

There are a number of factors that have to be considered in design of long-distance oil/gas transmission pipelines, such as determination of the market need, specification of pipe and components, route selection, environmental assessments, public consultation, land acquisition and permitting. Furthermore, in order to achieve the optimum operation and management for a pipeline system, complex engineering and technological studies must be conducted to determine pipeline steel material and size selection, pressure requirement, flow velocity, and coating and cathodic protection design. Therefore, initiation of a pipeline project usually begins several years in advance of the actual construction.

Generally, major factors affecting the pipeline design include (Mohitpour et al., 2007):

Fluid properties: The properties of fluid to be transported, including both gas and liquid, have a significant impact on the pipeline system design. Transmission of natural gas and liquid petroleum imposes different design criteria. The equations for steady-state isothermal flow of a compressible gas and a liquid in a pipeline are usually the start point for pipeline design (ASCE, 1975). The fluid flow efficiency as a function of varying gas/liquid and pipeline parameters under the different flow regimes (partially turbulent and fully turbulent flows) is then examined. Issues related to pipeline, such as pipes in series, pipeline looping, line packing, pipeline maximum operating pressure and some pipeline codes, will be considered. Finally, the pipeline optimization process is performed for the preliminary hydraulic simulation and preliminary economic evaluation (Mohitpour et al., 2007) in order to optimize the operating parameters, ensuring the pipeline to operate most efficiently under the daily average volume.

Temperature and pressure: Temperature and pressure influence all fluid properties and thus the fluid flow efficiency. Moreover, temperature and pressure affects the properties of pipeline materials and the pipeline maintenance and integrity management program. Generally, a rise of temperature is beneficial in liquid pipelines since it lowers the viscosity and density of liquid and thus the pressure drop. However, the temperature rise could result in the decrease of transmissibility of a gas pipeline due to an increase in gas pressure drop, resulting in an increase in frictional loss along the pipelines.

Temperature also affects the material properties. Generally, the strength of the steel increases as temperature drops. However, the brittlement of the steel also increases. Steels could show low-temperature induced embrittlement. Furthermore, the corrosion rate of steel usually increases with the increasing temperature. Pressure of the transported fluid is an essential factor to affect the pipeline cracking process. It is acknowledged (Baker, 2004) that cracks in the pipe steel will not grow if the fluid pressure remains constant. Pressure fluctuation is the key reason to result in the significant crack propagation (Zheng et al., 1997).

Route selection: Route selection is a process identifying constraints, and maintaining the economic feasibility of the pipeline (Mohitpour et al., 2007). The preliminary route selection involves planning the route on maps or photo mosaics, which is followed by a field survey to confirm the acceptability of the route. The main factors considered for selection of an optimal route include cost efficiency, pipeline integrity, environmental impacts, public safety, land-use constraints, and restricted proximity to existing facilities. Prior to preparation of alignment sheets and crossing drawings, an engineering survey is required to document the information including the proposed ditch lines, an elevation profile for the entire route, detailed profiles at crossings, and site information at all proposed facilities. Also, a geotechnical design is critically important in pipeline route selection, avoiding unstable or potentially unstable slopes, controlling surface and subsurface drainage and the resultant soil erosion, recognizing the potential for surface and subsurface seepage to collect and flow within the loose pipe backfill, and preparing river-crossing design.

Environmental impact: Evaluation of the environmental impact resulted from a pipeline project is an essential component of its design. The overall purpose is to ensure effective and successful protection and conservation of environment. Resources in the immediate or nearby areas of the pipeline have to be identified and the potential impacts to be evaluated. These include wildlife, fisheries, water, forest, soil, vegetation, and archaeological resources. In selecting a pipeline right-of-way that is economical and complies with environmental regulations, a comprehensive environmental impact assessment is usually undertaken to develop environmental quality management guidelines for pipeline construction and operation.

Material selection: Undoubtedly, one of the most significant costs in terms of capital investment is the cost of pipe material for a long-distance pipeline system. Pipe material/grade affects the wall thickness, decides the choice of welding/installation techniques, and determines the pipeline operating pressure. In general, higher grades of steel are associated with the smaller wall thickness, but accompanying with more stringent construction/welding techniques. Nowadays, development of large-diameter, thin-wall-thickness high-grade steel pipeline technology has been proposed as a major solution to solve the high economic cost to transport natural gas from the Arctic sources to the southern markets. Furthermore, steels with different grades have different susceptibilities to corrosion and cracking in the buried soil environment, posing the technical challenge to pipeline integrity maintenance. Thus, in selecting materials, considerations should be given to their safe and reliable performance under the anticipated in-service conditions over the lifetime of the component.

Pipeline protection and integrity management: Buried pipelines are subject to external corrosion caused by the soil environment. Therefore, one important consideration in pipeline design is to select an external coating and cathodic protection system based on economics and ability to protect pipelines. Pipelines are also prone to internal corrosion resulted from fluid containing corrosive species, such as salts, water, oxygen, hydrogen sulfide and carbon dioxide. In general, many internal corrosion problems can be corrected in the design stage. For example, the use of corrosion inhibitors has proven to be the effective method to mitigate internal corrosion in wet sour gas pipelines. Piping is generally sized to limit flowing velocity below the critical velocity to avoid erosion-corrosion. Pipeline integrity management uses an engineering approach to develop programs to analyze, detect, evaluate and reduce or mitigate the risks facing a pipeline, which includes corrosion, stress corrosion cracking, third-party damage, geotechnical failure and other causes. The goal of a pipeline integrity management program is to prevent integrity problems from producing a significant impact on public safety, the environment, or business operation (Mohitpour et al., 2007). Generally, pipeline integrity management includes pipeline risk assessment, inspection, defect and repair assessment, and rehabilitation and maintenance management.

Design is actually the first stage of pipeline construction. As stated, highly trained engineers work to design a system that meets the needs of producers and shippers in moving their product to the marketplace. At the same time, pipeline employees who specialize in planning work minimize the impact of construction projects on the environment, in addition to consulting with communities and landowners along the route about the project. Every pipeline project planning team must meet federal and state requirements, obtain necessary permits and respond to local concerns. Typically, the actual construction phase of a project occurs in the shortest amount of time. The construction phase can only begin after route selection, easement negotiations, environmental permitting, and many other pre-construction actions have been accomplished. Before the line pipe can be buried, the pipeline right-of-way must be cleared and prepared for construction. Once ready, the pipeline is carefully placed in the pre-dug trench or bored under waterways or roads. If trenching is involved, the trench is filled and post-construction restoration begins.

The post-construction phase of any project addresses several aspects including restoring the surface of the land affected by the trenching. Work then begins to reconstruct the surface of the land. Before the pipeline is placed into service, the pipe and components are again tested in the field with a water pressure, weld x-rays and a variety of other inspection tests. Each stage of this process is overseen by qualified inspectors to ensure compliance with the engineering plan, codes, permit conditions, landowner and easement agreements, and regulatory requirements.

With the increasingly energy demand, the exploration of oil and gas from the Arctic and sub-Arctic areas has become an integral part of the energy industry. The extreme temperature, soil condition and the environmental unpredictability in the North pose major challenges to the traditional pipeline design and construction technologies. A permafrost and terrain research and monitoring along the pipeline route is needed to obtain knowledge and information for pipeline design and construction. Moreover, unique design features and preventive measures have to be adopted to minimize disturbance to the thaw sensitive permafrost terrain and to ensure pipe integrity. Of particular concern in the design is the potential for differential thaw settlement or frost heave across transitions from frozen to unfrozen terrain, and the stability of thawing permafrost slopes. A usual measure is to insulate permafrost slopes that are thaw sensitive (i.e. unstable if thawed rapidly) with a layer of wood chips to prevent thaw. A series of instrumented sites should be established to monitor the increase in thaw depth and the associated ground surface settlement and pipe settlement following construction. The stability of ice-rich permafrost terrain and slopes along northern pipeline corridors, including sensitivity to climate change and forest fires, should be part of the pipeline research program. Furthermore, temperature cables should be installed in the "natural" terrain adjacent to the pipeline right-of-way, and long-term monitoring of these cables will provide data for permafrost and climate changes.

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Biographical Sketch

Dr. Cheng earned a PhD in Materials Engineering at the University of Alberta in 2000. After two years as an Industrial Research Fellow in the NOVA Research and Technology Center and three years as a Research Scientist in the Centre for Nuclear Energy Research at the University of New Brunswick, Frank joined the University of Calgary in 2005 where he is an Associate Professor and Canada Research Chair in Pipeline Engineering in the Department of Mechanical and Manufacturing Engineering.

Dr. Cheng has worked on a wide spectrum of pipeline engineering areas, including pipeline corrosion and stress corrosion cracking, hydrogen-induced cracking, internal corrosion, external corrosion, coating failure mode and effect analysis, CO_2 corrosion, erosion-corrosion, passivity and pitting corrosion, electrolytic deposition and electrochemistry. He has published over 90 journal articles in the general areas of corrosion, electrochemistry and materials science.

Dr. Cheng is serving as the member of the Board of Directors of Canadian Fracture Research Corporation.