PETROLEUM PIPELINE NETWORK OPTIMIZATION

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Summary

The transportation of hydrocarbons, oil and gas, makes heavy use of pipelines. Their design has been a long established engineering exercise incorporating flow characteristics and the hydrostatic and friction pressure losses. These calculations are presented in this article. Of particular interest is the two- (or three-) phase nature of

hydrocarbon fluid flow, which is all the more unique in that the phases are miscible. This is unusual because pressure drop calculations must also incorporate the phase behavior that is a function of the very pressure that is to be calculated. This creates trial and error approaches and often lengthy and calculation-intensive computations. Optimization of pipelines involves decisions, such as the number vs the size of pipelines, the utilization of satellite stations and the position of pumping or compressor stations along the route.

Pipelines are generally divided into three main categories:

(a) flowlines from wells to surface production facilities;
(b) trunk lines for massive;
(c) long-distance transportation and distribution lines for the transportation of finished products to industrial and domestic consumers.

An analysis of these functions is included in this article. Both liquid (oil) and gas trunk pipelines are presented and their salient differences are outlined. Novel applications with unique features are in arctic and offshore and underwater service. They pose different demands and specific operational problems which must be considered during the pipeline design and construction. These problems are also described in this article.

1. Introduction

Petroleum pipelines, carrying oil and gas, perform three distinct functions:

- gathering of individual well production en route to surface treating facilities;
- trunk/transmission to and from refineries and treatment plans;
- distribution of finished products to domestic or industrial consumers.

Carrying what is perhaps the most important commodity in the world economy, pipelines and their construction are affected by many factors including geopolitical and macroeconomic considerations. Whether a pipeline is built between the North Slope of Alaska to connect with the year-around open ports of Southern Alaska or with the Canadian pipeline system, or whether oil from the Caspian would best be piped through Turkey, Iran or Russia, are issues that appear in the popular press on a regular basis.

Other questions are environmental regulations, environmental permitting, compliance with laws and “rights of way,” i.e. the entire exercise of building a pipeline through private property.

Below, we will address only the technical issues in constructing pipelines, although it must be emphasized that the other issues mentioned above can be overwhelming and can control clearly the decision to build pipelines, their size and direction.

2. Optimization

Optimization in petroleum pipelines uses invariably economic criteria namely, maximization of the net present value.

For large pipelines, there are really no universal criteria for optimization because the technical issues such as pressure rating vs. flow rate are often insignificant compared to the right-of-way, permits and environmental compliance. Pipelines of similar technical specifications in e.g., Canada or the United States vs. Russia may cost the same, ultimately, but the actual construction in North America may constitute 30% of the cost with 70% going to legal, governmental compliance and right of way compensation, whereas in Russia, with far less efficient construction and work force, the construction may cost 80% (with a large portion unaccounted for) with the remainder going to the other cost centers.

Where optimization is possible is in gathering systems where the gathering system configuration (e.g., one or two large mother-manifolds) vs. satellite systems, the separation of high, intermediate and low-pressure systems and the size of the resulting surface equipment vs. their pressure rating. Such optimization uses standard linear and dynamic optimization schemes and the objective function is always the maximization of the net present value.

Below, the nuances of the optimization of petroleum-producing systems and their attached gathering systems are described.

Petroleum, oil and gas, which can be in the form of free gas or gas-in-solution, are found in special geologic structures which are characterized first by their *formation geologic depth*. These formations must have certain desirable properties, the most important of which are *porosity* and *permeability*. Reservoir flow into a well that is drilled targeting the formation is described by the *inflow performance relationship* (IPR). Generally the well IPR describes a relationship between the well flow rate and the flowing bottom hole pressure. The latter is directly linked with the reservoir pressure which changes with time from the *initial reservoir pressure* as the reservoir depletes. The IPR is then connected to the vertical lift performance.

For a given wellhead flowing pressure at the top of the well, a relationship between the flowing bottom hole pressure and production rate can be established. This production rate, except for the pressure, depends on other parameters also, such as reservoir *net thickness* (which is distinguished from the gross thickness, the latter including also non-producing layers) and the lateral dimensions of the reservoir, the viscosity of the fluids and the formation permeability.

Other phenomena that affect the calculation are the two-phase miscible nature of oil and gas flowing simultaneously and the intrinsic relationship between the actual pressure value and the state of phase behavior of the fluids. Lower wellhead pressure would make the fluid more gas-like because it departs further from its bubble point pressure. Consequently, gas is liberated from the liquid in which it was originally dissolved. This would provide a lower bottom hole pressure but not monotonically proportional because the more gas-like nature of the fluid will result in a large friction pressure drop. The latter can be favorably affected if a large diameter pipe is used but with an unavoidable increase in the cost.

The lower wellhead pressure, which could result in higher production rate, is likely to affect adversely the cost of surface equipment such as separators, pumping units and storage facilities. The size of the pipelines will also have to be larger. In remote or offshore location where construction costs are very large and where the 'footprint' of the facilities must be minimized these additional costs may be prohibitive. In onshore locations minimizing the bottom hole pressure may be attractive.

It is outside the scope of this review article to present detailed descriptions of such optimization calculations which can be cumbersome and very much site- and country-specific.

3. Pipelines

3.1 Oil Pipelines

Petroleum production is from underground reservoirs and the produced fluid invariably contains liquid oil, natural gas and water. These three constituents of petroleum production must be separated in surface facilities before they are sent to refineries or other manufacturing. Water must be disposed off usually through injection wells into underground reservoirs.

Flowlines (providing transportation from the producing well to a centralized treating facility) are generally small-diameter (2.5 to 10 cm) pipelines functioning at relatively low pressures (around 0.7 MPa or, even lower). They are made usually of steel or plastic. Welding or threaded couplings connect joints. Flowlines are coated internally to shield against corrosion. When buried, they are also coated externally to minimize corrosion. Figure 1 presents typical configuration schematics of oil-field flowlines.

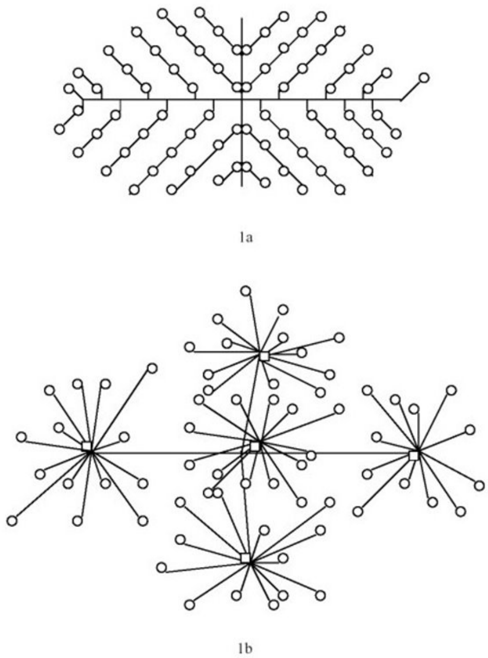

Figure 1. Gathering systems into main lines (1a) and satellite gathering systems (1b).

Trunk lines are much larger diameter pipelines, with diameters ranging from 0.3 to 1.2 m. The Alaska pipeline shown in Figure 2, is 1.2 m in diameter and it traverses approximately 1300 km from Prudhoe Bay, in the North Slope of Alaska, to the port of Valdez. Pumps and pumping stations are used at the beginning and along pipelines at selected stations to maintain the pressure at the level required to overcome friction, changes in elevation, and other head losses.

Distribution pipelines are, again, small diameter lines and are used to transport finished products such as fuel oil to consumers.

Figure 2. The Trans-Alaska pipeline.

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Biographical Sketches

Michael J. Economides is one of the most instantly recognizable names in chemical and petroleum engineering and the petroleum industry for his seminal contributions to technology development and application. Economides is University Professor of Chemical Engineering at the University of Houston. Until the summer of 1998, he was the Samuel R. Noble Professor of Petroleum Engineering at Texas A&M University—home of the nation's top ranked undergraduate and graduate programs—and served as Chief Scientist of the Global Petroleum Research Institute (GPRI). The GPRI is the first, large-scale petroleum research organization based at a university. Prior to joining the faculty at Texas A&M University, Professor Economides was the Director of the Institute of Drilling and Production at the Leoben Mining Institute in Austria (1989-1993) where he earned recognition for transforming a traditional European institution to a global competitor in the energy marketplace. From 1984 to 1989, Dr. Economides worked in a variety of senior technical and managerial positions with the Schlumberger companies, including Europe Region Reservoir Engineering and Stimulation Manager (1984-86) and Dowell Schlumberger Senior Staff Engineer, North America (1987-1989). Publications include authoring or co-authoring of 7 textbooks and more than 150 journal papers and articles. Economides' texts are used in almost all academic Petroleum Engineering departments in the United States, several overseas universities, and in the training programs of most of the major companies in the petroleum industry. Economides does a wide range of industrial consulting, including major retainers by the Halliburton Companies, PDVSA (Venezuela) and PDO (Oman). He is the founder and a major shareholder in OTEK (Australia), a petroleum service and consulting firm with offices in five Australian cities. He is also a partner in Eclipse Resources, a Canadian Independent producer of oil and gas. Complementing his command of the academic, technical and commercial dimensions of the global energy industry, Michael Economides is also the author of the Pulitzer Prize nominated bestseller *The Color of Oil: The History, the Money and the Politics of the World's Biggest Business.* He writes regularly for the *Houston Chronicle* and he is a columnist for *the Dallas Business Journal.*

Leonidas Kappos obtained his Bachelors' Degree in Chemical Engineering at the National Technical University, Athens, Greece in 1995. Subsequently, in the period 1995-1996, he obtained his Master's degree in Chemical Engineering at the University of Rochester, N.Y., his research focusing on porous media properties statistical estimation. As of 1996, he is working on his Ph.D. at the University of Houston, at the Enhanced Oil Recovery Laboratory, dealing with the effect of viscosity ratio and rate dependence on oil recovery and with the dependence of core orientation, wettability, and injectant gas composition, on the oil production at residual oil saturation.