Pipeline Hydraulics, Design, Fuel, and Costs

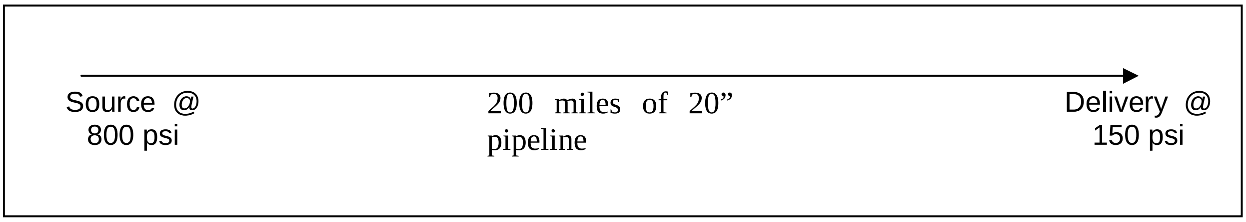
Gary Choquette
August 31, 2010

Introduction

The purpose of this document is to illustrate the various parameters that can be changed in pipeline design, evaluate their effect on capacity, and determine the effect on installation costs and fuel rates.

Assumptions

For the sake of illustration, a simplified hydraulic analysis will be performed where gas is transported from a source location to a delivery point located 200 miles away. As a standard for comparison, 20-inch pipe will be assumed with a source pressure of 800 psi, and a delivery pressure of 150 psi. The product to be transported is 60°F natural gas with a specific gravity of 0.6 and compressibility of 0.95. Compression assumes a compressor efficiency of 80% and a break specific fuel consumption of 9000 BTU / HP-Hr higher heating value. Capital costs are assumed at $7.5 / diameter-inch-foot for pipelines and $1.5M + $1500 / HP for compression.



The maximum capacity of a 20-inch pipeline under these assumptions is 145 MMSCF/D and would cost approximately $158M to build; unit costs to build this pipeline are $1.09 MMSCF/D.

Capacity as a Function of Diameter

In this analysis, the source and delivery pressures remain constant and the diameter is changed. In Figure 1 below, the pipeline capacity and capital installation costs are noted as a function of diameter. For the smallest diameter line (4-inch), the pipeline capacity is only 2.4 MMSCF/D and costs almost $32M to build. At the other extreme, a 30-inch line has a capacity of 413 MMSCF/D and costs $238M to build. Note that construction costs are largely proportional with pipeline diameter while the capacity is exponential to diameter; specifically, the available capacity is proportional to the pipeline diameter to the power of 2.5. This results in a significant reduction in unit costs as the diameter is increased as shown in Figure 2.

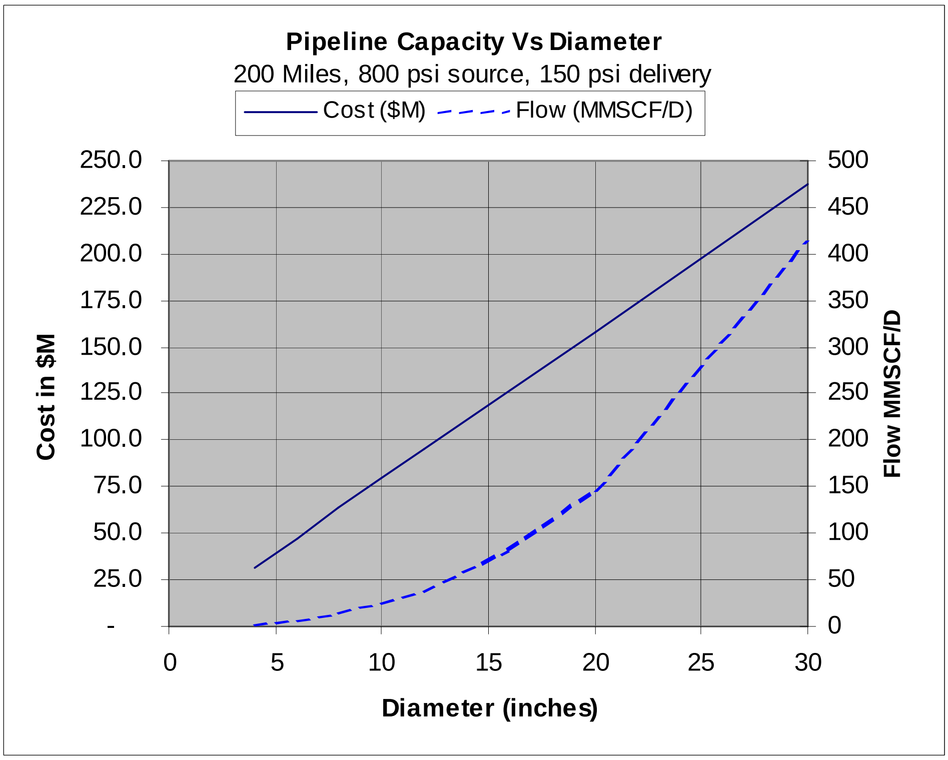


Figure 1 – Pipeline Capacity as a Function of Pipe Diameter

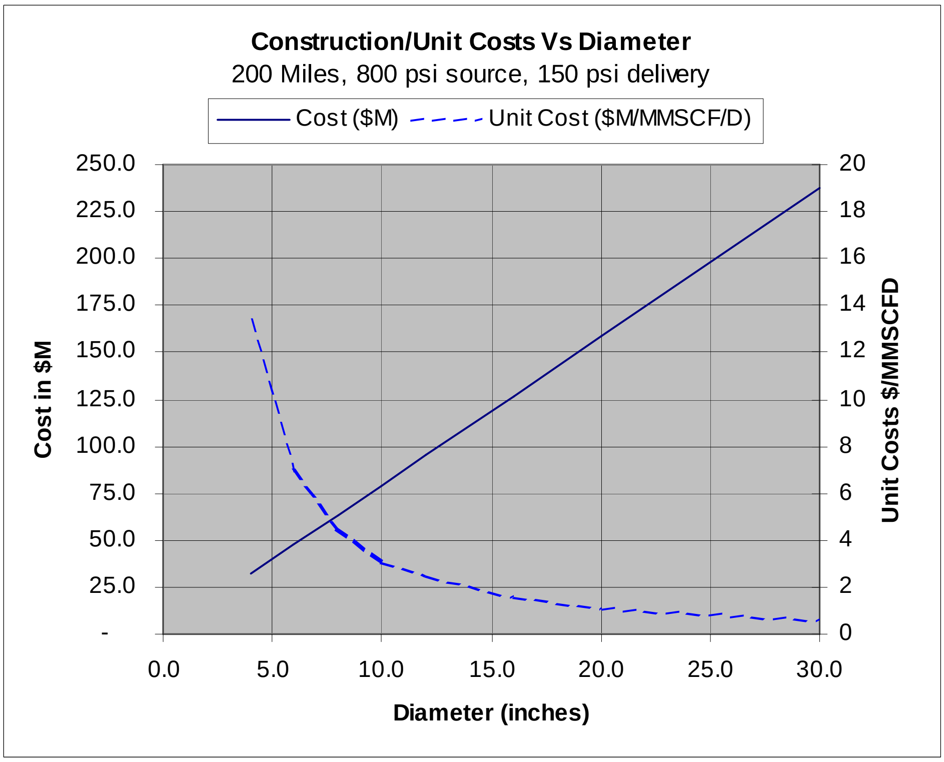


Figure 2 – Pipeline Construction Cost and Unit Transport Costs

The Effects of Delivery Pressure

In this analysis, a 20-inch pipeline is analyzed with the source pressure remaining constant and the delivery pressure varied. The intent is to show the capacity impact of higher delivery pressures. As shown in Figure 3, the pipeline capacity decreases from 148 MMSCF/D at a 150 psi delivery to 86 MMSCF/D at a 650 psi delivery. The loss in pipeline capacity results in the unit capital costs increasing from $1.07 to $1.84 / MMSCF/D.

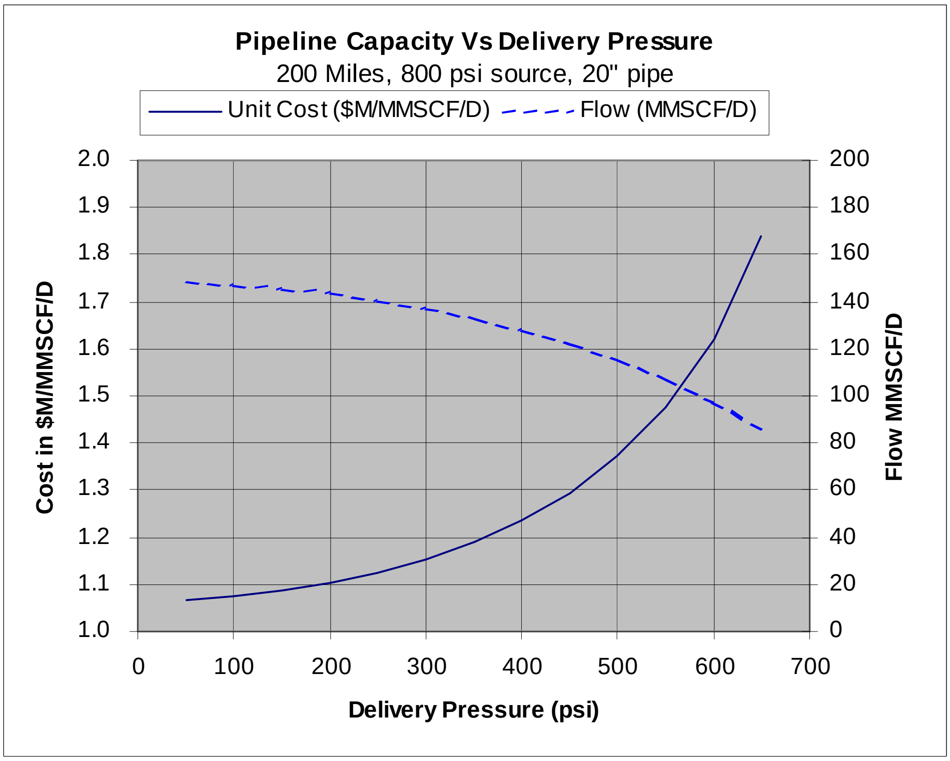


Figure 3 – Pipeline Capacity as a Function of Delivery Pressure

The Effects of Source Pressure

In this case, a 20-inch pipeline is analyzed with the source pressure varied and the delivery pressure remaining constant at 150 psi. The intent is to show the capacity impact of higher source pressures. As shown in Figure 4, the pipeline capacity increases from 108 MMSCF/D at a 600 psi source to 220 MMSCF/D at a 1200 psi source. The increase in pipeline capacity in this comparison results in the unit capital costs decreasing from $1.46 to $0.72 / MMSCF/D.

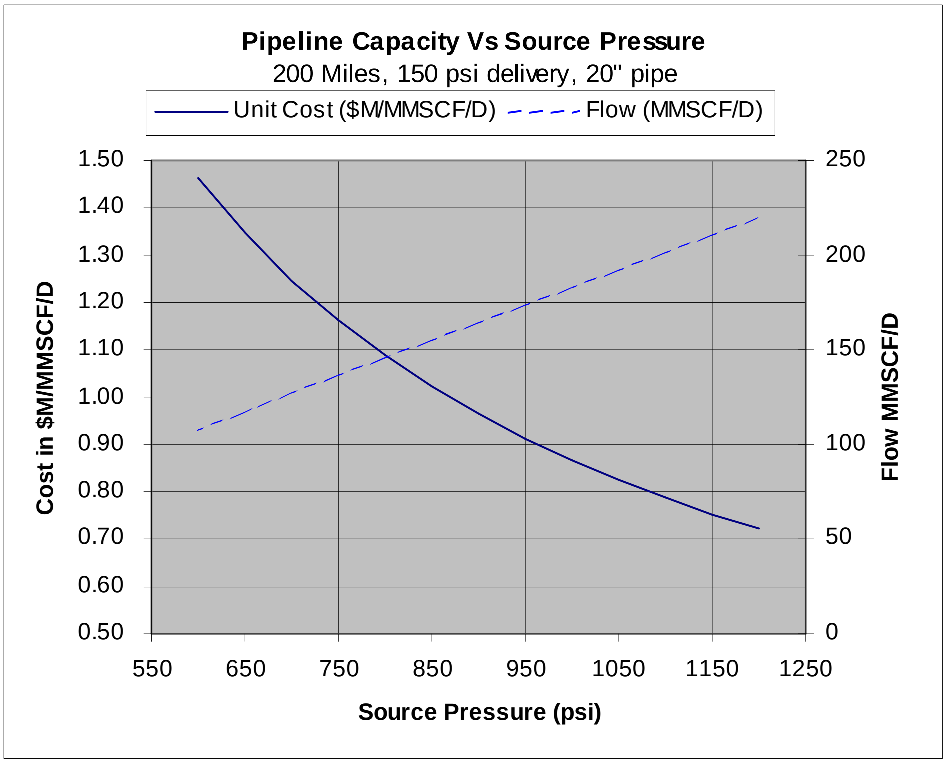


Figure 4 - Pipeline Capacity as a Function of Source Pressure

Capacity Effects of Compression

In this analysis, a compressor is installed at the source location. Gas is received at 800 psi and the size of the compressor is varied to determine the effect on pipeline capacity. In Figure 5, the pipeline capacity is increased significantly with compression. This is achieved by effectively increasing the source pressure of the pipeline. The addition of 5000 HP increases the pipeline capacity from the base case of 146 MMSCF/D to 220 MMSCF/D. For a relatively small capital cost ($9M), the capacity is increased by more than 50%. The increase in pipeline capacity results in the unit capital costs ranging from $1.09 to $0.76 / MMSCF/D as depicted in Figure 6.

Contrast this to achieving this capacity by using only larger diameter pipe. To achieve the same 220 MMSCF/D, the line size would have to be increased from 20-inch to 24-inch pipe. This would cost an incremental $80M in capital costs to produce this same capacity. While the capital costs are lower per unit transported with compression, it does so at the expense of fuel and operation & maintenance costs. Figure 7 shows the relationship between fuel usage and unit capital costs as capacity increases from the use of compression. Note that the fuel per unit transported always increases as additional compression is added and the flow is increased.

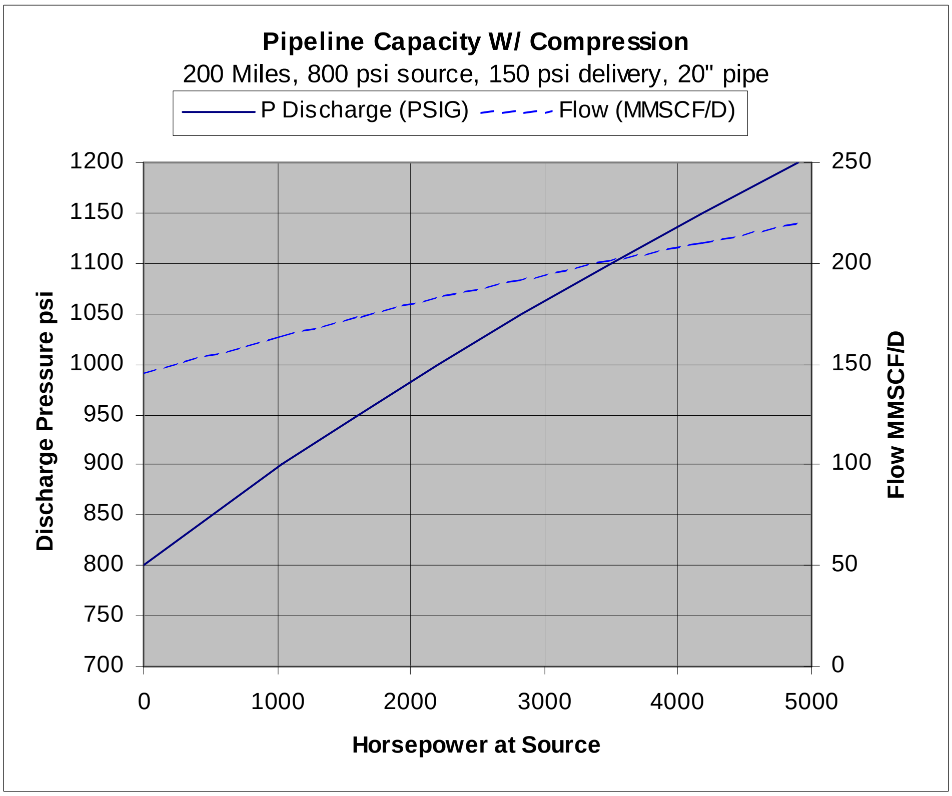


Figure 5 - Pipeline Capacity with the Addition of Compression

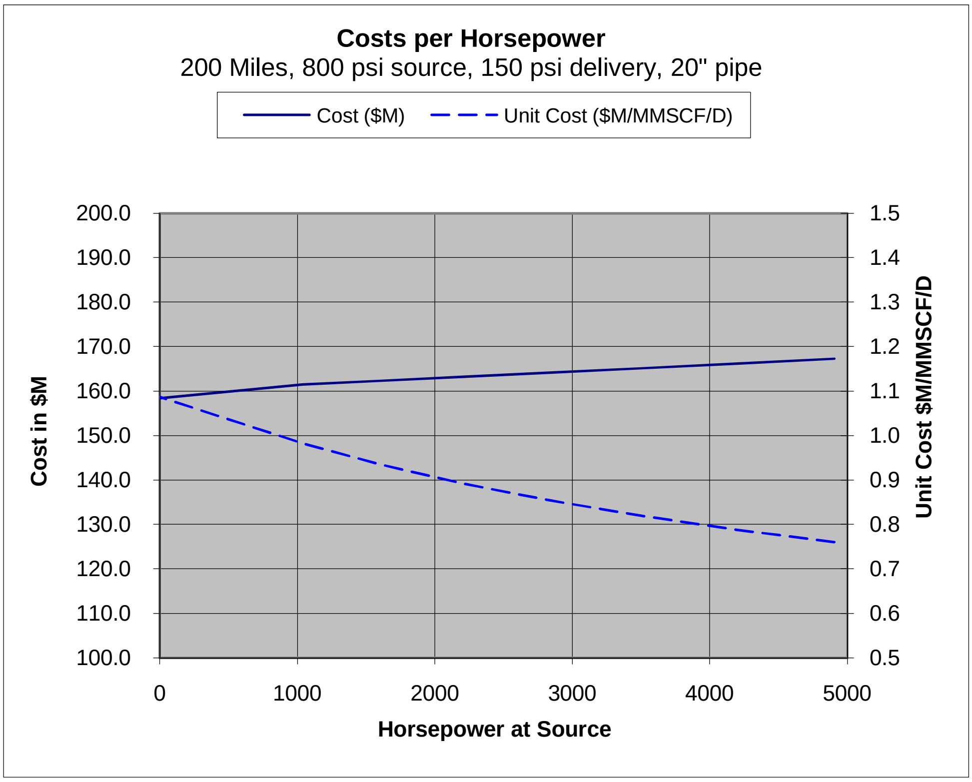


Figure 6 - System Construction Cost and Unit Transport Costs with Compression

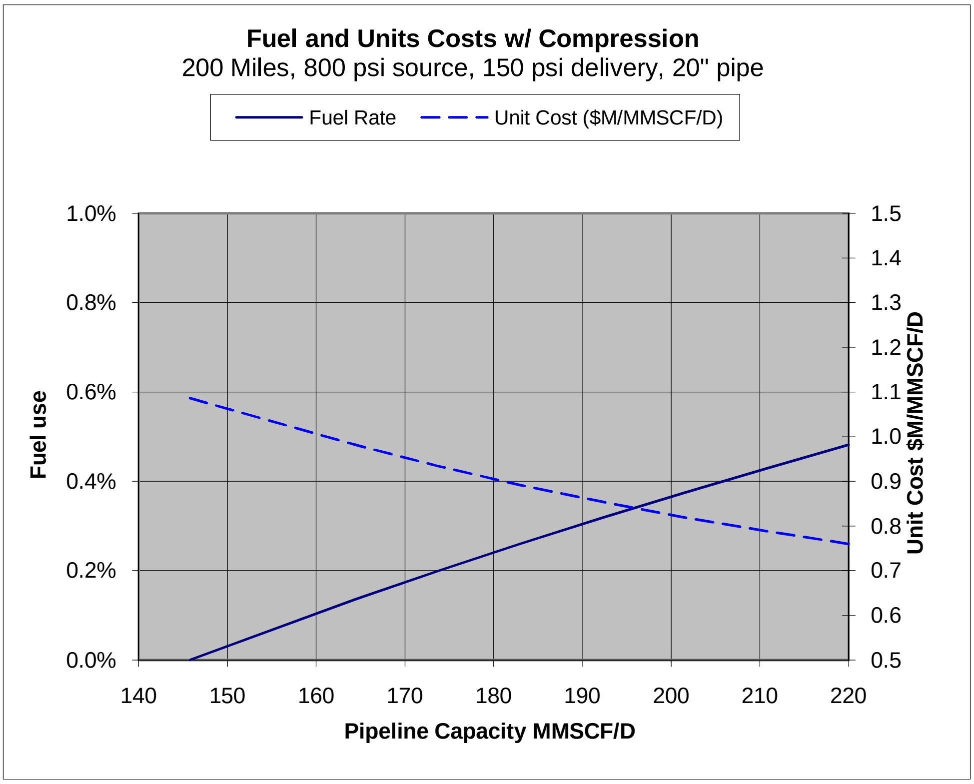


Figure 7 – Fuel Costs with Compression

In real world situations, the fuel usage can vary significantly depending on the mix of pipeline and compression facilities. Modifying existing systems with pipeline loop will reduce fuel costs while installing additional compression without installing additional pipeline will increase fuel costs.

In general, designs where the compression facilities are spaced between 50 and 100 miles result in the best overall compromise between capital costs and fuel/operating costs for mainline transportation systems. As the operating pressure of the system increases, the optimum economic distance between compression facilities also increases. Physical factors that limit the use of additional compression facilities to increase capacity include differential pressure (compressor wheel or compressor valve limitations), heat generated during compression, excessive fuel rates, and high operating costs.

Pipeline and Compression, Pros and Cons

Pipelines systems without compression generally cost more per unit transported than a design that utilizes compression. The use of pipeline over compression reduces the overall fuel usage and has the ability to store gas in the form of pipeline pack. In the situation where the pipeline is already installed, capacity expansions can typically be achieved through additional compression more economically than they can through pipeline looping. Compression has the obvious disadvantage of higher variable operating costs and environmental emissions. The optimum balance between compression and pipeline is dependent on the goals and objectives of the operating company and the specific design constraints of the existing pipeline facilities.