Effective Pipeline Simulation Modeling

Augusto Garcia-Hernandez

Introduction

Upstream gas supply issues present new challenges to natural gas pipeline operators. These supply issues include variability in gas compositions, gas clean-up and processing and increased demand in remote areas. Due to the aging pipeline infrastructure in many areas within the United States, many pipeline companies are utilizing pipeline simulation modeling to take a “big picture” view of their assets to better manage resources and identify potential reliability concerns.

When implemented correctly, pipeline simulations provide a thorough and detailed view of a pipeline network to evaluate reliability, minimize downtime, and investigate specific operational issues. Pipeline models may be used to investigate various issues, such as hydrocarbon liquid dropout, transient effects (e.g., compressor station ESD events), gas emissions, and station MAOP limits. These issues are not easily determined without a full system model. Full system modeling will mitigate operational and safety hazards for the pipeline operator. The following paper describes typical simulation methodology used by Southwest Research Institute (SwRI) and provides specific examples of how simulation tools are being utilized to optimize pipeline performance.

Application to Gas Companies

Pipeline simulations have been utilized as optimization tool in many different liquid and gas processes. In addition, new designs and equipment selection are usually validated through computational models due to their flexibility, time and cost. Simulation of an entire pipeline’s operating conditions and process before proceeding with the detailed engineering is a very common strategy employed on new systems. For existing pipeline systems, simulations are used to aid the modernization and optimization of the existent pump and compressor stations or study modifications involving connecting new supply areas or acquisitions.

Accurate pipeline simulations must involve a detailed analysis of the real system to produce an accurate model of the simulated pipeline or facility. The expression, “Garbage In, Garbage Out,” is relevant here in that the simulation will only be as accurate as the geometry and operating conditions provided by the operating company. SwRI has developed several specialized in-house codes as well as modeling capabilities using commercially available codes to deliver accurate results for some of the most challenging dynamic problems. The examples provided below illustrate these capabilities and the benefits of accurate pipeline simulations.

Modeling

Transient and steady state flow modeling of pipeline systems and other fluid transient responses are performed at SwRI with a variety of one-dimensional and three-dimensional fluid dynamic codes. These codes include in-house non-commercial that use the full Navier Stokes fluid equations, method of characteristics or similar finite difference solution techniques transient pipe flow simulations. Other commercially available packages such as Stoner, Caesar, CFDesign and CFX are also utilized on a routine basis. The choice of software package depends on the pipeline application being simulated, the level of detail required, the influence of 3-D effects and the budget / time available to the project.

All computer codes whether in-house or commercially available have the same basic requirements to solve for transient pressures and flows in piping sections as well as other responses of the system. The equations in the computer programs allow for the determination of pressure and flow at each time step at each end of interior section of pipe. The conditions at the ends or nodes of the first and last section of pipe (non-interior points) are determined by boundary conditions. Correct implementation and interpretation of boundary conditions is critical to the accuracy of the solution.

All of the process piping that connects a compressor to scrubbers, coolers, or recycle valves between a large volume source or main pipeline and a final delivery pipeline or discharge volume must be divided into sections with designated lengths and diameters. The choice of time-scale and length-scale will also influence the accuracy and precision of the solution (as well as the stability of the model in the case of high transient effects or abrupt area changes). The piping solution techniques provide a method for defining pressure and flow at each point in the system at each time step, as affected by initial and boundary conditions.

Special Nodes

Special nodes are required for centrifugal compressors, for every valve that opens, closes, or changes its flow resistance during the simulation, for heaters, coolers, filters, or scrubbers that change gas temperatures or properties, and for any other elements that affect the flow like junctions or "Tees" that combine, divide, add, or remove mass. In a transient flow model, a centrifugal compressor is represented by an element with a suction node and a discharge node with boundary conditions such that the suction mass flow rate, proper for the speed and head rise, is transported to the discharge node at the proper pressure and density. At the next time step, both head and suction flow are re-calculated and speed may change as the compressor accelerates or decelerates.

Valves that open, close, or change their resistance during normal operation or an upset and particularly recycle or bypass valves are modeled by special nodes or elements, which calculates flow rate based on valve flow coefficient (Cv) and differential pressure at each time step. The pressures upstream and downstream of a valve are calculated for the next time step, by the normal transient simulation techniques. Then the flow calculations are repeated for the next time step with the new differential pressure. A change in density is required across a valve that takes a pressure drop and this change in density is used to adjust the volume flow rate to properly account for the mass flow rate.

Other special nodes include those elements that represent scrubbers, filters, or large volumes. Junctions, such as "Tees" or branch lines, where flow to or from parallel compressors or other parts of a piping network are combined or divided are simulated by special nodes or elements with assumptions appropriate for pipe junctions. Heaters and coolers are another set of special nodes in which the gas temperature between the inlet and outlet change and hence, the gas density and volume change but not the mass flow rate.

Features Influencing Accuracy

Several important features of any modeling program are controls or routines that adjust and affect the pipeline system response to controller inputs based on operating conditions. Valve controllers and other control components are a key part of a pipeline system response during changing operations or upsets. A valve controller and the valve actuator determine how rapidly a valve changes its stroke or percent opening during an event.

In the transient flow model, a valve controller can be simulated, as simply as a stroke rate or as completely as a full integral, proportional, and derivative controller. Controllers for a compressor driver may also be simulated including fuel controllers, acceleration and deceleration curves, inertial limits for coast down, and other system behaviors. Heater or cooler controls can be modeled such that the effects of more cooling fans or a higher heating rate can be included.

Another subroutine and additional feature of any transient gas flow modeling programs is a complete gas properties calculation routine based on selected Equations of State that are suitable for the gases or liquids involved. Equations of State such as the BWR and the SRK equations are typically used as well as the new AGA 8 equation. The gas properties subroutine for most software packages is carried out such that the gas density and other critical properties are determined at each new pressure and temperature level.

The Input Data

It is clear from the preceding description of the pipeline flow and control system modeling techniques, that a great deal of detailed data is required in order to develop an accurate and complete model of a pipeline system and its controls. The complete pipeline system must include:

- Lengths, diameters, elevations, pipe material (e.g. Young Modulus), manifolds, flow and pressure regulators, etc. and all branches or connections.
- Details such as volumes, lengths, and heat transfer surface areas, thermal coefficients, and ambient temperatures for pipeline, coolers, heaters, scrubbers or filters.
- The rotational inertia of the compressor or pumps with their driver and the torque characteristic of the driver.
- The normal and upset condition pressures, temperatures, flows, and gas compositions.
- Complete performance data for the compressors (performance map) or pumps (performance curves) for normal and off design operating conditions.
- Boundary conditions such as constant suction flows or fixed delivery pressures are required or sufficient information should be available so that the analysts can make a proper selection of the boundary conditions.

- Each of the valves that change resistance with the flow coefficient (Cv) as a function of stroke and stroke rate limits given.

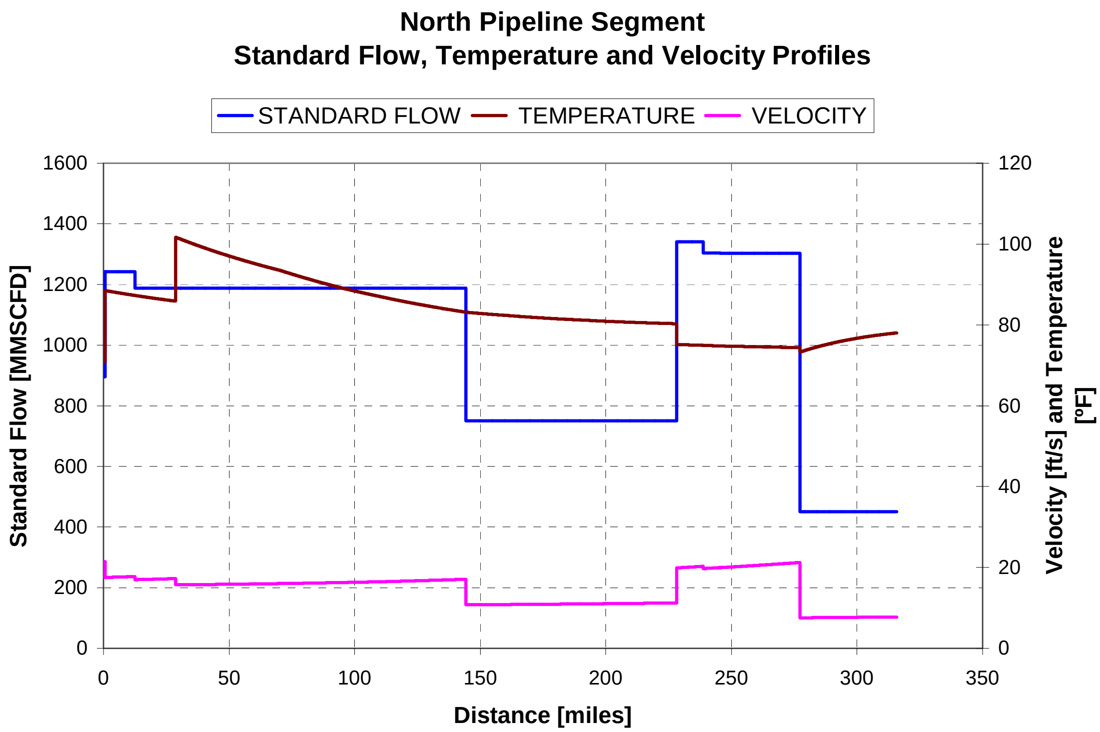
Not only should the normal operating conditions be well defined with pressures and temperatures throughout the system but the upset conditions should be completely defined with the initiating events and conditions fully described. Control system logic and sequences, either a simple time delay or a complex proportional opening based on some variables, must be provided in order to model the controllers. Once all of the necessary data is input to the model, the program is compiled and the model of the system is ready to simulate both steady operations and transient upsets.

Typical Applications

Liquids Drop-out

Predictions of liquids drop-out in a gas pipeline involve a detailed analysis of the pipeline under normal and transient conditions. A pipeline model for those types of prediction should take into account heat transfer with the surroundings, changes in elevation, flow and pressure regulations points as well as diverse operating conditions. Simulations of the system operating under steady-state conditions can provide velocity, temperature and pressure profiles of every single pipe branch as shown in Figure 1.

There are several specific conditions that can be identified with velocity, temperature and pressure profile data, in which condensate formation is most likely. Utilizing an equation of state and an initial gas composition, the phase envelop of the gas transported is generated. Comparison of the pressure and temperature results obtained from the pipeline simulation with the phase envelop data is used to determined if the gas flow is under possible mixture conditions that could result in liquid drop condensation. In addition, low velocity points can indicate possible locations where the condensate liquids and solids may accumulate in the piping system, resulting in caked solid deposits and liquids hold-up.



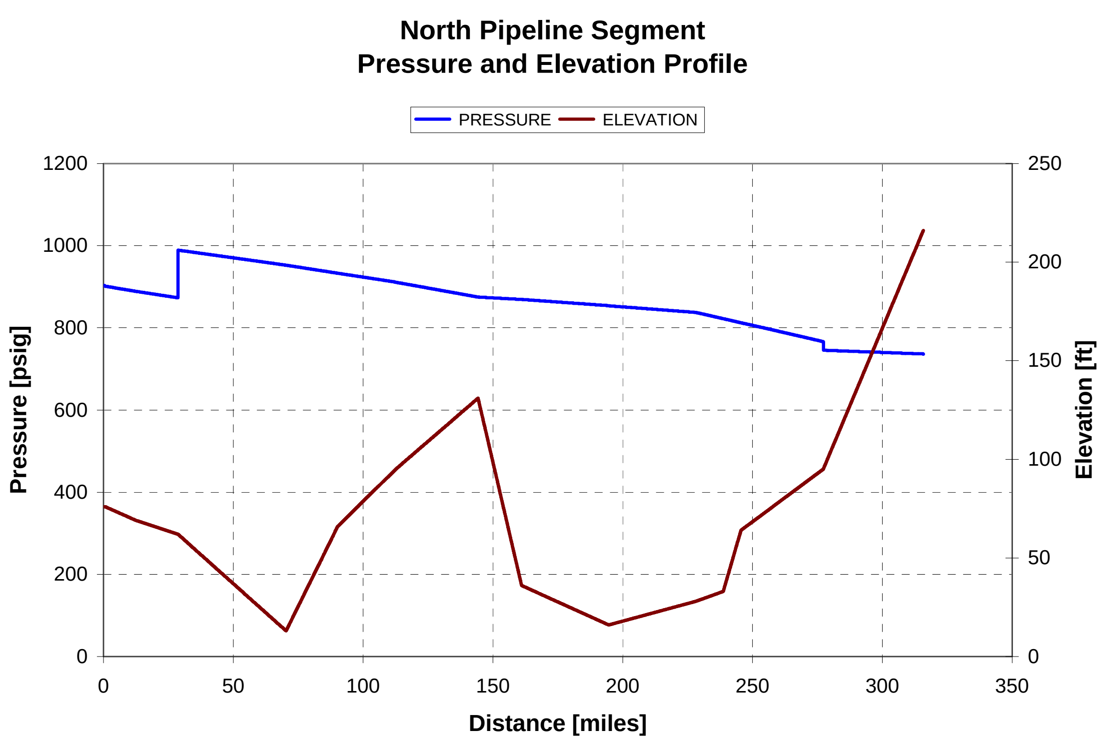


Figure 1. Typical Temperature, Pressure, Flow, Velocity and Elevation Profiles for a Pipe Branch of a Pipeline Network

Centrifugal Compressors Surge Design

Transient simulations of centrifugal compressors are very helpful for validating or designing existing or new recycle systems. Commercial codes provide a tool to model rapid trips of centrifugal compressors in order to avoid energetic and potentially damaging surge events. These simulations account for the actions of recycle valves, control system responses and the capacitance function of upstream and downstream piping. The simulations require modeling of small pipe sections, very small time steps, and full details in terms of compressor performance curves, recycle, and other valve characteristics. Figure 2 illustrates the effects of anti-surge valve changes on the transient performance of a centrifugal compressor during an emergency shutdown event.

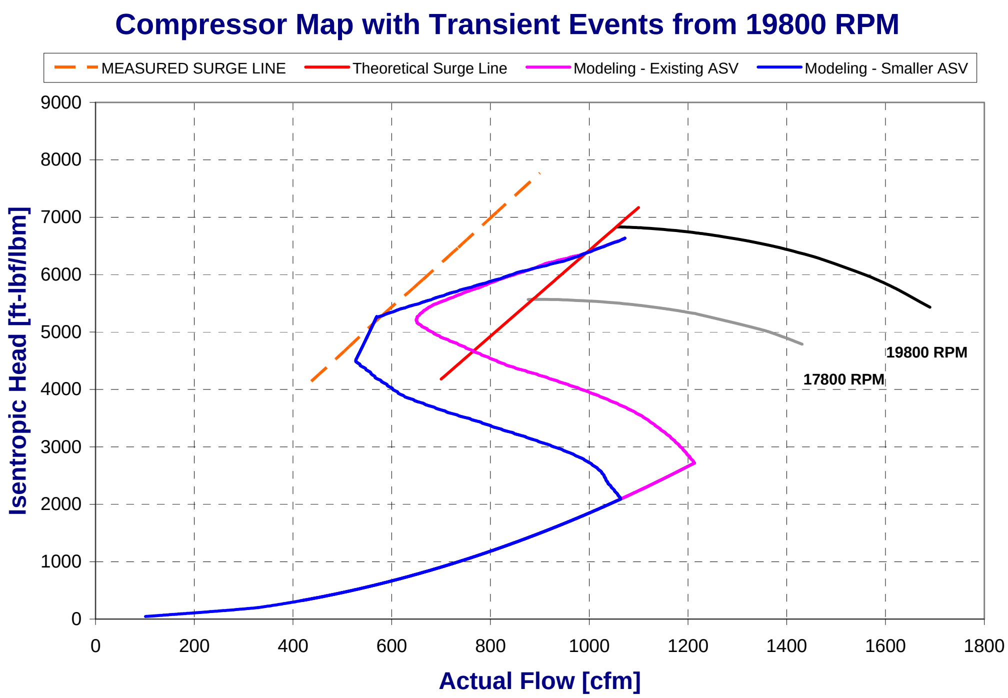


Figure 2. Effect of ASV Modification on Transient Path of Compressor During Emergency Shutdown Event.

Fluid Batch Tracking

A multi-product pipeline is used to transport two or more different products in sequence in the same pipeline. Therefore, there is no physical separation between the different products. Some mixing of adjacent products occurs, producing an interface between the fluids. This interface is removed from the pipeline at receiving facilities and segregated to prevent contamination. However, the proper determination of the interface length and volume is critical from the operation and economical stand point. A simulation approach is often considered for a 1-D or 3-D analysis of the mixing volume interface. Figure 3 illustrates the velocity contours of a single fluid, which were later applied in a mixing scenario to evaluate interface length and volume. For the type of analysis, the Slightly Compressible Liquid (SCL) equation of state is most commonly used, as it allows for batched tracking of fluids, blending, and definition of several liquids with their respective percent composition.

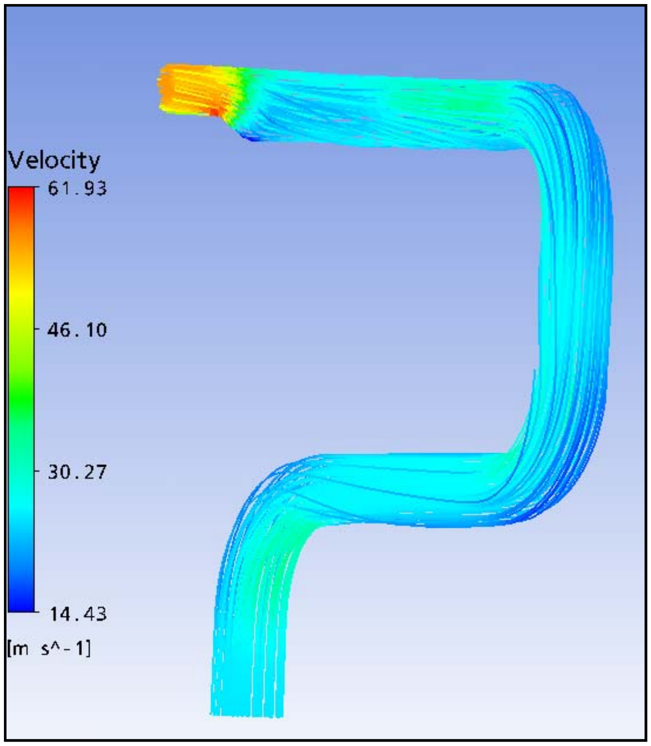


Figure 3. Velocity contours of flow in pipeline 90 deg elbows.

Pipeline Capacity and Definition Operating Philosophies

Detailed models of pumping facilities including fractionators plants, storage tanks, pumps, valves and its main headers are generated to simulate hydrocarbon processing plants. In addition, detailed interconnecting pipelines are incorporated for each pumping station as well. Therefore, a representative model of the entire process and its transporting pipeline system is built, such as the system simulated in Figure 4 for a pipeline with changing elevation, flows and MAOP limits. Then this model is tuned and validated again real operating conditions. Thus, critical scenarios could be simulated and analyzed further. Simulation results include steady state and transient events. Steady state conditions are used to determine possible bottlenecks, determine the pipeline capacity, validate MAOP values and optimize the liquid forwarding process. While transient results provide guidance to improve operating philosophies and to identify critical operating conditions that should be avoided.

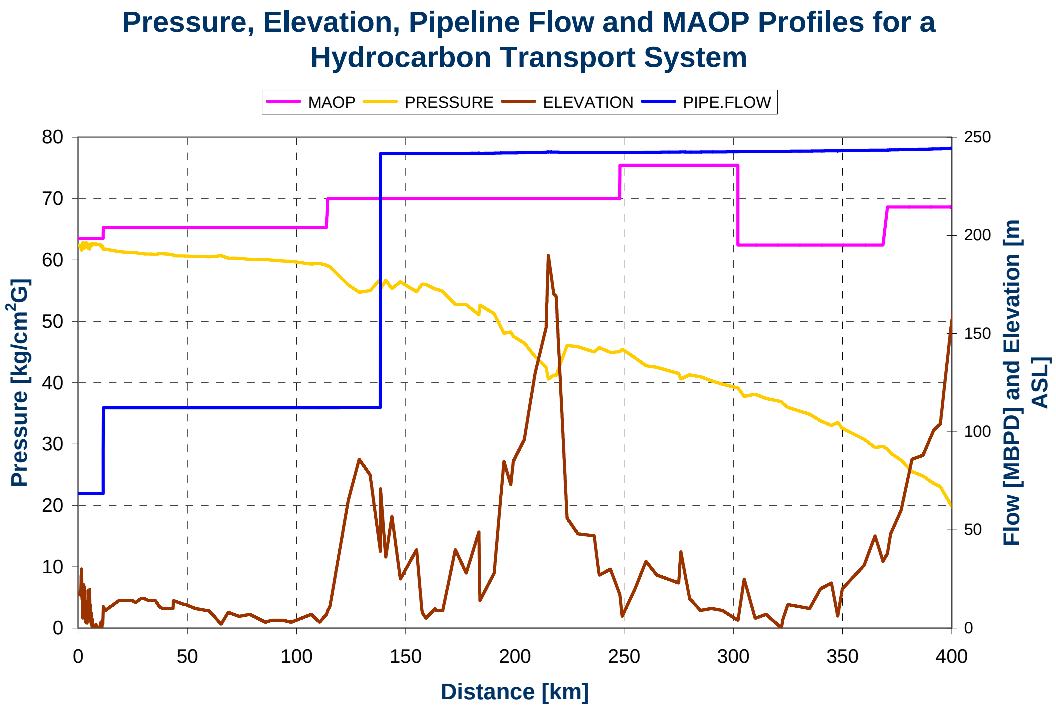


Figure 4. Pipeline profile for Pressure and Flow Evaluation as a Function of Elevation and Distance from Pump.

Conclusions

Pipeline simulations have been utilized by as an optimization and design evaluation tool in many applications including evaluation of liquid drop-out, centrifugal compressor surge control system design, pipeline design for capacity limits and MAOP determination, and fluid to fluid interaction / contamination. Simulation of a compressor station, refining operation or large transmission pipeline before proceeding with the detailed engineering specifications is often more cost-effective than having to modify the system at a later time based on overlooked system issues. For both new and existing pipeline systems, accurate modeling based on validated codes and experienced modelers will help to avoid significant costs in redesign for the operating company.