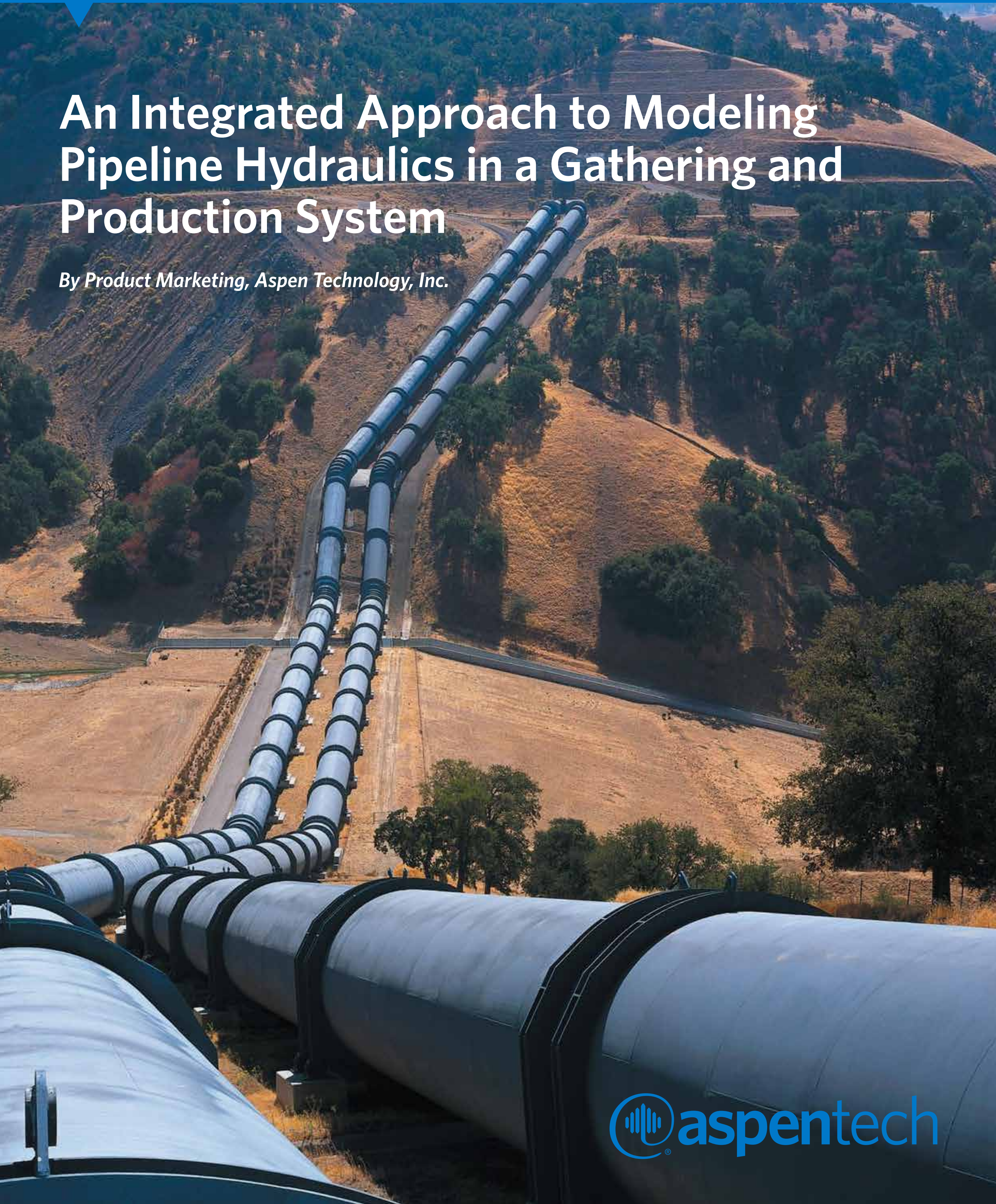
WHITE PAPER

An Integrated Approach to Modeling Pipeline Hydraulics in a Gathering and Production System

By Product Marketing, Aspen Technology, Inc.



Executive Summary

In recent years, as oil and gas fields become less accessible and their hydrocarbon quality lower and more variable, maintaining or increasing production levels has emerged as a key field development goal. One of the most pronounced challenges in meeting this goal is managing the complex hydraulics of pipelines used in gathering systems and to transport the oil and gas from wells to processing facilities. As these pipelines get longer in new fields, deeper in offshore environments, or simply older in aging implementations, E&P companies face critical problems for which they need better performance predicting and troubleshooting tools. From a business standpoint, solving these technical challenges is an increasing priority, since the capital expenditures involved in constructing and retrofitting gathering systems are a high proportion of development costs, but pale in comparison to the possible loss in field profitability due to flow interruptions.

This paper provides an overview of a new pipeline hydraulics modeling capability that eliminates the need to employ separate third-party tools for pipeline hydraulics. There are many benefits to modeling the entire gathering and production system (be it offshore, onshore, topside, etc.) within one tool, including not only being able to optimize the design from a capital and energy perspective, but also ensure the overall safety of the system.

Aspen HYSYS® has been widely used to model many facets of the oil and gas production fields, including separation systems, environmental control systems, gas dehydration, H2S and CO2 removal, and more. It is the tool of choice to determine the heat and material balance, separation performance, and regulatory compliance, among other key performance criteria (Gulbraar, 2011). In the past, third-party hydraulics packages were employed in conjunction with or separately from Aspen HYSYS to address that specific aspect of the design problem. This data then needed to be incorporated in the HYSYS model, which led to an inherently inefficient approach. Now the entire gathering system and production system can be addressed in an integrated fashion.

Aspen Technology offers two tools within Aspen HYSYS to accurately and rigorously model complex pipeline hydraulics: Aspen HYSYS Pipe Segment Model and Aspen HYSYS Upstream Hydraulics. With these two products, companies can model simple pipelines or a complex network of pipelines; they can simulate the dynamics of the multiphase flow through the pipe, and implement flow assurance measures to reduce erosion, corrosion, deposit formation, and slugging. These two products allow producers to simulate pipelines from wellhead to processing facility, startup to shutdown, from the beginning to the end of the field lifecycle, in steady state or dynamically, reducing the design time from several months to three days or less (2. Genesis Oil and Gas, 2011). This paper demonstrates the solution and its capabilities.

Need for Accurate Modeling of Hydraulics

One of the key expectations in modern energy production is reliability. In industrialized societies, the need for reliable energy sources is paramount, and therefore the need for reliable sourcing is fundamental. This reliability starts with the exploration phase of oil and gas fields. Since the formation of these fields is a natural phenomenon, the composition of the material extracted is unknown. However, there are tools Exploration and Production (E&P) companies can use to reliably extract these resources, even with unknown compositions.

The design of any gathering system and production network must contend with a variety of ever-changing business priorities and engineering constraints—with reliability being the constant objective. The system must achieve maximum uptime and performance to support the expected production throughput efficiently. A second objective is to support changing hydrocarbon compositions, which naturally differ over the lifetime of a production field, but also change unpredictably due to new and unconventional production flows being fed into the gathering network.

While the typical production involves an oil phase, a gas phase, and a water phase, sometimes solids such as sand and gravel also get mixed into the flow, depending on the field geology and its age. All of these factors need to be taken into consideration when an extraction strategy and the pipeline gathering network are developed. The design of the pipeline network is fundamental to ensure the flow from the field is consistent and steady, so that downstream processing can be equally steady and uninterrupted. The integrated consideration of the pipeline network, its hydraulics, and the separation and production systems is critical to ensure that safe operations are correctly built into the design.

The pipeline network must be designed in accordance with industry standards such as API, ANSI, and ASME as well as environmental (EPA), safety (OSHA), and any national, state, regional, or local regulations. The engineering design must take into account the envelope of expected temperatures, pressures, and volumes of the mixture going through the pipeline, as well as the entire geography it covers to transport the products, and environmental conditions and restrictions along its path. With a growing number of fields being located offshore or in hard-to-reach areas, pipelines have become increasingly longer and the surrounding environment more diverse, creating the need for better simulation of these new characteristics. It is also important to consider possible flow composition changes along the lifecycle of the field, depositions of impurities on the pipeline walls such as wax and asphaltene, as well as the corrosion of the pipes and slugging. With ageing pipelines all over the world, these considerations have become very important when deciding how to best extend the lifetime of a field, as well as whether maintenance is enough or if the pipeline needs to be replaced.

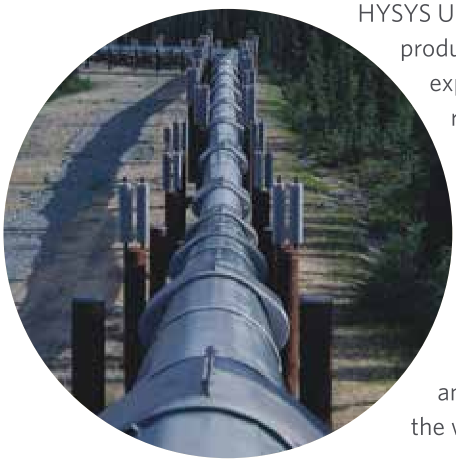
For the pipeline to be reliable, another important factor is flow assurance, or ensuring that the multiphase mixture containing oil and gas is constantly flowing to assure production and avoid damage to downstream equipment such as pumps and valves. This is especially difficult with deepwater wells, as any maintenance necessary in the pipeline is costly and incurs significant production losses. Taking all these factors into consideration, it is easy to see why correct pipeline design is so important. In fact, the pipeline usually accounts for the second largest component of the capital cost forecast for deepwater field development at 30%, second only to drilling and completion of subsea wells. The cost to build the pipelines is high, around $10 million per well, but miniscule compared to the billions of dollars in potential production losses incurred from incorrect designs over the lifecycle of the field. (John & MacFarlan, 2008) Safety and controllability are also important considerations when designing pipelines. Transient operation—including changes in temperature, composition, and pressure inside oil and gas pipelines—is common, and must be taken into account. In addition, startups, shutdowns, and downstream production requirement changes to the steady-state conditions must be considered in a dynamic model.

All of these requirements make pipeline hydraulics an extremely important step in field development planning. Therefore the accurate modeling of the pipeline and the connection between the pipeline and the equipment for midstream and upstream processing is fundamental in assuring optimized flow and production throughout the lifecycle of the field as well as safe operations of the entire network. This model can be used to optimize new production, and revamp or add new assets to an existing process.

Overview of Pipeline Modeling Solutions

To meet these industry needs, Aspen Technology makes available two approaches for modeling pipeline hydraulics, both within Aspen HYSYS. Both have similar capabilities, and both support the use of dynamics for transient flow conditions with the supported pipe model, but one uses simplified solvers for quicker results, while the other offers more rigorous modeling for complex pipeline designs.

The Pipe Segment Operation is the recommended solution for modeling a single pipeline that can be divided into multiple parts. Usually, these segments are determined by terrain or environmental changes along the path of the pipeline, where different flow correlations must be used to more accurately model the pipe. The second approach, Aspen Hydraulics— which is part of Aspen HYSYS Upstream—is designed to model a network of pipelines, such as offshore production. In this scenario, multiple wells with different characteristics are explored, and the resulting network of pipes with multiphase flow mixing requires more rigorous modeling.



Both approaches support the use of dynamic simulation, with Aspen Hydraulics supporting more rigorous calculations for pipe networks. The integration of both approaches with Aspen HYSYS makes it possible to model not only the pipeline, but the interface between the pipes and the processing equipment at midstream and upstream facilities. Coupled with the dynamic simulation to make the process safer and to adapt as the field and pipeline age, these tools are crucial for the operation of pipelines all over the world.

The Basics of Flow Simulation

When modeling a pipeline, there are several important factors to consider in the design, the most significant of which are the pressure drop, flow rate, flow geometry, and changing flow patterns. When modeling any flow through a pipe, the basic necessary inputs are inlet and outlet pressure, and mass or molar flow. A large number of variables affect pressure drop, which makes it a complex yet very important variable when considering pipeline calculations. These variables include thermodynamic properties of all components of the mixture traveling through the pipe, as well as their interactions with each other and the pipe material at the interface. There are also considerations for compressibility, difference in density, and the spatial arrangement of the different components during flow.

Flow Correlations

The large number of variables involved makes it practical to use flow correlations when modeling pipelines using Pipe Segment in Aspen HYSYS or Aspen Hydraulics. Both products offer a variety of industry-recognized flow correlations that can be used for different flow characteristics. These correlations can be either empirical (made to fit experimental data using dimensionless parameters) or mechanistic (developed to model particular flow pattern). Neither empirical nor mechanistic correlations can be used in all conditions, since they are developed for a particular set of flow characteristics. Therefore, when choosing a correlation model, it is important to know the most appropriate one depending on flow direction, and the necessity to model a flow map and liquid holdup, as shown in Table 1.

The last model on the table was created by the Tulsa University Fluid Flow Projects (TUFFP), a cooperative Industry-University research group supported by member companies and government agencies. (University of Tulsa, 2013) The group was formed to research and develop solutions for challenges encountered by the member companies pertaining to multiphase fluid flow in pipelines. Among other activities, this consortium has constructed physical test beds in which they test the behavior of oil and gas flow in pipeline segments on an ongoing basis. Aspen Technology is a member of this group and, as such, has access to the most up-to-date results obtained in the group's ongoing research, using results to provide a more accurate flow correlation for multiphase pipelines. Aspen Technology includes the latest TUFFP correlations within the Hydraulics modeling capability in Aspen HYSYS.

Model	Horizontal Flow	Vertical Flow	Liquid Holdup	Flow Map
Aziz, Govier & Fogarasi	No	Yes	Yes	Yes
Baxendell & Thomas	Use with Care	Yes	No	No
Beggs & Brill (1973)	Yes	Yes	Yes	Yes
Beggs & Brill (1979)	Yes	Yes	Yes	Yes
Duns & Ros	No	Yes	Yes	Yes
Gregory, Aziz, Mandhane	Yes	No	Yes	Yes
Hagedorn & Brown	No	Yes	Yes	No
HTFS Homogeneous	Yes	Yes	No	No
HTFS Liquid Slip	Yes	Yes	Yes	No
OLGAS 2-Phase	Yes	Yes	Yes	Yes
OLGAS 3-Phase	Yes	Yes	Yes	Yes
Orkisewski	No	Yes	Yes	Yes
Poettman & Carpenter	No	Yes	No	No
Tulsa 99	No	Yes	Yes	Yes
TUFFP	Yes	Yes	Yes	Yes

Table 1: Pipe Flow Correlations Available in the Aspen HYSYS Pipe Segment Model

Dynamic Modeling

Multiphase flow is intrinsically unstable, especially when traveling long distances over different terrains in a pipeline that may be corroded or eroded, or may contain obstructions. Therefore, it is important to design not only a steady-state model for the pipes, but also a dynamic model that takes into account changes to the flow as it moves through the pipeline as well as changes to the pipeline itself as it and the field age. This transient model is important not only for these variations, but also for startup, shutdown, and changes in production.

Dynamic simulation is possible using both Aspen Hydraulics and Pipe Segment Model in Aspen HYSYS. The only difference is that the dynamic modeling performed within Aspen Hydraulics is more rigorous, and therefore, should be applied to more complicated scenarios such as multiple producing fields that are served by one network of pipelines with convergences. The Aspen HYSYS dynamic model uses the same physical property packages as the steady-state model, and the steady-state model is easily converted to a dynamic model. The software features a Dynamics Assistant to ensure an easy transition with no under- or over-specification. This approach maximizes the value of the steady-state model and reduces the expense and complexity associated with building and integrating a separate dynamic model. The engineer should always consider employing Dynamic Modeling to achieve the best design to ensure flow assurance and network reliability.

Flow Assurance

The key to a reliable pipeline is ensuring continuous flow from the production site to the processing site at as close to design-flow throughput as possible. Flow assurance encompasses the thermal-hydraulic design and assessment of multiphase production fluids through pipelines, as well as the prediction, prevention, and remediation of flow stoppages. The purpose is to ensure successful and economical flow of multiphase fluids from reservoir to point of sale. Flow interruptions can cause the disruption of production and damage to the processing equipment, which combined can cost a refinery millions of dollars in lost revenue. In fact, the cost of lost production due to flow assurance issues can dwarf the installation costs for the entire pipeline. Therefore, it is important to consider such factors when designing the production pipeline.

Flow interruptions may be caused by the corrosion or erosion of the pipe materials, the unstable nature of multiphase flow, or the formation of blockages in the pipes—either physically or due to chemical reactions, such as hydrate formation. The instability of multiphase flow, usually referred to as slugging, can cause significant pressure differences along the pipeline due to the interactions between the gas and liquid phase, which is accentuated due to terrain changes. Blockages in the pipes are caused by the deposition of solids found in the flow, the most common of which are wax, hydrates, and asphaltene. These depositions occur under certain temperature conditions that can be minimized, and remediation usually includes production stoppage, so it is important to use the correct dynamic tools to design the pipeline to minimize these issues.

Aspen HYSYS V8 for Usability

Although hydraulics modeling capabilities were introduced earlier than Aspen HYSYS V8 (released in December 2012), it is highly recommended that engineers use Aspen HYSYS V8.0 or later when performing the modeling described in this document. The later versions of Aspen HYSYS introduce a completely redesigned user environment, with an Office 2010 “ribbon” paradigm and a workflow/workspace that makes this capability more accessible to new users.

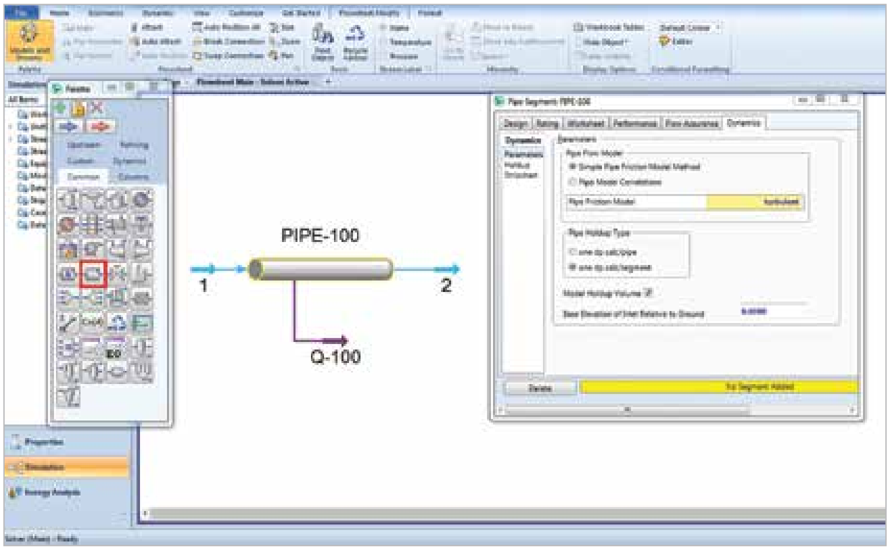


Figure 1: Example of a pipe segment in an Aspen HYSYS V8 flowsheet. The segment can be selected from the palette on the left and has selections for Flow Assurance and Dynamics on the right.

Aspen Pipe Segment Model

Developed specifically for basic pipeline design, Aspen HYSYS includes a tool called Aspen Pipe Segment Model. This tool can be used much like the other unit operations available in Aspen HYSYS; it is available in the "common" object palette and can be added to the main flowsheet (see Figure 1). It is used primarily in modeling single pipelines without mixing, and uses simple solvers for faster calculations.

With pipe segments, the entire pipeline is divided into smaller pipe sections depending on the characteristics of each segment to ensure more accurate modeling. Each pipe segment can have a different flow correlation, for example, to adapt to different geographical characteristics (see Figure 2).

When using the Pipe Segment Model, you need to specify just two of the following: inlet pressure, outlet pressure, or mass/molar flow rate; once two variables are specified, the third can be calculated. Other specified inputs include the length of the segment, elevation change, outer and inner pipe diameters, pipe material, and the number of increments. The design also includes models for heat loss based on heat loss through pipe, outlet temperature, and heat transfer coefficients. Depending on the characteristics of the simulation, it might be helpful to disable some segments of the pipe while solving the rest of the flowsheet, and the Pipe Segment Model allows for that with an "Ignore" option.

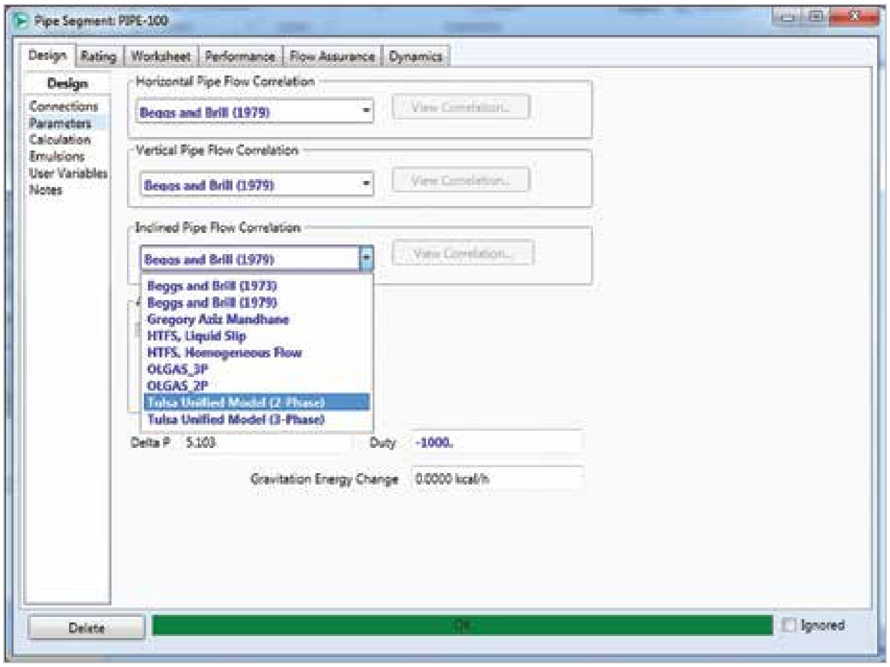


Figure 2: Multiple correlation selection for horizontal, vertical, and inclined pipe flow in a Pipe Segment.

The Pipe Segment Model also performs dynamic calculations for flow, to account for changes along the pipeline as well as for pipeline aging. These calculations are also important when conducting Flow Assurance analysis, using specific tools within Aspen HYSYS that examine CO2 Corrosion, Pipe Erosion, Slug Analysis, Wax Deposition, and the formation of Hydrates (see Figure 3). These tools are important when assessing conditions that could permit interruptions to flow, especially as the field (and pipeline) ages, and then minimizing the risk of that occurrence.

The simulations using the Aspen Pipe Segment Model can be used by Engineering and Construction companies designing field production systems, to predict the behavior of the fluids in the well as they progress through the pipeline, over distance as well as over time. The models also empower the operator of the field to predict and avoid possible interruptions in flow, along with scheduling maintenance on the pipeline, in order to improve production and extend the lifetime of the field.

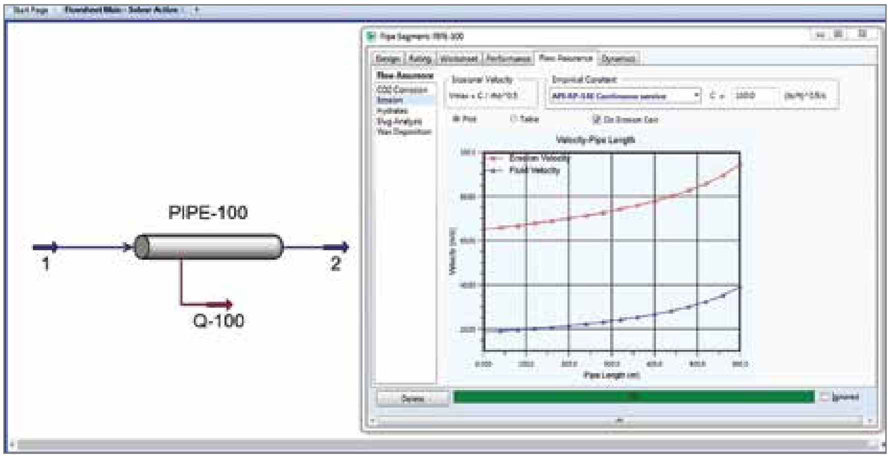
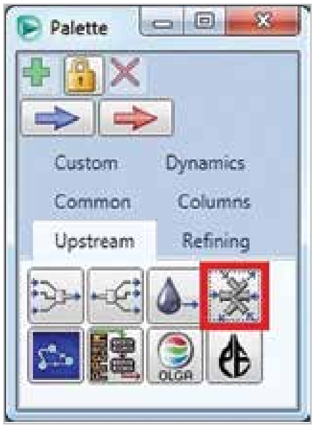


Figure 3: The Flow Assurance tab (right) for a Pipe Segment (left) showing erosion calculations related to flow velocity along the pipeline.

Aspen HYSYS Hydraulics Subflowsheet

Unlike the Pipe Segment Model, Aspen HYSYS Hydraulics is a subflowsheet available as a part of Aspen HYSYS Upstream Operations (see Figure 4). This means that the subflowsheet can be added to a broader Aspen HYSYS flowsheet and connected to other equipment in that flowsheet, while still providing rigorous calculations for all the specialized equipment contained within the subflowsheet.



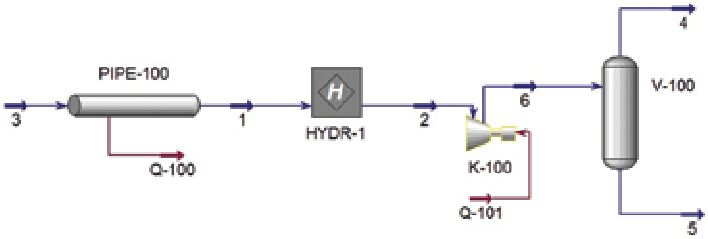


Figure 4: The Aspen Hydraulics Subflowsheet in the Upstream Palette in Aspen HYSYS V8 (left), and the Aspen Hydraulics Subflowsheet (HYDR-1) integrated into a broader Aspen HYSYS flowsheet (right).

The Unit Operations available in the Aspen Hydraulics Palette include a single pipe segment mode, a complex pipe, a valve, an orifice, a bend, a swage, and a T-Junction mixer and splitter (see Figure 5). The subflowsheet can be added to a more complete Aspen HYSYS flowsheet to create a complete model of a pipeline network and a production facility, from well head to sales point.

The Aspen Hydraulics subflowsheet breaks down complex pipelines into components, making it possible to model complicated pipe networks comprised of multiple flow branches within a single flowsheet. This is made possible by including mixers and splitters in the flow model, which significantly increases the number of pressure and flow variables that define the system. As a result, there are more boundary conditions available for the user to specify. Aspen Hydraulics is very flexible, enabling users to specify boundary conditions for the flowsheet, with various combinations of pressure and flow possible.

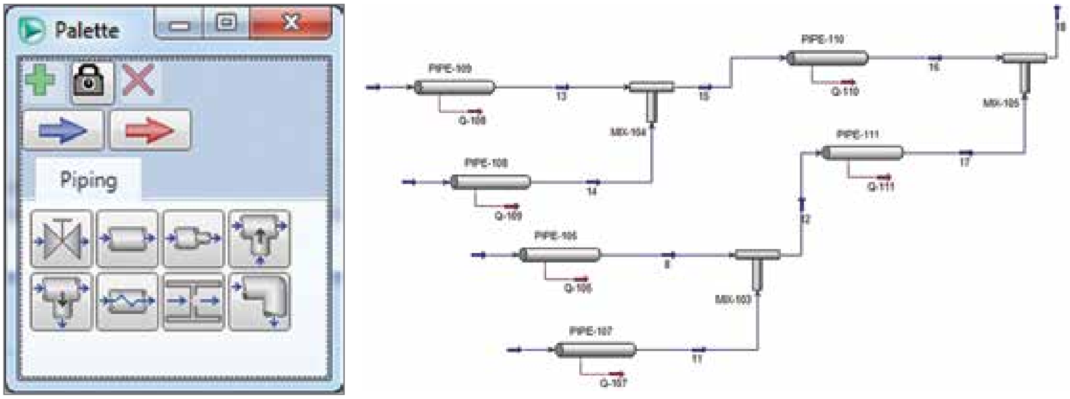


Figure 5: Aspen Hydraulics Subflowsheet Palette in Aspen HYSYS V8 (left), and an example of a pipe network build in Aspen Hydraulics (right).

More user-defined and calculated variables to help define the multiple branches make the pipeline solving more rigorous. Each pipe in the subflowsheet also needs the user-specified composition, along with a thermodynamic state variable such as temperature, enthalpy, pressure, or vapor fraction, in addition to pressure drop and flow rate.

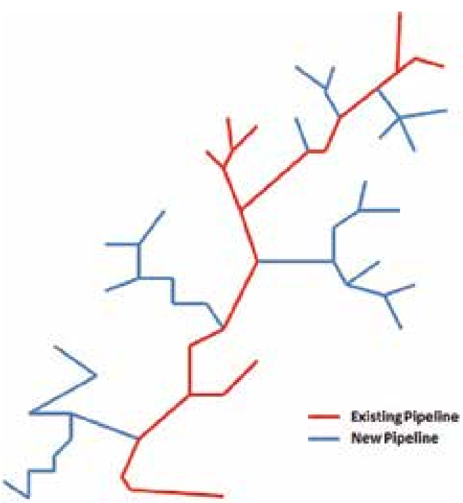
As with the Pipe Segment Model, when using Aspen Hydraulics it may be useful to ignore parts of the pipeline selectively to quickly implement modeling scenarios, such as those sections of a field that are shut off. For this purpose, Aspen Hydraulics pipes also allow the “Ignore” option, which if selected will cause the simulation to ignore all units downstream from the ignored pipe.

Uses of Aspen HYSYS Hydraulics Subflowsheet

Emerging unconventional gas opportunities, including shale gas, have required many companies to re-evaluate their existing gas and oil gathering pipeline systems. In some cases, it has been necessary to increase the pipeline capacity, while in other cases, the pipelines might need to be extended to reach the new wells coming onstream. For both of these scenarios, it is important to fully understand the interactions at work within the pipeline to identify potential improvements and additions.

For an accurate assessment of these interactions, it is important to model the entire pipeline gathering system, including compression, multiphase (gas, oil, water) pipeline hydraulics, and pipeline heat losses. This is crucial to determine bottlenecks in current capacities, and to identify the need for and characteristics of new pipes. If only changes to existing equipment, such as debottlenecking, are necessary, the model will prevent the expense of perhaps millions of dollars in pipeline construction.

With that in mind, a global pipeline engineering and construction company needed to assess operational constraints on their pipeline hydraulic network, identify potential flow assurance issues and mapping the compression requirements as new wells came online. For that purpose, they used Aspen Hydraulics and modeled their existing pipeline, as well as their planned additions (see Figure 6). By utilizing the Aspen Hydraulics capabilities, the company was able to identify and remove existing bottlenecks in their pipeline, as well as reduce the horsepower requirements in their pumps—all with minimal capital expenditures.



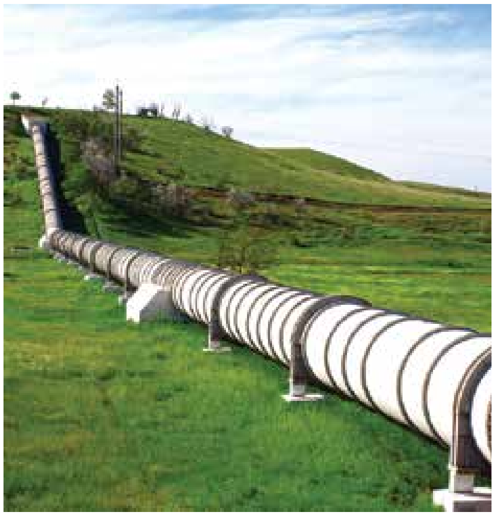


Figure 6: Sample pipeline modified by a global engineering and construction company to model and add to their shale pipeline.

Another global E&C organization, WorleyParsons, has employed the hydraulics capability in Aspen HYSYS in a diversity of E&P applications, ranging from the accurate measurement of pressure drops across a complex series of gas processing trains to the safe design of subsea gathering systems. (Gomez, 2013)

The Bigger Picture

Pipeline network hydraulics modeling within Aspen HYSYS is just part of a bigger engineering picture in the conceptual design of E&P facilities. The integrated aspenONE engineering solution provides the process modeler with a versatile and comprehensive engineering workflow—all accessible from within Aspen HYSYS. Figure 7 provides an overview of aspenONE engineering.

After modeling the production systems in Aspen HYSYS and the gathering system in the pipeline modeling functionality within Aspen HYSYS, there are several other key engineering tasks that are enabled, which together help achieve an optimized design more efficiently. These include:

- Conduct an energy analysis of the complete system to optimize the design from an energy and carbon emissions standpoint, using Aspen HYSYS Activated Energy Analysis
- Conduct rigorous design of all heat exchangers within the system, using Aspen HYSYS integrated rigorous exchanger design models
- Achieve a preliminary estimate of capital and operating costs for the designed production system and gathering network, using Aspen HYSYS Activated Economics

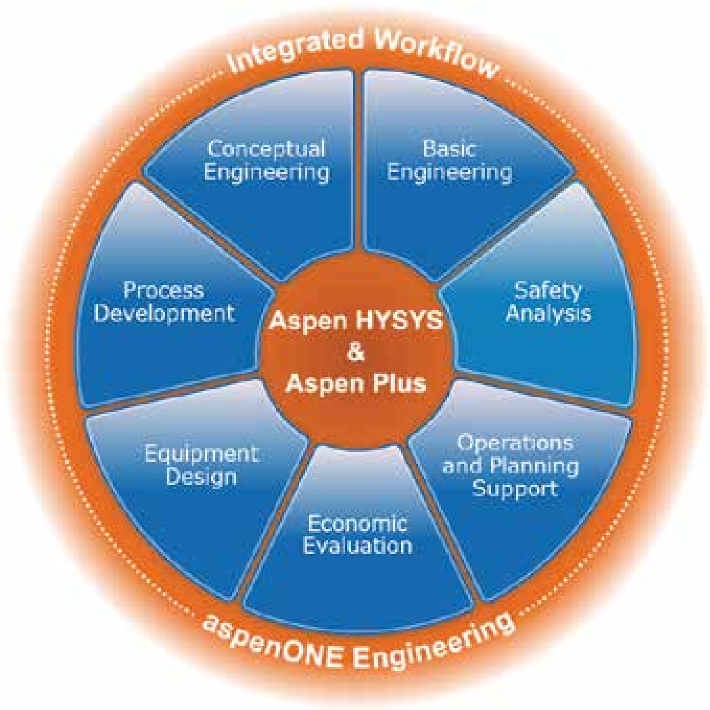


Figure 7: Integrated workflow of aspenONE Engineering.

Conclusion

As the oil and gas industry requires more accurate and comprehensive modeling capabilities for pipeline hydraulics, Aspen Technology has risen to the challenge with two product offerings: Pipe Segment Model and Aspen HYSYS Hydraulics. Both are a part of Aspen HYSYS, the industry leader in oil and gas modeling software, which makes integration with existing Aspen HYSYS models for upstream production and midstream processing simple and accurate.

Both Pipe Segment Model and Aspen Hydraulics offer simulations for flow through pipelines, with variables including pressure drop, flow, pipe materials, heat transfer, flow correlations, altitude change, and many more. Aspen Hydraulics provides more rigorous modeling in a subflowsheet format with additional variables, while Pipe Segment Model can be added as a unit to any Aspen HYSYS flowsheet for quick pipeline calculations. Both support dynamic modeling to account for transient flow conditions such as startup and shutdown, and also to support critical flow assurance calculations.

By utilizing these capabilities, customers in the oil and gas industry can simulate pipelines easily and accurately from within their Aspen HYSYS models, not only in steady-state operations but also as the field and pipeline age. With the information provided by their Aspen HYSYS models, these companies can save millions of dollars in construction and maintenance costs associated with debottlenecking and flow assurance, and prevent production losses that could run into the billions of dollars across the lifespan of the field. This makes Aspen HYSYS solutions for pipeline hydraulics modeling crucial for the modern oil and gas industry.

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Additional Resources

For further information on this workflow, or any of the products covered in this paper please consult:

Public website:

aspenONE Engineering **http://www.aspentech.com/products/aspenone-engineering/**

Aspen HYSYS **http://www.aspentech.com/products/aspen-hysys.aspx**

Aspen HYSYS Upstream **http://www.aspentech.com/products/aspen-hysys-upstream.aspx**

Aspen HYSYS Upstream Dynamic **http://www.aspentech.com/products/aspen-upstream-dynamics.aspx**

On-demand Webinars:

The New Aspen HYSYS Applied to Hydraulics and Flow Assurance

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Recorded Presentations (Brainsharks): **https://www.brainshark.com/aspentech1/MultiphaseFlowModelingHYSYS**

AspenTech Support Website: **http://support.aspentech.com**

The support website provides an extensive and growing knowledge base on aspenONE products and solutions.

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