PIPELINE ENERGY CONSUMPTION OPTIMIZATION

A novel power optimization utility software

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TODAY PIPELINE OPERATORS ARE REQUIRED TO balance operational efficiency, financial performance, and long-term sustainability. Transporting hydrocarbons efficiently and safely is a demanding task, and energy consumption is one of the major operating costs and sources of emissions. New applications based on pipeline simulation can contribute to reducing energy costs and optimizing operations while continuing to achieve the required delivery schedules within the safety and operating margins. This

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simulation-based approach considers the different energy costs across the pipeline pump/compressor stations, utility contracts, pump/compressor efficiency, and the costs and benefits of using drag-reducing agents (DRAs). It is a valuable tool that allows energy managers and pipeline operators to optimize energy costs. It can be seamlessly integrated into the supervisory control and data acquisition (SCADA) infrastructure, which provides the real-time views and reporting of all energy and process variables, including the cost savings achieved. The SCADA system monitors and controls one or more complete pipelines used for transporting liquid or gas products from one location to another. Each pipeline may be very long and may have several branches.

The human–machine interfaces (HMIs) provide the means of communication between the SCADA system and the pipeline operators. HMIs are workstations with screens to visualize information and the means necessary to execute commands. The data are collected using remote terminal units (RTUs), which are installed at different locations along the pipeline, as shown in Figure 1. The measurements shown in Figure 1 are the flows (F_I, F_O), the pressures (P_I, P_O), and the product temperatures (T_I, T_O). A ground temperature measurement, $T_{G,I->O}$, is also shown.

Power Consumption Optimization

Moving hydrocarbons efficiently through miles of pipeline has always been demanding due to the large number of variables and the severe constraints of safe operation. The operators must optimize schedules, resources, staffing, maintenance, and other critical operating factors. Even the most experienced personnel find it challenging to optimize the processes manually; therefore, a reliable and user-friendly front-end tool would facilitate making operational decisions that aid operators in meeting delivery goals and business objectives.

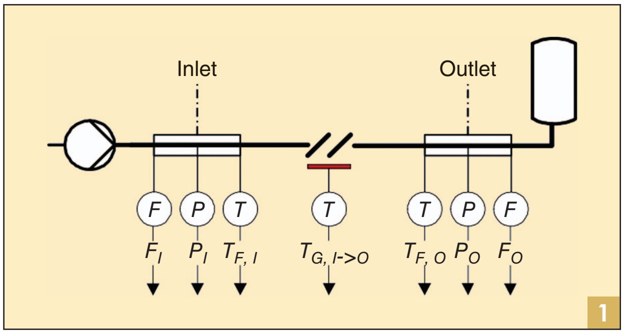
The energy consumption is typically the highest operating expenditure of a large pipeline system. This is because the processes are driven by large pumps and/or compressors that require substantial power to meet the product displacement and flow requirements. To maximize profitability, pipeline companies challenge their operators to focus their efforts on increasing pipeline energy usage efficiency, thereby managing energy costs, which continue to rise.

The use of high-efficiency equipment can somewhat reduce the operating costs on a site-by-site basis, but significant gains in efficiency can only be achieved by considering the entire system. A power optimization utility provides users with a means to measure energy consumption and pumping/compression costs for a pipeline system in a real-time manner via its integration within the SCADA system. Based on the current operating conditions and energy tariffs for each pump station, this utility also calculates the costs for different setpoints and equipment availability, thus allowing operators to select the most efficient configuration for the whole system for scheduled future events, such as electricity consumption rate changes. Such projections must be consistent with the operational and safety constraints. The power consumption optimization applies to all types of pipelines transporting both liquids and gas [1], [2].

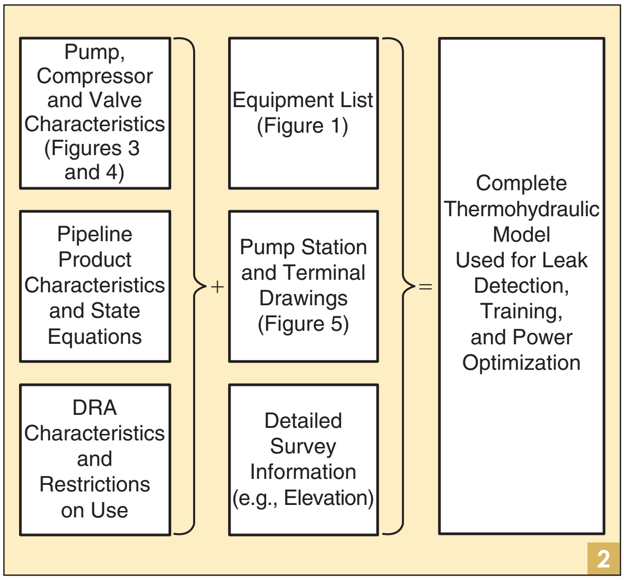
A power optimization utility requires two separate yet key modeling subsystems. The first is a realistic pipeline thermohydraulic model, which simulates the operating conditions of the pipeline. A second subsystem is a costing model that takes an operating condition of the pipeline and accurately returns the total cost needed to operate in this state, including the energy usage, demand charges, and DRA costs.

Two primary types of simulations make up the power optimization utility: current costing runs and cost optimization runs. The current costing runs take the pipeline information, such as pressure, temperature, and flow measurements, along with the batch line fill, valve, and pump lineups from the SCADA, and return the cost per hour to run the pipeline in its current configuration. The costing optimization runs consider the constraints, such as the product flow rate, the current batch lineup, the minimum and maximum injection and delivery pressures, and the equipment operating limits. Based on these constraints, the most cost-efficient operating condition is calculated and recommended to the operator.

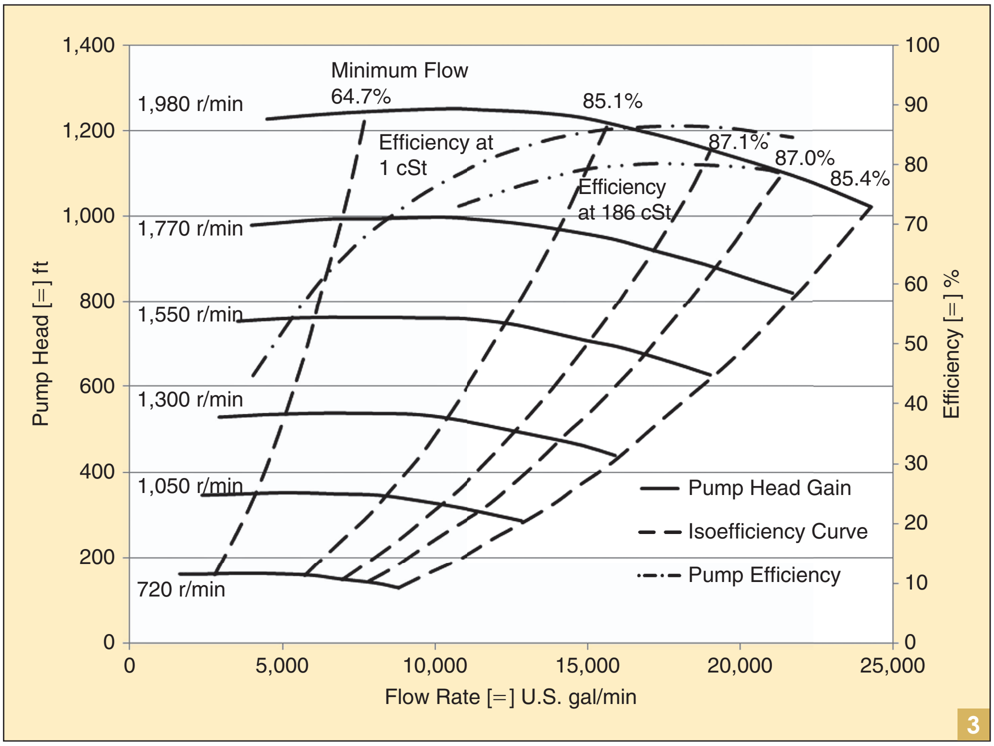
Based on the descriptions of the various pieces of equipment, such as the pumps, compressors, valves, and transmitters, and the equations of state for the fluids that will be moved through the pipeline, detailed models of the pump



A pipeline data transmission.



The components of a thermohydraulic model.



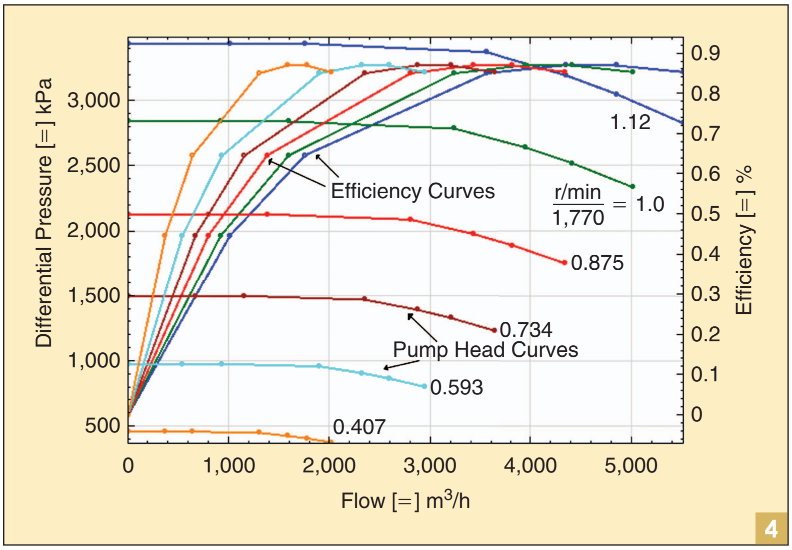
The manufacturer's typical pump curve.

Component Modeling

Since the primary energy consumers in a pipeline are the pumps or compressors, accurately modeling their behavior is critical. If power usage meters are present at a given pump, they will be used to help tune the efficiency curves for the pumps. The tuning results in a better performance of the optimization algorithms. If no power meters are available, the energy usage will be calculated based on the data from the manufacturer's curves, as shown in Figure 3.

To be used in the thermohydraulic model, pump curves like those shown in Figure 3 are digitized and input into the model as shown in Figure 4. The pumps are described internally in the model with a pair of nonlinear equations, one representing the head gain and the other representing the pump efficiency as a function of the mass flow rate, their current operating speed, and the density and viscosity of the pumped material. The pump data can be input either using the coefficients for the two equations or directly using the manufacturer's pump head and efficiency data. The power optimization utility can then extract the proper values of the coefficients for the various equations, and the mathematical model of the pump can be used as a building block for the pipeline simulation.

stations and the pipeline as a whole are made, as shown in Figure 2. The optimization algorithm within the power optimization utility (the optimizer) will use this thermohydraulic model and carry out a steady-state solution methodology that solves the detailed mass, momentum, and energy balances on the liquids and gases present in the pipeline. The result of this simulation will be a complete thermohydraulic profile of the pipeline; more than 80 physical properties are calculated along with the state of each piece of equipment that is included in the model, i.e., whether the pump is on or off, the variable-frequency drive speed, the valve status and position, the transmitter values, and so on.



The manufacturer's pump data as used in the model.

Once the various types of equipment are described, they are used to build an accurate representation of the pipeline and all of its stations. The piping and instrumentation diagrams are used as the basis for understanding the hydraulics of a given station and its pump and valve arrangement. These are developed in a graphical representation that is analogous to how they are connected in reality. The detailed station models are combined with the pipeline survey information to create a full description of the pipeline. Figure 5 shows a typical pump station model where P, T, and F are the pressure, temperature, and flow sensors, and W is the work meters.

In addition to the pumps and energy-consuming devices, another key factor is the DRA. Small amounts of a DRA injected into the pipeline can reduce the amount of head lost per unit length along the pipeline, requiring less energy to move the same amount of product or, for the same energy usage, allowing the pipeline operators to move the products at a higher flow rate. The effect of the DRA is described via a reduction in the fluid-wall friction factor when solving the momentum balance equations. How much it is capable of reducing the effects of friction is again described by a nonlinear equation that is a function of the concentration of the DRA in the line at a given point in parts per million. Two correlations can be used to model the effectiveness of the DRA as a function of its local concentration.

An accurate method is needed to model the effectiveness of the DRA, and the fact that it degrades as it passes through the equipment (pipe walls, valves, pumps, and so on) must be considered. Generic degradation rates can be specified for each type of equipment, or specific values for a given instance of an equipment type can be used. On the cost optimization side, the use of a DRA opens up the range of solution space that must be searched. Additional DRAs may allow for the usage of fewer pumps but at the added cost of the DRA itself. If the DRA can be used, it will be up to the optimizer to find the best tradeoff between the DRA levels and the energy consumption by the pumps as well as any restrictions that may be present, such as the fact that the DRA cannot be injected into certain products or that the total amount of degraded DRA cannot rise above a given limit at the end of the pipeline.

These descriptions of the equipment, the products, the DRA, the stations, and the pipeline survey information, taken together, represent the thermohydraulic model that will be used in the various power optimization calculations. This model also forms the basis of other applications, from the operator training systems [3] to the leak detection systems and the power optimization utility calculations discussed here.

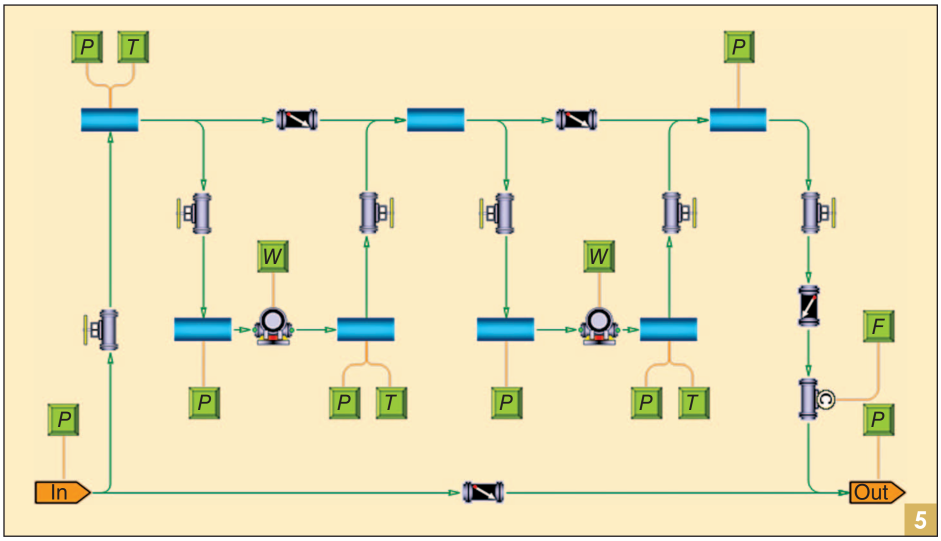
The SCADA System

The SCADA system is a very important part of any pipeline operation, and it is a client–server architecture integrating several functions. The most basic is the communication with all of the sensors and I/O devices in the electrical and process equipment through the I/O server. There is often communication with other systems, such as batch scheduling when this is done by the pipeline company's product management system. The servers include object linking and embedding for process control (OPC) server application software with the other systems as clients. The HMIs serve as the interface with the operators and have the ability to trend all analog values. Trending shows a measured value as a function of time and is very useful for detecting anomalies. The RTUs are used to perform the required control functions. The SCADA system may operate in a redundant configuration, in which case it will be able to continue to provide monitoring and control in the event of a faulty device. The SCADA system provides the reliable data necessary for the simulations and also ensures the operator interfaces for the monitoring and control of the pipeline.

All communication is performed by Ethernet via managed routers and switches that send the data through the right communication channels, i.e., very small aperture terminal (VSAT), Global System for Mobile Communications (GSM), radio, or optic fibers. The SCADA networks are based on Transmission Control Protocol (TCP)/IP. Self-healing rings are commonly used and provide a redundant communication path [1]. The day-to-day control and operation of a pipeline is carried out by a team of operators whose job is to ensure that the product is moved through the pipeline in a safe and efficient manner. The operators get their information about the current state of the pipeline through the HMIs that are part of the SCADA system. It is through this system that they are able to alter the state of the pipeline by changing the injection pressures, changing the flow rate, opening or closing valves, or starting/stopping pumps or compressors.

The Energy Costing Module

This thermohydraulic model tells us how much energy is being used by the pipeline under a given operating state. However, to know how much this will cost, a separate utility costing model must be constructed as well. The costing module must work in conjunction with the thermohydraulic model and the optimizer to inform the operator how much it currently costs to run the pipeline and how to run it in its least costly setup while satisfying the required constraints. The costing module will represent the power contracts that the pipeline company has with the various utility suppliers through which the pipeline runs. The details about the rates, peak times, demand charges, holidays, weekdays, weekends, and historical use



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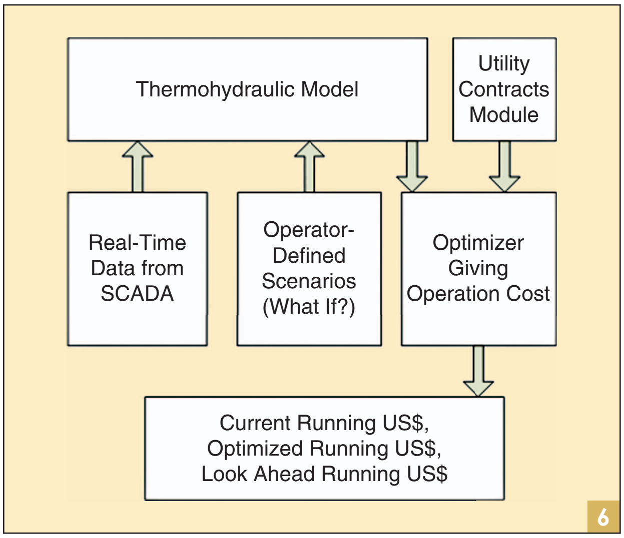
A typical pump station model.

are all accounted for. Each pump in the thermohydraulic model is configured to be described by a given utility costing contract.

The optimizer will then use the energy usage information from the thermohydraulic model, along with the model of the power company's utility contract, to calculate a cost for the current or recommended operating configuration. The operation of the power optimization utility is shown schematically in Figure 6. The scheduling applications within the power optimization infrastructure control how often each type of calculation, either current costing or optimization determination, are run. Such calculations are typically carried out once every couple of minutes with the current costing runs occurring more frequently.

The current costing runs are carried out by retrieving the field measurements from the SCADA system that define the current state of the pipeline, computing the thermohydraulic state of the system, and then determining the cost of running in this state. An optimization calculation will run a large number of steady-state thermohydraulic cases, searching the state space of the pipeline that respects the current throughput while attempting to elucidate the most cost-effective way to operate the pipeline. In addition to the raw kilowatthour and product (DRA) costs, these calculations also consider the potential demand charges that a customer may incur with their power supplier, should they exceed some base level of energy usage over a given time period. This cost can be substantial and can easily exceed the raw power costs. In the pipeline industry, it is rumored that turning on a pump for testing can cost more than US$100,000 due to the demand charges.

Alongside the current and optimization runs that are carried out, there is a separate set of runs that seek to alert a pipeline operator about a change in the rate structure that is on the horizon. Such early warning simulations are carried out a certain amount of time before a rate change. For example, if the power cost transitions from on-peak to off-peak hours at 8 p.m. each evening, then the system can be configured to carry out these early warning runs at 7 p.m. and alert the operator. There are three types of early warning runs. The first is a recosting calculation that imforms the user how much it will cost to run their pipeline in its current configuration at the new rate schedule. The second is an optimization run that will generate a new optimized solution, given all of the constraints but using the new rate schedule. Finally, there is the early warning at current, which will inform the end user how much it will cost to operate the pipeline using the optimized solution for the new rate schedule at the current time, i.e., the cost of running the post-8 p.m. optimized solution between 7 and 8 p.m.



The power optimization utility.

Operators are often interested in knowing what would happen if a certain parameter changes, such as the flow rate or availability of some equipment. Operators can run what-if scenarios without making any changes in the real operating conditions. Such simulations allow for overriding or specifying the constraints that the optimizer will use when attempting to determine the cost or derive an optimal operational recommendation. In addition to setting the physical requirements, it is also possible to specify at what time such a calculation is to be carried out since the rate contracts can change depending on the time of day or the day of the week. New calculations required because of predictable changes can be scheduled. Those required due to what-if scenarios are run in an on-demand manner. Examples of the use of this functionality include setting a pump to be unavailable due to a scheduled maintenance, specifying that a certain pump is used, setting the throughput to be different from the current, or setting a given station's discharge pressure to a fixed amount.

The optimizer will use the power meters that are connected to the pumps along the length of the pipeline for the direct computing of the current cost of the pipeline. If the power meters are not available, the optimizer will calculate the power from the SCADA flows and pressures and the pump curve data. The information about the current batch lineup is also critical in a multiproduct line. This information is available from the batch tracking system. Since the different products can have vastly different physical properties, knowing the location and type of each product becomes a key input into the power optimization utility. The batch lineup that was used in each calculation is displayed as part of the standard output to the end users so that they can be aware of what the complete state of the pipeline was when the calculation was performed.

Tuning the Model

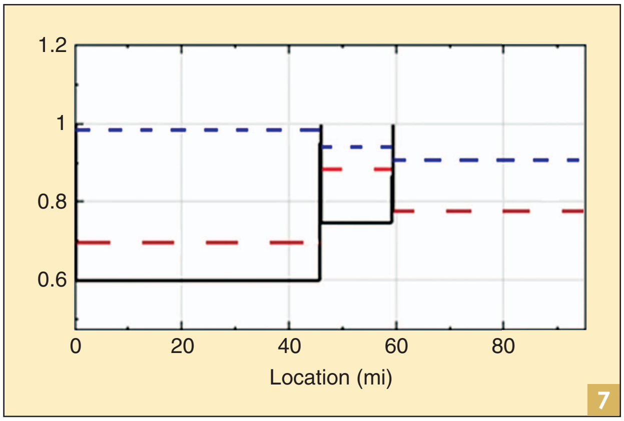
The thermohydraulic model that forms the basis for the power optimization utility is often constructed with idealized data: what it was on day one of the pipeline's life or what it was designed to be. This means that the model often differs from the real-world conditions. To address this inconsistency, a tuning process is continually carried out and applied on each run of the simulation. This process seeks to correct the model to more closely match the real world by examining the pressure drop between two pump stations and, separately, the pressure rise across a given pump or pump station.

The tuning process matches the pressure drops between the stations by modifying the friction factor, the physical term that partially determines the head loss per unit length during the flowing conditions. There are three time windows and, hence, three tuning options over which this process is carried out. The simplest of the three options is the instantaneous modification factor. Under this regime, the pressure between the two stations is read from the SCADA system, and the friction factor used in the simulation is modified so that the simulated pressure drop matches the SCADA values exactly. On each pass, this modification factor will change—potentially drastically—depending on the operating conditions. It is recommended that this tuning method be used only in extreme cases, such as when cold starting the model or testing a new configuration.

The next method uses a window on the order of minutes to determine what the friction factor modification factor should be. By gathering a short amount of historical data, the system can compute what is historically the best way to compensate for the nonidealities in the data that were used to create the model. This regime is most useful during the initial tuning so that the system can react to the changes and new conditions in a responsive fashion. As time goes on and the system begins to stabilize, it is recommended that the third and longest window be used as the dominant tuning mechanism. Here, the data stored for times ranging from hours to days is used to determine what the overall friction factor modification factor should be. This is best for systems that operate in a quasi-steady-state fashion and do not often see drastic changes in operating conditions (flow rate or products). This modification factor can range from as low as 0.3 to as high as 3.0. If the data entered perfectly match the conditions of the pipeline, this modification factor will be 1.0. The power optimization utility allows the model behavior to be examined long after it is deployed. The data for the current runs can be extracted, and it is possible to plot these friction factor modification values to see how they vary along the length of the pipeline. Figure 7 shows a typical set of the three possible friction tuning factors from a system that has been in production for a significant amount of time (the solid line represents the instant tuning, the long dashes represent the short-term tuning, and the short dashes represent the long-term tuning).

In addition to attempting to correctly predict the pressure drop between the two pump stations, the system also strives to determine the correct pressure rise across a single pump station. This is done by applying a similar tuning factor to the pump head gain and/or the pressure drop across a control valve. Since the pumps play such a key role in the power optimization utility, a good deal of effort goes into ensuring that the model correctly accounts for the pumps' behavior.

The historical values of the key pump-related variables—flow rate, pressure rise, and energy usage—are recorded, and adjustments are made to the model to correctly predict the real-world behavior of the pump. As with the other parts of the system, the online data can be used to determine how closely the pump is behaving compared to how it was initially modeled. Figure 8 shows how it is possible for the engineer to check the results of the tuning. The data were initially defined as the pump head gain and the pump efficiency as a function of the flow rate. These are shown as the input curves. The corrected curves show the results of the tuning.



The friction tuning factors.

In Figure 8, it is clear that this pump was modeled correctly as the efficiency points primarily lie on the appropriate line. The lower grouping of the two sets of historical pump pressure rise points do not appear to line up correctly with the input pump pressure curve. This is not the case, however, because the amount of pressure generated by the pump is a strong function of the density of the fluid being pumped. When plotted as a pump head, where the density is corrected for, the historical points lie on or near the input curve.

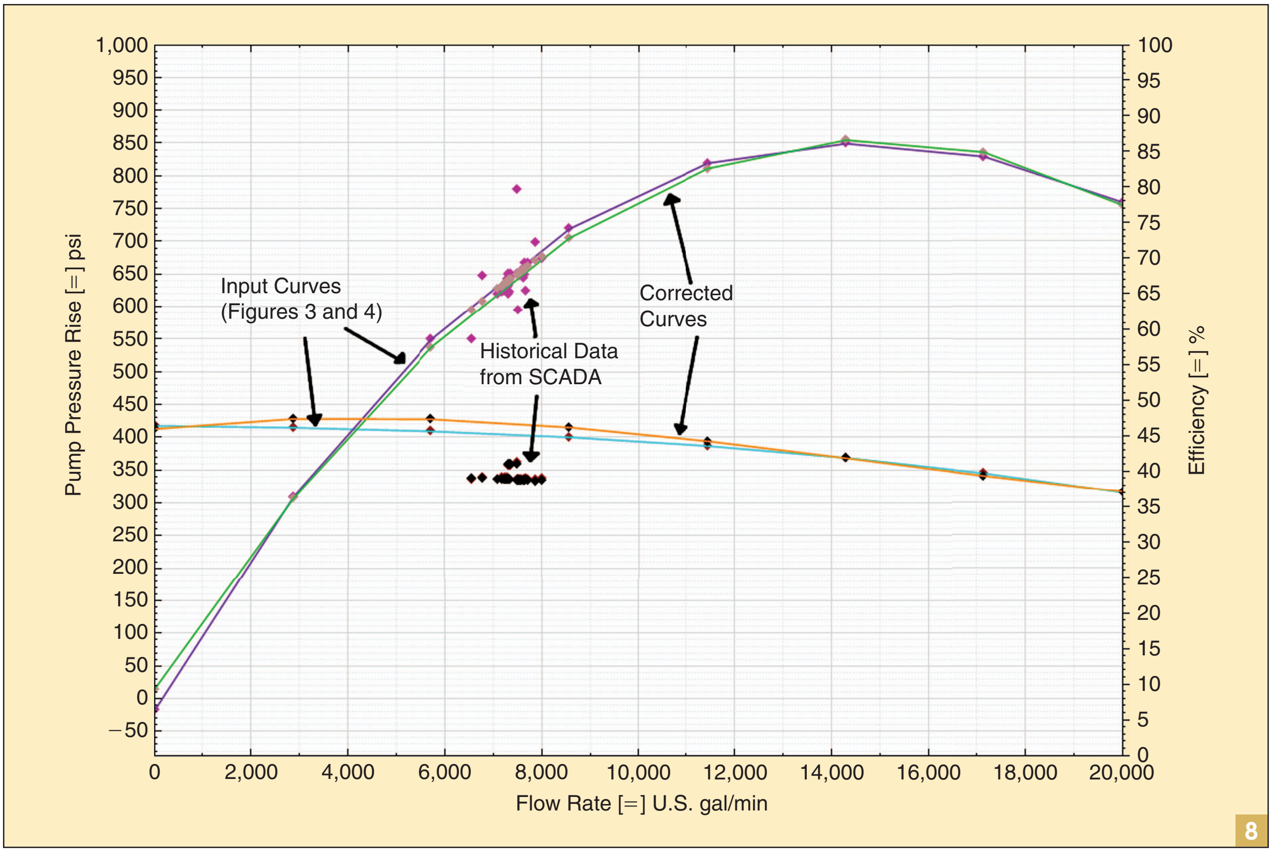
Safety

The safety of personnel and the safe operation of the pipeline are the pipeline operator's chief concerns. It is important that the optimizer, when recommending new solutions, especially those that have not been tried before, respect all of the established safety boundaries and margins. As part of the development of the thermohydraulic model, the maximum allowable operating pressures (MAOPs) can be entered as shown in the top curve in Figure 9. If they are not available, a realistic approximation of the MAOPs is calculated based on the physical characteristics of the pipe material and the appropriate safety factor. The bottom curve is the lower limit corresponding to the required net positive suction head, which is viewed as a fixed amount above the elevation profile. The lower limit ensures that the optimizer does not recommend a configuration that would lead to cavitation in the pumps.

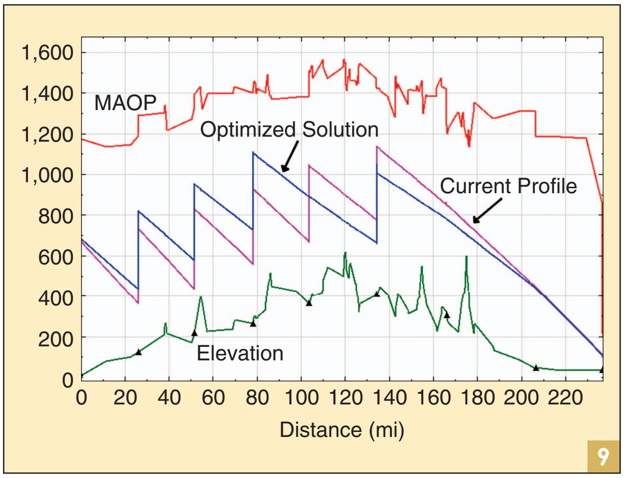
As described in [4], leak detection and location is vital to the safe operation of a pipeline. The same thermohydraulic model used for the power optimization utility is used for leak detection and location. Each application makes use of the information that it needs, which is made available in the common thermohydraulic model. Using a common model for all applications helps avoid errors, which are inevitable when different models are used for each application.

System Aspects

A system is more than just the sum of its parts. This is especially true in the case of pipelines due to the



The pump tuning based on the measured values.

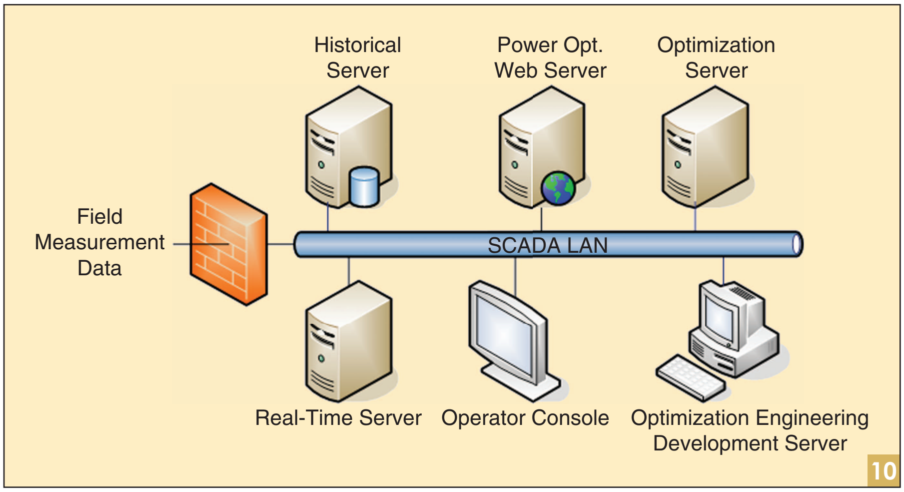


The current and optimized hydraulic profiles.

distances involved and the wide variety of products transported. The selection of the type of instrumentation and its location along the pipeline will depend on several factors. Ensuring that reliable real-time data that the operator needs to make correct decisions are made available is the key factor. However, information from the instrumentation alone is not enough since it can be located thousands of miles from the operator's workstation. The SCADA communication system must be designed to transmit the data from the instrumentation in a timely manner, and it must also be very robust. Robustness is the capacity to operate correctly under disturbed conditions such as the failure of a key component or communication path. Since reliable data are vital for safe operation as well as for meeting business objectives, some means of verifying the data should be implemented. This will enable alarms to be generated should real-time data not be coherent with the actual state of the pipeline. The comparison of the real-time data to the simulated condition of the pipeline is one means of verifying the output of the instrumentation.

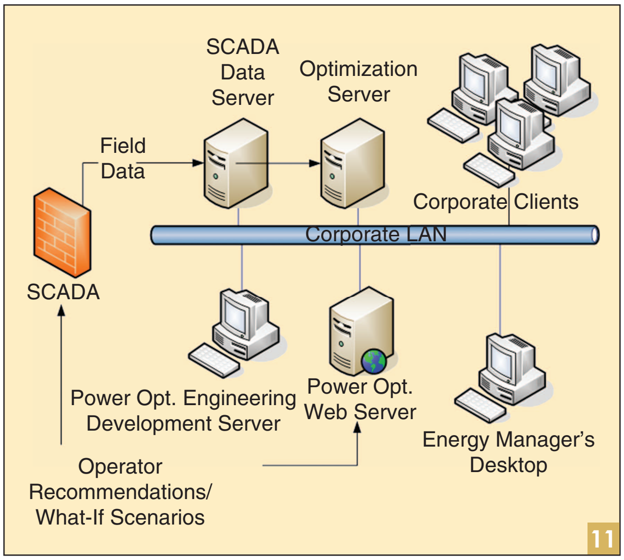
The power optimization utility runs separately from the main SCADA system and presents users with two key pieces of information: how much it currently costs to run the pipeline per hour and how much can be saved by using the equipment state recommended by the optimizer. Since the HMI for the power optimization system is a thin Web-based client, the user, in this case, can be an individual in one of multiple roles and does not have to be in the control room. In the most straightforward case, the end user could be an operator getting the results and recommended equipment states and operating conditions directly on the SCADA console. It could also be an energy manager working in an area completely removed from the control room who is studying how to develop new efficient strategies for operating the pipeline. An engineer working on a new pipeline design for future capital projects could also easily use this information to see how different strategies affect costs.

Since the power optimization utility is a business tool as well as a SCADA tool, its complete architecture can reside either on the direct SCADA LAN or outside of a firewall on the corporate network. If it exists inside the SCADA LAN, as shown in Figure 10, the system is capable of receiving real-time data from the main SCADA server directly. On the other hand, if it exists outside of the firewall protecting the SCADA system, as shown in Figure 11, the power optimization utility can be configured to receive the data from an external (to the SCADA LAN) data server that provides the SCADA information to users outside the firewall on the corporate network.



The deployment within the SCADA control center.

There are three roles that must be fulfilled in a power optimization utility deployment: the engineering development station, the power optimization server, and the Web server. The number of computers that this requires can vary from a single machine to a full set of three servers with each taking on a single role. A typical architecture includes the engineering development station as a dedicated machine that is just for model development and engineering maintenance of the model after deployment. The roles of the optimization server and the Web server can be combined on a single machine or split as the project demands specify.



The deployment as a business application server.

A dedicated engineering station allows the engineers tasked with creating and maintaining the power optimization model to have full flexibility in carrying out their work without impacting any of the other real-time applications that are used to run the pipeline. In addition to its use in developing models, it can play a number of key roles in testing, maintaining, and ultimately deploying the power optimization model to the optimization server. Before a model is deployed to the optimization server, the engineer working on the engineering station can employ the properly formatted historical SCADA data to run the power optimization simulation in a hindcast mode. In this mode, the model can complete a good deal of the initial tuning that will be needed before it is deployed to an online environment. It can also function in a maintenance mode, where the additions or enhancements to the model can be run against the recently gathered live data from the optimization server. These modes of operation provide a robust environment in which to create new models or test and improve the existing ones. Once a model is deemed ready, the engineering station has the ability to deploy the model to the optimization system to be run against the live SCADA data.

The optimization server is responsible for communicating with the SCADA system to retrieve the measurement values and equipment statuses as required. The optimization server will be the machine that is responsible for scheduling and running the costing and optimization simulations that are central to the power optimization utility. If there is a large number of pipelines, this machine will need to be powerful enough to handle all of the calculations, or, otherwise, runs will need to be scheduled in such a way that the CPU never becomes overloaded. In addition to running the simulations, the optimization server also needs to ensure that the results of each run are available to the Web server so that they can be used by all who are interested in accessing the power optimization utility. It will also need to be able to handle the on-demand runs that come from the users via the Web server.

The power optimization results are available through a thin client via the Web and are served up by the Web server. This machine serves the results to the clients and parses the incoming requests for the on-demand runs or specialized what-if cases. Depending on the project requirements, this can either function on its own or run as part of the optimization server.

Pipeline	Current	Optimization
	US$/h (Time Stamp)	US$/h (Time Stamp)
gbt	US$372 (03/12/12 05:01 PM)	US$276 (03/12/12 05:00 PM)

Early Warning	EW Optimization	EW Opt@Current
US$/h (Time Stamp)	US$/h (Time Stamp)	US$/h (Time Stamp)
3/12/2012 8:0:00 PM US$306 (03/12/12 04:55 PM)	3/12/2012 8:0:00 PM US$242 (03/12/12 04:55 PM)	3/12/2012 8:0:00 PM US$395 (03/12/12 04:55 PM)

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The cost summaries, current and optimized, with the early warning information.

Achieving Energy Optimization

Energy optimization is achieved by considering the complete pipeline as a system. It is not enough to consider individual pump stations and apply energy optimization to subsets of the system. The optimizer itself efficiently searches the state space of the operating conditions of the entire pipeline looking for the cases/regions of lowest operating cost. The optimization is done by going through and varying the setpoints of the numerous operating control points (e.g., the station's suction/discharge pressure and DRA flow rates) and exploring the feasibility of the solution with those new setpoints. The feasibility is checked from both a safety point of view—i.e., not violating any limits or margins—and from a hydrodynamic stability/consistency point of view.

Typical examples of cost savings results are cases where pressurizing the fluid to a higher level at an early pump station allows for a station down the line to run entirely unused. Another common solution is to use more DRAs in combination with pressurizing the fluid to a higher level so that the downstream pump stations can be bypassed. In addition, switching which station is set to be on, when there is a choice, can result in sizable savings if the price of energy at one station is less than at another. This is not information that an operator would have at his or her disposal when running the pipeline, so the optimizer provides a whole new perspective as to how to best operate the pipeline.

Since the optimizer recommends a manner to run the pipeline under the current conditions, there are deadbands and checks in place to ensure that it does not simply flop back and forth between two equally good solutions that may be very different hydrodynamically. A simple monetary cost of start-up/shut-down of a pump is added to the optimizer's calculations to prevent the recommendation of such cases to an operator; constantly seeing two different solutions would degrade the end user's confidence in the predictive power of the system.

The results of the optimizer are only presented to the end user as a recommendation. The end user will see, by default, a summary page of all of the pipelines running under the power optimization utility and a simple table listing how much it costs to run them under their current configuration and how much it would cost to run under the recommended configuration. It is up to the operator to make a yes or no decision as to whether to move the pipeline to operate in this optimized manner in accordance with the standard operating procedures of the pipeline and the company that owns it.

The cost summary display, as shown in Figure 12, represents a high-level summary of the current results of the optimizer. The display shows the current operation cost of the pipeline(s), both in terms of energy usage and money, and its recommended optimized costs. Also present is the horizon time. This is when the energy rates will change. Early warning runs commence that will alert operators or managers to the upcoming rate changes and allow them to plan ahead.

Selecting a pipeline brings up a tabular summary of the current state of the pipeline equipment as well as the current operating hydraulic profile. The tabular result is displayed in Figure 13. These results can be changed to display the recommended optimized results as well, but it is often more insightful to examine the differences between the two cases, current and optimized, as shown in Figures 9 and 14. Figure 9 shows the hydraulic profiles of the current condition and the optimized condition plotted against one another. The bottom saw-toothed curve represents the current operating state of the pipeline; the upper saw-toothed curve is the optimizer's recommendation as to how to run the pipeline in a more cost-effective manner. It can be seen that the optimizer recommends running the pipeline at slightly higher pressures for the first 80 mi so that the fourth pump station can be shut off entirely. What is not obvious from this plot is the fact that the fourth pump station has the highest utility costs of any station in the pipeline. The cost savings of switching to this mode on this pipeline with this product lineup are US$96/h, as can be seen in Figure 12. If that value is the average savings per hour for the entire year, it will result in a direct savings of US$800,000.

For an operator to know what changes need to be made to move into the recommended operating mode, the power optimization utility provides convenient tabular data through the Web interface that highlight the changes. Figure 14 shows the tabular results that correspond to a case where the optimizer recommends that one pump station with cheaper utility costs be run instead of the next one down the line, which has higher energy costs. For each station, it displays the equipment state (whether the pump is on or off, its speed, and the control valve position), the total energy usage occurring there, the current cost per hour that is being incurred at that station, and the demand charge that is being factored into the total bill.

The changes that exist between the current operating condition and the recommended optimized condition are highlighted in blue and appear immediately below the current operating condition for a given piece of equipment. This enables an operator to easily see what changes need to be made

Station	Energy	Demand	Pump	Status	kW	Speed	C-Valve	Pos.	Flow Rate	Suction	Case	Discharge	Throttle
	US$/h	US$			kW	%		%	Barrels/h	Pounds Per Square Inch Gauge	Pounds Per Square Inch Gauge	Pounds Per Square Inch Gauge	Pounds Per Square Inch Gauge
SP24	US$3.50	US$4,893.20	SP24_U4MRUN	OFF	0	0%	SP24_CV1POS	100%	7,298.2	71	428	418	10
			SP24_U5MRUN	OFF	0	0%							
			SP24_U6MRUN	OFF	1,255	100%							
RY24	US$2.98	US$4,167.15	RY24_U5MRUN	ON	1,275	100%	RY24_CV1POS	99%	7,298.2	187.5	555.1	557.1	−2
			RY24_U6MRUN	OFF	0	0%							
NW24	US$2.24	US$3,184.80	NW24_U4MRUN	ON	732	100%	NW24_CV1POS	100%	7,298.2	345	563	575	−12
			NW24_U5MRUN	OFF	0	0%							
			NW24_U6MRUN	OFF	0	0%							
SH24	US$89.65	US$16,140.82	SH24_U5MRUN	OFF	0	0%	SH24_CV1POS	3%	7,298.2	398.6	393	398.6	−5.6
			SH24_U6MRUN	OFF	0	0%							
LS24	US$209.29	US$19,714.07	LS24_U4MRUN	OFF	0	0%	LS24_CV1POS	100%	7,298.2	203	515	505	10
			LS24_U5MRUN	ON	1,204	100%							
			LS24_U6MRUN	OFF	0	0%							
SU24	US$645	US$18,437	SU24_U5MRUN	OFF	0	0%	SU24_CV1POS	0%	7,298.2	345	2	345	−343
			SU24_U6MRUN	OFF	0	0%							
HW24	US$0	US$33,075	HW24_U4MRUN	OFF	0	0%	HW24_CV1POS	1%	7,298.2	325	323	325	−2
			HW24_U5MRUN	OFF	0	0%							
			HW24_U6MRUN	OFF	0	0%							
SC24	US$0	US$9,922.50	SC24_U5MRUN	OFF	0	0%	SC24_CV2POS	63%	7,286.7	259	140	145	−5

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The current operating state of the pipeline.

Name	Energy	Demand	DRA	Total Cost	kW	US$/barrels	Delta	Time Stamp
Current	US$372	US$109,535	US$0	US$372	10,038	US$0.0302	US$0.0007	03/12/2012 4:59:00 PM
Optimization	US$364	US$109,570	US$0	US$364	10,543	US$0.0295		03/12/2012 4:55:08 PM

Station	Energy	Demand	Pump	Status	kW	Speed	C-Valve	Pos.	Flow Rate
	US$/h	US$			kW	%		%	barrels/h
SH24	US$89.65	US$16,140.82	SH24_U5MRUN	OFF	0	0%	SH24_CV1POS	3%	7,298.2
			SH24_U6MRUN	OFF	0	0%			
			SH24_U6MRUN	ON	1,191.3	100%			
LS24	US$206.29	US$19,714.07	LS24_U4MRUN	OFF	0	0%	LS24_CV1POS	100%	7,298.2
			LS24_U5MRUN	ON	1,204	100%			
			LS24_U5MRUN	OFF	0	0%			
			LS24_U6MRUN	OFF	0	0%			

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The recommended operational changes.

to operate in the lower condition. The results for each current and optimization run are stored in an XML-formatted file. These files may be archived on a time basis allowing for a record of how the system and the operators are performing.

Conclusion

The cost-saving performance of a power optimization system depends on many factors, such as the pipeline structure and operational limitations. It is, therefore, not possible to make general statements about what cost saving can be achieved. However, cost savings in the 5–10% range are not unusual.

The power optimization utility software provides direct benefits for the company operating the pipeline, the customers and consumers, the utility provider, and the DRA provider. For the company operating the pipeline, the power optimization utility

- provides the operator with real-time operating costs
- presents the operator with the optimal equipment lineup and DRA injection rates for the current operating conditions and objectives
- makes the operator aware of the cost impact of the day-to-day operating decisions
- gives energy managers a method to verify their billing, manage their power contracts, and perform what-if cost analyses.

The power optimization utility gives the customers of the pipeline operating company confidence that they are buying competitively priced products from an environmentally conscious and sustainable provider. The utility and DRA providers to the pipeline company are assured of the efficient and effective use of their products and services including, for the utility company, a level of peak load management that is not easily obtainable.

The use of such a power optimization utility allows a company to make direct, realizable gains in energy efficiency not by making high-level decisions but by making actual changes at the day-to-day process level.

References

[1] G. Stanley, K. Taylor, and R. Dzierwa, "Power optimization in liquid pipelines," in *Proc. Pipeline Simulation Interest Group Annu. Meet.*, 2007.

[2] K. Rittie, "Software application helps reduce energy consumption," in *Proc. Pipeline Gas Technology*, June 2010.

[3] M. Malinowski, S. Smith, and K. Nelson, "Developing and implementing a 'full scope' operator trainer simulator for the TransCanada Keystone pipeline," in *Proc. Pipeline Simulation Interest Group Annu. Meet.*, 2010.

[4] T. Hazel, G. Geiger, and D. Vogt, "Integrated SCADA-based approach for pipeline security and operation," in *Proc. 57th Annu. Petroleum Chemical Industry Conf.*, 2010, pp. 1–8.

[5] T. Hazel, I. Condamin, and F. Audemard, "Facilitating plant operation and maintenance using an electrical network control and monitoring system simulation tool," in *Proc. 51st Annu. Petroleum Chemical Industry Technical Conf.*, 2004, pp. 361–370.

[6] D. Trung, "Modern SCADA systems for oil pipelines," in *Proc. 42nd Annu. Petroleum Chemical Industry Conf.*, 1995, pp. 299–305.

[7] W. Osborne, "Choosing a SCADA system with the operator in mind," *IEEE Trans. Ind. Applicat.*, vol. 23, no. 6, pp. 1073–1076, Nov.-Dec. 1987.

[8] B. Quartey, D. Shaw, and P. Waked, "An application of PLCs as an RTU in SCADA systems," in *Proc. 39th Annu. Petroleum Chemical Industry Conf.*, 1992, pp. 271–274.

[9] G. Geiger, D. Vogt, and R. Tetzner, "A survey of leak detection and localization," presented at the Gulf International Convention, 2009.

[10] G. Geiger, D. Vogt, and R. Tetzner, "State-of-the-art leak detection and localization," presented at the Abu Dhabi Int. Petroleum Exhibition Conf. (ADIPEC), 2008.

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