

Piping System Model as a Life Cycle Document

White Paper by Ray Hardee, P.E., Chief Engineer for Engineered Software, Inc.

Introduction

When designing piping systems, a variety of documents are created providing the details necessary to design, purchase, build, and test the piping system. After the system is completed these design documents are turned over to the client for use in operating and maintaining the system.

During the life cycle of a plant, modifications are made to the system to meet the changing process needs. As these changes are proposed, engineered, and implemented they must be added to the original design documents. By keeping these documents up-to-date, everyone involved has a current and accurate picture of the piping system.

Design documents fall into the following categories: drawings, calculation spreadsheets, specification documents, purchase orders, vendor supplied manuals, and test and operating procedures.

These documents are often created using commercially available software such as Computer Aided Design (CAD) software, electronic spreadsheets and word processors. Plant owners are now requiring design engineering firms to include the program files used to create these design documents in the project turnover package. For example if the owner has a copy of the drawing file along with the CAD software used to create the drawing, they can keep the drawing current during the life of the plant.

This article describes how fluid flow software and their computerized piping system models are rapidly being recognized as valuable life cycle documents by the owners and operators of the piping systems.

Example Life Cycle Documents

Now that we have discussed the various types of design documents available, let's see how these documents are used. For example when working on a pump in a plant the following documents are used:

- The Piping & Instrumentation Drawing (P&ID) shows where the pump is located in the system. In addition, the pump's unique equipment identifier is listed on the piping schematic.
- The original purchase specification document provides the pump's initial requirements including its performance and test requirements.
- The purchase order provides the details on what the pump manufacturer supplied along with any contract modifications.
- The manufacturers test package provides the pump performance data and test documentation that is used to compare the pump's current performance to the pump's performance when installed.
- The manufacturer's equipment and maintenance manual provides troubleshooting instructions along with recommended maintenance procedures.
- The startup test documentation includes the pump's baseline performance when operating in the system.
- Plant operating procedures provide the information needed to properly operate the pump in the piping system.
- A review of the system modification documents provides a history of plant modifications that may have adversely affected the pump.

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The majority of these documents are typically created as part of the initial system design, yet they are continually referred to throughout the life of the plant. Another important point to consider is the people using these life cycle documents most likely did not create the original documents.

The Piping System Model – a New Life Cycle Document

Fluid piping software was originally used designers and engineers to size individual pipelines and analyzes the operation of the total piping system. Over the years, fluid piping software has gained wide acceptance among owners and operators of piping systems because of its ability to accurately simulation the operation of the system, along with the wealth of design data the programs make available.

Elements of the Piping System Model

In order for the piping system model (created by the program) to meet the objectives of a life cycle design document, they have evolved to contain the following elements:

- The primary interface of the piping system model is a schematic drawing similar to a flow diagram or P&ID. Behind the drawing is a database of detailed design data about each item in the piping system.
- The calculation module is tightly integrated into the piping schematic and accurately simulates the operation of the total piping system.
- To increase the value of the piping system model some vendors have added hypertext links to external electronic documents that are useful in designing and operating the piping system.
- The ability to share the results with everyone involved in the project, regardless of their access to the program that created the piping system model.

The remainder of this article describes how the piping system model provides the information needed to be an effective life cycle document; in addition, a series of examples are presented showing how the piping system model is currently being used.

Drawing & Design Data

The schematic drawing is the central feature of the piping system model, showing the equipment in the system along with the interconnecting pipelines (see figure 1). The piping system model's piping schematic looks similar to a flow diagram or P&ID, typically created by CAD software.

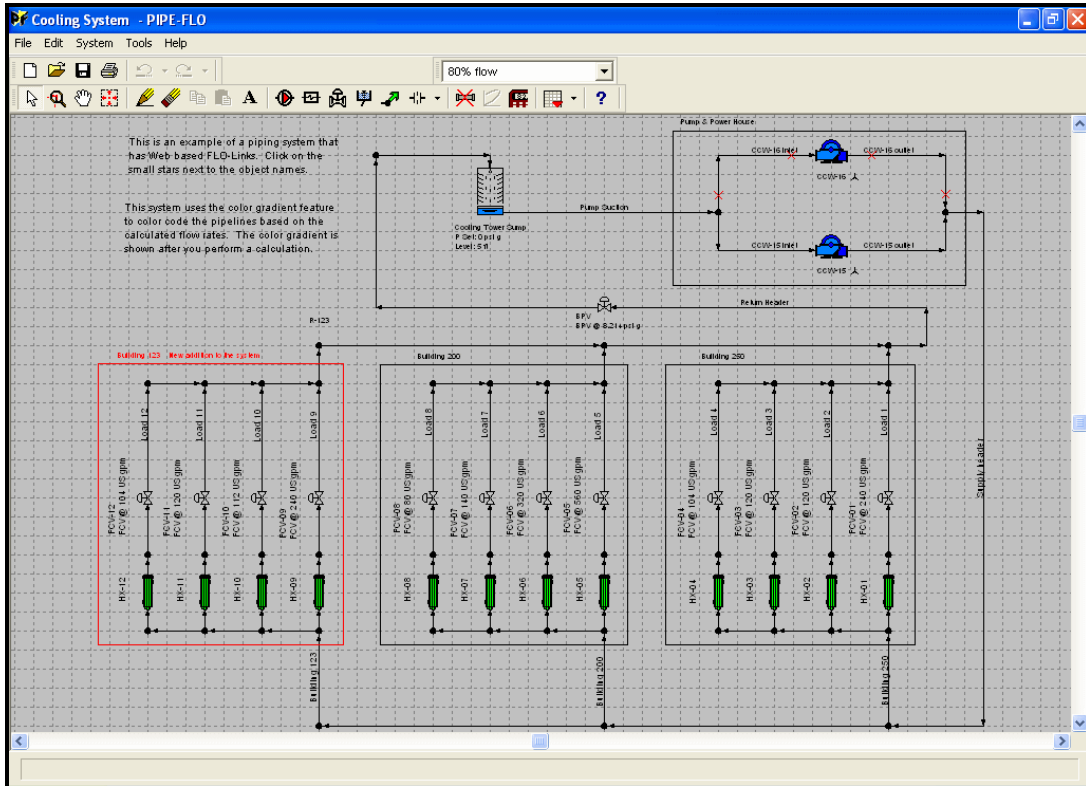


Figure 1. The piping schematic is the central feature of the piping system model and provides an intuitive program interface.

The various components in the piping system (pumps, tanks, cooling towers, heat exchangers, filters, etc.) are represented by symbols on the drawing. Each symbol is drawn to look like a standard shape found on a P&ID. In addition to using a familiar looking symbol, each item in the piping system model is identified by the user with a unique name (names can be up to 30 alpha numeric characters). Utilizing the shapes and naming convention for each item on the piping schematic increases the familiarity everyone can have with the piping system model.

A wealth of design information about the various items in the system is stored in the piping system model. This information provides the user with an accurate database of the pipelines, pumps, control valves, components and tanks that make up the system. For example, when a user selects a pipeline they immediately know the pipelines; material of construction, nominal diameter, length, the process fluid in the pipelines, valves, and fittings.

Finally, the calculated results are displayed on the piping schematic showing the user how the entire piping system operates. The user can gain additional information about a specific item by pointing to it with the mouse; the details about that item are displayed in the “fly-by viewer” on the bottom of the program’s window.

Calculation / Simulation

The calculation and simulation capability of the program is used both in the initial design and operational phases of the plant.

The following calculation features are incorporated into the program to assist the designers and engineers:

- Provide design control and streamline the design process
- Size individual pipelines for optimal diameter
- Perform a full system hydraulic network analysis
- Perform equipment selection of pumps and control valves
- Size differential pressure flow meters and balancing orifices
- Simulate the operation of the piping system under steady-state conditions
- Perform a dynamic hydraulic analysis showing how the system operates over a period of time.

There are a variety of program features meeting the specific needs of designers and engineers, such as calculating the optimal pipe diameter and determining the head loss in a pipeline for a specific range of flow. In addition, the program has the ability to evaluate the same pipe with various pipe diameters, pipe material, and fluid conditions. The majority of information used in the calculations comes from engineering data tables supplied with the program. This not only streamlines the design process, but it insures accurate information is used in the design.

With a completed piping system model, the program performs a full hydraulic network analysis of the system by calculating the balanced flow rates and pressures in each pipeline. This provides a clear picture of how each item in the system affects the operation of the total system. The result of the network analysis also provides the user with design point values needed for pump and control valve selection.

To assist in equipment selection, the program includes the ability to select centrifugal pumps and control valves from manufacturers supplied data in electronic form. The program also supports the manual entry of pump and control valve operating data thereby allowing the user to enter the performance data for any pump or control valve from data supplied in paper catalogs.

Using the piping system model, the user can simulate the operation of the piping system under any expected operating condition. For example, the user can turn pumps on/off/vary the speed, open/close individual pipelines, change the levels and pressures in tanks, and adjust the set points in control valves. The program then calculates the balanced flow rates and pressures providing an accurate picture of the entire system operation. The various operating scenarios or lineups can be saved, allowing the user to simulate the system under a variety of conditions.

Access Information

Hypertext links to electronic documents within the piping system model provide the user immediate access to CAD drawings, maintenance manuals, specification documents, operating procedures, or any document needed to design, built, operate, or maintain the piping system.

The ability to gain access to documents is accomplished by attaching hypertext links to the various items in the piping system model. The hypertext links provide access to electronic documents on the user's network or the Internet. In addition, these hypertext links can be used to start other applications such as spreadsheets, word processors, or CAD software.

The following example demonstrates how linking to electronic documents can help troubleshoot problems in operating a piping system. Suppose someone in the maintenance department used the piping system model to trouble shoot the operation of a pump in the system. With the operating information provided by the program, they are able to determine that a problem in the system was isolated to the primary chilled water pump. Since the next step is to fix the pump, the mechanic can use the hypertext links embedded within the piping system model to gain immediate access to:

- The purchase order the pump was originally purchased under (in Word format on the client's network).
- A link to the pump manufacturers Website where the most current Operations and Maintenance manual can be found.
- The company's maintenance management software that displays the maintenance history for that pump.

Since these links are in the piping system model, the intended user does not need to know how to navigate through the various computer programs containing the necessary information they simply click on a link. Since the hypertext links make reference to the original document on the user's network, the program is always accessing the most current document available.

Communicate

The primary function of fluid piping software is providing a clear picture of the operation of the total piping system. This is accomplished by:

- Generating reports in both printed and electronic format.
- Providing the ability to e-mail reports and working piping system models to users.
- Sharing a read-only version of the piping system model with anyone involved with the project.

Printed reports are the mainstay for providing the information needed to fully understand the operation of the system. The piping schematic can be printed, complete with calculated results. There are a wide variety of list reports providing detailed information about each item found in the system including the calculated results. Detailed data sheets for individual items in the system provide the user with sufficient information that they can document and validate all calculations made by the program. A detailed bill of materials report identifies every item found in the piping system model.

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Since e-mail has become an essential part of today's business, most fluid piping software provides the user with the option of e-mailing the reports in Portable Document Format (PDF). The recipient can then view and print the documents using the Adobe® Acrobat program.

To make the piping system model available to everyone involved with the piping project (even if they don't have access to the program), some software manufactures have created a read only version of the program that can display the piping system model. The viewer program provides the recipient with the ability to view and print the piping schematic along with the ability to perform the system calculations.

Next we'll see how the software is used in various times in the life of the plant. In this section of the article we'll see how various groups involved with design and operating fluid piping systems

Piping System Model as a Design Tool

Most documents used in a piping system are originally created during the design process, and the piping system model is no exception. In this section we'll describe how the piping system model is created and used to size individual pipelines, select pumps and control valves, and simulate the operation of the entire piping system.

Drawing the Piping System Model

The primary feature of the piping system model is the piping schematic. It is similar to a traditional flow diagram or Piping & Instrument Drawing (P&ID) created by a CAD package. Each item on the piping system has a graphical symbol, along with a unique user assigned identifier. Each symbol also has a record in the program's database providing a wealth of design data about each item in the system.

Sizing the Pipelines with Specifications

The pipe specification and engineering data table features of the program streamline data entry and provide design control while entering the pipeline details.

Each pipeline in the system is designed based on user created pipe specifications. The pipe specification references the pipe data table and pipe schedule used. A variety of pipe data tables are shipped with the software containing the available nominal pipe diameters associated with the specified pipe material and schedule. When the user enters the available nominal size, the program looks up the pipes inside diameter and roughness, and automatically inserts the design data into the pipeline record. This information is used for the pipeline pressure drop calculations.

The pipe specification contains sizing rules to help the user select the optimum pipe diameter for the design flow rate. Also, a set of design guides can be entered for fluid velocity and pressure. During a calculation, if one of the design guides is exceeded, the program provides the user with a warning.

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To assist the user, notes can be added to the specification providing a description of the type of piping system the specification applies to. In addition, hypertext links can be associated with the pipe specification providing access to a given specification document.

Finally, the pipe specification can be saved to a template file, allowing the user to start new projects simply by selecting a saved design template. Once opened, all the pipe specifications contained in the design template are immediately available for use, streamlining the creation of a piping system model while providing design control.

Using the Calculated Results to Size Equipment

After all the pipelines are sized, the program calculates how the entire piping system operates. For example, when a pump is placed in the system, the user can specify a design flow rate needed for the process. The results of the piping system simulation provide the user with the required total head needed for pump selection along with the Net Positive Suction Head available (NPSHa) at the pump suction. In addition, the piping system model contains the inlet and outlet pipe diameters, fluid name and properties, and a preferred operating range for the pump including the NPSH design margin. This information is used for proper pump selection.

The user has a variety of options for pump selection. The program contains a pump selection feature that can select pumps from manufacturers supplied electronic pump catalogs. Over 70 pump manufacturers provide their data in this form. The user also has the ability to manually enter pump performance data for any centrifugal pump by entering the pumps head, efficiency, and NPSHr as a function of the flow rate.

The piping system model also allows for entry of control valves, strainers, heat exchangers, tanks, and other items typically found in a piping system.

Once the model is complete, the calculation engine simulates the operation of the total piping system showing the affect each item has on the total system. The user also has the ability to create a variety of operating scenarios; the program then simulates how the system operates under the defined operating conditions. In addition to a steady-state simulation in which the piping system is modeled at a specific point in time, the piping system model can be used to perform a dynamic simulation of the system showing how the system works over a specified period of time.

The piping system model (like all the other design documents), is typically created when the piping system is originally designed. Much like other design documents, those who use the documents are not typically the ones who created the documents. Many owners and operators of piping systems see the value of the piping system model and are creating them for piping systems already in operation.

Piping System Model as an Plant Modification Tool

After a piping system is put into operation, plant conditions are continually changing. Often the process is modified to increase capacity or improve system efficiency, addition loads are added to cooling loops, or energy conservation becomes a major concern as power costs increase. These

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are a few of the challenges project engineers are faced with every day when working with piping systems.

With a piping system model readily available as a design document, project engineers are able to simulate the operation of the piping system to help them gain a better understanding of how the actual system is working. Since the project engineer does not have to create the piping system model they can easily examine a copy of the model, make the proposed changes to the system, and quickly perform a simulation. The next set of examples describes how the software is being used by project engineers as a Plant Modification Tool.

Minimizing the Cost of Compressed Air

The Utilities Group at a Monsanto facility in Louisiana expanded their compressed air system in a step-wise fashion to meet increased demand for instrument air. After years of constant changes, the group realized that the overall efficiency of the combined system had not been studied. Using the piping system model they were able to optimize the pressure settings for the individual compressors to maximize compressor loading. The study found that by base loading two large compressors and cycling the third compressor to meet the changes in system loads, they could realize \$30,000 per year in energy savings.

After further analysis of the piping system model, they were able to minimize the pressure drop in the system by opening a number of existing cross connection distribution lines. This was confirmed with pressure readings in the field and allowed the overall system pressure to be reduced by about 4 psig. The lower operating pressure resulted in an additional \$10,000 per year energy savings. This \$40,000 dollars per year in energy cost saving did not require any physical changes to the piping system.

Identifying the Choke Points in a Cooling Water System

A chemical plant in Texas was experiencing capacity problems with one of their cooling water system. The system pumps cool water from the cooling tower basin through two pumps in parallel (with a third pump in standby). The water is distributed to the various loads in the plant and the warm water is returned to the cooling tower.

During summer operation, one of the two operating cooling water pumps tripped because of high load on the pump's motor. After further investigation, it was discovered the pump motor tripped on high electrical load caused by excessive flow rate through the pump. When the third pump was started the flow rate through each pump returned to acceptable levels eliminating the problem of the overloaded motor. Since the plants operating procedure requires a standby pump for critical systems, project engineering was tasked to add a fourth pump (to be the required standby pump) to the existing system.

While evaluating the piping system model in preparation for adding the fourth pump, the plant engineer discovered that the common discharge header of 120 ft pipe was accounting for more than a third of the total system losses. By increasing the discharge header pipe diameter from 36 in to 48 inches the project engineer discovered he was able to increase the system's capacity without adding the forth pump. Not only did this approach save the one-time capital cost of

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adding the fourth circulating water pump to the system, it also saved on the power cost of continually running the third circulating water pump.

After changing the diameter of the common discharge header to 48 inches, the piping system model was then used to balance the loads in the system so each heat exchanger received the required flow rate. Using the piping system model the project engineer was able to determine the valve position on the throttle valve at each load. By performing a system balance the project engineer also increased the available system capacity for future loads.

Piping System Model as a Troubleshooting & Maintenance Tool

The piping system model is a valuable troubleshooting tool because it shows users how the piping system was designed to operate. By comparing the operation of the actual piping system to the operation of the piping system model, one can quickly identify problem areas within a system.

In order to perform this type of analysis the piping system model must be current and validated to a baseline condition of the actual system. This is typically done during the initial startup phase of operation, but if necessary it can be conducted at any time as you'll see in the next example.

Finding the Blocked Heat Exchanger

At a pharmaceutical facility in Ohio, a combined process cooling / HVAC chilled water system was going through a system upgrade in which four new cooling loads would be added to the system. The engineering firm tasked to do the work created a piping system model to determine the pump head after adding the four new loads.

In addition to the four new loads, there was an existing air conditioning load in the system that was not able to achieve the flow rate needed to meet its cooling demands. The client also asked the engineering firm to determine what additional pump head would be required to ensure all the loads, including the existing HVAC load, in the system had sufficient flow.

To create the piping system model, the engineering firm used the client's existing flow diagrams and vendor pump and component information. While reviewing the results, it was determined that the one existing HVAC load that was not meeting its flow requirements had sufficient differential pressure across the load to achieve its design flow rate.

The supplier of the heat exchanger was contacted; the manufacturer provided a curve showing the differential pressure across the heat exchanger for varying flow rates. The pressure drop across the existing heat exchanger was much higher than expected. It was then determined that something must be wrong with the installed heat exchanger.

After referring to the maintenance history for the heat exchanger it was discovered the tube sheet head water box was removed 8 months previously to repair a leak in the tube sheet. Based on the results of the piping system model, an inspection was conducted on the tube sheet of the affected heat exchanger. After inspection, it was discovered that a sheet of plastic was accidentally left over a portion of the tube sheet blocking flow to some of the tubes. The plastic was removed, and the flow rate through the heat exchanger returned to its normal value.

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By using the newly created piping system model, plant personnel were able to determine that the flow rate through the heat exchanger was less than required because of an abnormally high differential pressure. This was a physical problem that would have been difficult to isolate without the aid of the piping system model.

The Piping System Model as an Operational Tool

Once a baseline is performed on the piping system model, the user has a clear picture of how the entire piping system operates. This information can be extremely valuable when operating a fluid piping system. These two examples demonstrate how an accurate model of the fluid piping system provides information vital to operating a plant.

Monitoring an Piping System Offline

At nuclear power plants, surveillance tests are performed on safety systems (containment spray, reactor core cooling, etc.) to determine if the pumps and control valves within the system are operating within their design margins. Since many of the pump safety systems are designed to work in major accident conditions, test loops are provided allowing the pumps, flow meters, and control valves to be tested to ensure they operate correctly.

It takes approximately 6 to 8 hours to set-up for one of these tests. Since many of these tests have to be performed while the plant is shut down for maintenance, time is at a premium.

In the past, the operators would set-up and run the surveillance test, and the engineers would gather the data. After completing the test, the system would be returned to normal operation and the engineers would review the results to ensure the system met its design requirements. If during the review it is discovered that an instrument was not operating correctly, the instrument would have to be checked and the test would be repeated. This was an expensive process because the operators would have to set-up for the test again, often requiring the shutdown to be extended.

After the plant engineers starting using the piping system model, they set up the model to simulate the operation of the system during the surveillance test. They would create a lineup using the piping system model by opening the necessary valves, turning pumps on, and adjusting the tank levels to their current levels. While running the actual test on the operating equipment, the engineers compared the calculated results from the piping system model to the observed results from the operating system.

By comparing the results, the engineers could immediately discover when the instrument results were not within specification. They then were able to get an instrumentation technician to correct the problem while the system continued to run. Once the changes had been made to the instrument, the engineers recorded the necessary data and concluded the results. Since using the piping system model, the engineers have not had to re-run a surveillance test because of instrumentation being out of calibration.

Online Monitoring of a Piping System

Glosten Marine had a unique requirement. They needed to measure the flow rate into and out of ballast tanks onboard a ship. The price of installing and maintaining flow meters was excessive – they needed to find a more cost effective method of getting the flow rates. The ballast system was designed using a piping system model, so one of their engineers suggested having the program calculate the flow rates based on the operating conditions of the vessel.

After a few conversations with the software developer, Glosten Marine discovered they could have the fluid piping software calculate the flow rates into and out of each ballast tank provided they could supply the tank levels, the position of the valves in the system, and the pump status. Further, by using a software development kit provided by the software manufacturer, Glosten developed a program that read the current status of the ballast system and had the fluid piping software calculate the flow rates into and out of each ballast tank.

Glosten developed a controlling program that polled the status of the ballast system every 10 minutes using the ships Programmable Logic Controller. The controlling program then sent the current tank levels, valve positions, and pump status to the piping system model. The program then simulated the operation of the ballast system and returned the calculated flow rates into and out of each ballast tank. To ensure the accuracy of the calculated results, the total flows into and out of the tanks are compared to the flow rate through the pump based on the pump curves. The calculated flow rate to each ballast tank had accuracy similar to a calibrated flow meter.

Conclusion

The piping system model is a very powerful design document. Not only does it streamline the design process, it also is a valuable tool for those who have to operate and maintain the system long after it becomes operational. The piping system model provides everyone involved with the system a clear picture of its operations. In addition, the model can be changed over time to show the effects of proposed system changes.