CHAPTER B3
PIPING LAYOUT

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Piping is a major expenditure in the design and construction of industrial, refinery, petrochemical, or power-generating plants when one considers engineering costs, material costs, and fabrication and field labor costs. Proper planning and execution of the design and routing of pipe can have a major impact on controlling the total installed cost (TIC).

Piping design and equipment arrangement are interrelated subjects that cannot be well taught in the classroom. Most good designers throughout history have learned their profession by a combination of academic and practical work. Field and design office plus a little shop experience is good preparation for designing or teaching. This topic is very broad-based and relies on a sound mechanical engineering background and a lot of common sense. The use of previous designs and drawings is a good way to learn and improve on current designs.

The experienced piping designer needs to have a working knowledge of plant layout, equipment arrangement, and system functionality associated with one or more fields of endeavor, such as commercial, industrial, refinery, petrochemical, or power. In addition, the designer must have an understanding of the practical application of piping materials, valves, pumps, tanks, pressure vessels, heat exchangers, power boilers, vendor-supplied skid assemblies, steam turbine drivers, and other machinery and equipment.

CODES AND STANDARDS

The various codes and standards applicable to the engineering, design, and fabrication of piping systems are discussed and summarized in Chap. A4 of this handbook.

These codes and standards were written to establish minimum requirements for safe design and construction with very little reference to the physical routing of piping. However, the piping designer should be familiar with them as they apply to his or her work. There are a few specific references to physical piping design of safety relief valve arrangements:

- The ASME Boiler and Pressure Code, Section I, *Power Boilers,* specifies that there is to be no intervening pipe, valves, or fittings between the safety relief valves and the vessel or piping to which they are attached. This means that they must be fitting-bound.
- The ASME B31.1, *Power Piping Code,* Appendix II, Non-Mandatory Rules for the Design of Safety Valve Installation, provides guidelines for the physical arrangement of safety valve piping, the most significant being that the distance between the centerline of the valve and the centerline of the discharge elbow must not exceed 4 times the nominal pipe size of the relief valve outlet.

The Pipe Fabrication Institute has a series of engineering standards (ES) covering the fabrication, design, cleaning, and inspection of piping. Three of these standards, listed below, specifically relate to the physical piping design:

ES2, *Method of Dimensioning Welded Assemblies*

ES3, *Linear Tolerances, Bending Radii, Minimum Tangents*

ES7, *Minimum Length and Spacing for Welded Nozzles*

For piping and valve drawing symbols, refer to ANSI/ASME Y32.2.3, *Graphical Symbols for Piping Fittings, Valves and Piping*.

It is essential that designers read and understand applicable codes and standards prior to developing fabrication piping designs.

PIPING LAYOUT CONSIDERATIONS

Project Client and Owner Requirements

Most projects have project-specific requirements imposed by the owner. These usually include additional requirements above the codes and standards which may have direct impact on both pipe layout and equipment location. Most of these requirements derive from operations feedback which the owner contractually invokes on future projects. Owners may not have a thorough understanding of all the levels of detail required to produce a piping design, but they know the finished product. It is very important that all project personnel and designers know and understand these requirements.

Hierarchy of Reference Design Information

To commence the routing and design of any piping system, the designer is referred to Chap. B1, Hierarchy of Design Documents. In the ever-expanding electronic engineering environment, the documents identified can and will be replaced with databases, but the flow of required information to design the piping systems will remain the same.

System Piping and Instrumentation Diagrams (P&ID). These are the schematic single line process diagrams which define the sequence of equipment, valves, in-line components, pipeline sizes, and overall system arrangement required for proper system function. Computer-aided P&IDs that link the schematic diagrams to electronic design data are preferred in order to perform computerized P&ID compliance checks.

P&ID Implementation and Physicalization. Piping and instrumentation diagrams are the piping designer's roadmap for laying out piping systems. The designer should understand the P&ID and the specific system characteristics. With this knowledge the designer is required to develop the P&ID and arrange connections and branches as required to best suit the process to actual physical design.

Project Piping Specifications. These documents or databases define the following essential information: the system design and operating pressures and temperatures; piping materials; pipe wall thickness or schedules; types of fittings to be used, e.g., butt weld, socket weld, or screwed; and the valve and flange pressure rating and insulation requirements. In addition, the piping specification defines the fabrication, examination, testing, inspection, and installation requirements, including the requirements for seismic installations, where applicable.

Equipment Outlines. These documents can be either imported computer-aided design and drafting (CADD) files or prints of the equipment being piped. They include overall dimensions and the pipe size, wall thickness, flange pressure rating, and locating dimensions of all pipe nozzles and other connections.

General Arrangements or Equipment Location Drawings. These drawings will indicate the location of all major pieces of equipment in the plant which the designer will either verify or relocate, as required, to accommodate the physical pipe routing as designed or redesign the piping to accommodate the particular piece of equipment.

Generally equipment location drawings are developed by senior-level piping designers during the proposal preparation and are taken over by the project team upon award of the contract. From this point on they are revised and updated as part of the normal process of design development. Equipment should be arranged with the piping layout in mind. Equipment locations and relational arrangements should be evaluated during the piping layout design process. Adjustments and occasionally major changes to equipment arrangement are required to solve major piping arrangement problems. Piping system design is dependent on the input from numerous reference sources prior to the start of piping design.

Collection of As-Built Information

CADD and electronic surveying capabilities have changed and are continuously changing. Photogrametry (photographs that are input into three-dimensional CADD models) and laser mapping (laser scanning using a time of flight laser connected to a computer that translates the scanned points to a three-dimensional CADD model) are applications that enable the designer to collect existing conditions which can be imported into the designer's CADD files. Total Station Surveying is the computerized surveying system which engineering should request for the collection of survey data points with the electronic transfer of information being able to be translated directly into the CADD environment.

Piping Layout Considerations and Planning Studies for Improved Piping Economics

Proper planning is an important activity performed by the piping designer in the early stages of a project. Space conservation and a symmetric piping arrangement are achieved when all the systems are evaluated in the preliminary stages of design. This study will become the final design. It is important to consider the cost of the piping material at this time for the expensive lines. These lines should be kept as short as possible, while maintaining proper piping flexibility even if this requires changing the equipment arrangement.

Detailed design should not start until the planning studies are complete. Expending engineering work hours on details that are subject to change pending the completion of the planning study is not recommended.

Piping layout then becomes a matter of designing dimensioned routings from one point to another point with the branches, valves, piping specialties, and instrumentation as indicated on the P&ID. This statement, however, is an oversimplification of the process, since many other factors must be considered, such as interference, piping flexibility, material costs, pipe supports, operation and maintenance, and safety and construction requirements.

An example would be moving a pump 3 in (75 mm) to avoid a compound elbow offset in order to connect to the top discharge nozzle. Perhaps the equipment was arranged while planning on a side suction and discharge. Refer to Fig. B3.1.

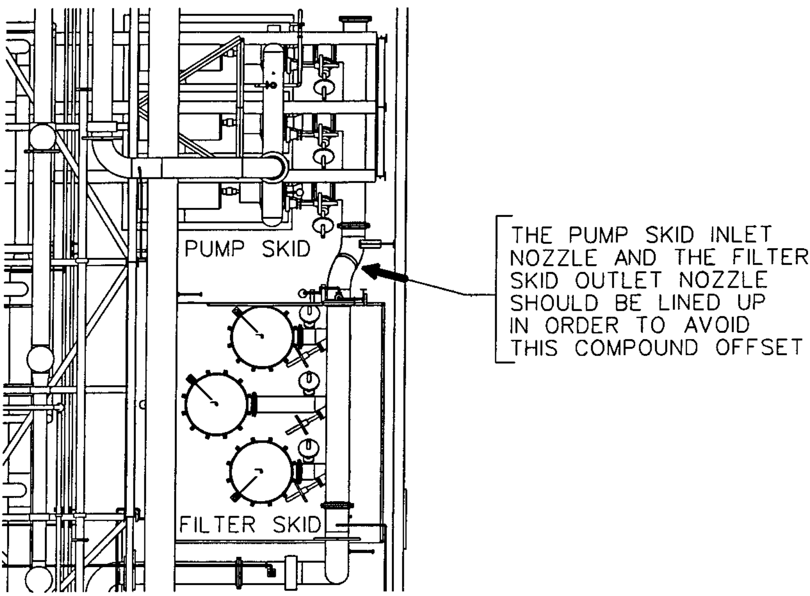


FIGURE B3.1 Nozzle alignment drawing.

Pipe Bending

Pipe bending has become increasingly widespread due to a desire for a decrease in fabrication costs. If bending is to be used, the designer should consider special requirements imposed by the process (i.e., tail ends and clamp dimensions are required by the bending machine, and increased distances and space are required because bends have a greater center-to-face dimension than conventional fitting dimensions).

Interferences

One of the most important aspects of piping layout is the avoidance of interferences with other facilities in the plant such as other piping systems; structural steel and concrete; heating, ventilating, and air-conditioning (HVAC) ductwork; and electric cable trays and conduit. For engineering firms using 2D CADD (two-dimensional computer-aided design and drafting) or manual drafting and design, the search for interferences is very tedious and time-consuming since the designer must mentally and visually look for interferences between the systems currently being designed and previously designed or the existing system or facilities, not to mention those systems or facilities in design concurrently. This process is extremely complex at best. Traditionally, this has been accomplished by the use of area composite drawings (see Fig. B3.2) and plastic scale models.

The composite drawings and plastic models show all plant facilities designed to date and are used by the designers to select an interference-free route for the system currently under design; however, the designer still must search out those systems or facilities in design concurrently. Once the designer is satisfied that the current system layout is interference-free, it will be added to the area composite drawing and the plastic model.

An alternative to composite piping drawings and plastic models for interference detection is the use of computer-aided design (CAD). Specifically, three-dimensional (3D) computer modeling can provide an efficient, accurate, and cost-effective alternative to the traditional manual methods for interference detection. This and other CAD applications for piping layout are addressed in the section ''Application of Computer-Aided Design to Piping Layout.'' Refer to Fig. B3.3.

Piping Flexibility

The effects of the thermal expansion of pipe and fittings as a result of system operating temperature changes cannot be overlooked during the layout and routing of any piping system. The function of piping flexibility or stress analysis has, for the most part, been delegated to the computer particularly in the case of high-temperature, high-pressure piping systems. The piping stress analyst translates and enters the piping design data into the computer, reviews the output data, and if the system is too rigid, may suggest appropriate corrective redesigns. However, it is the piping designer's responsibility to ensure that the final stress analysis results are incorporated into the final pipe support and pipe routing design.

In the past, a computer stress analysis, including the development of input data and the interpretation of the output, could be expensive and time-consuming if numerous iterations of computer runs were needed to arrive at an acceptable system design. The experienced piping designer, with the knowledge and capability of

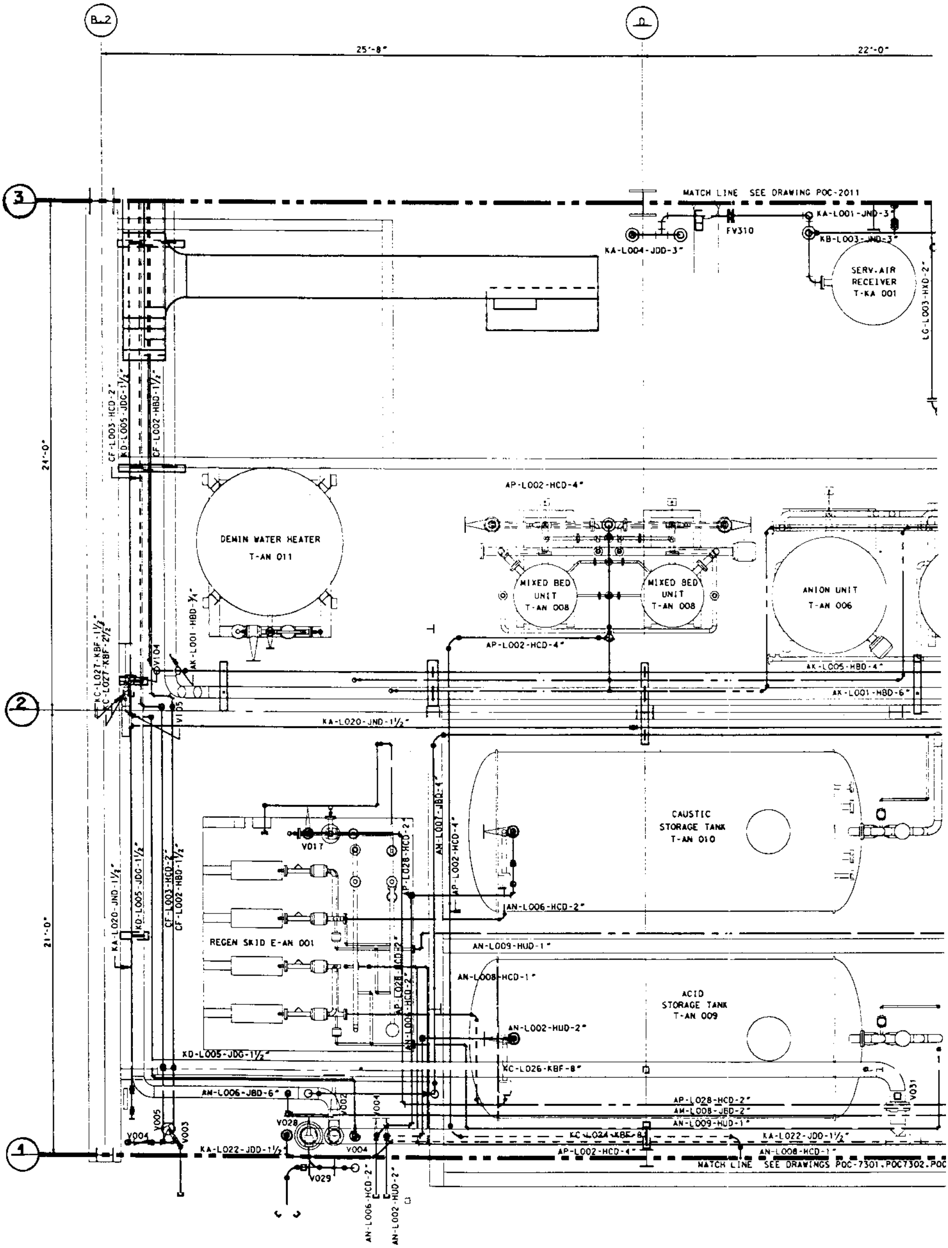


FIGURE B3.2 Area piping composite.

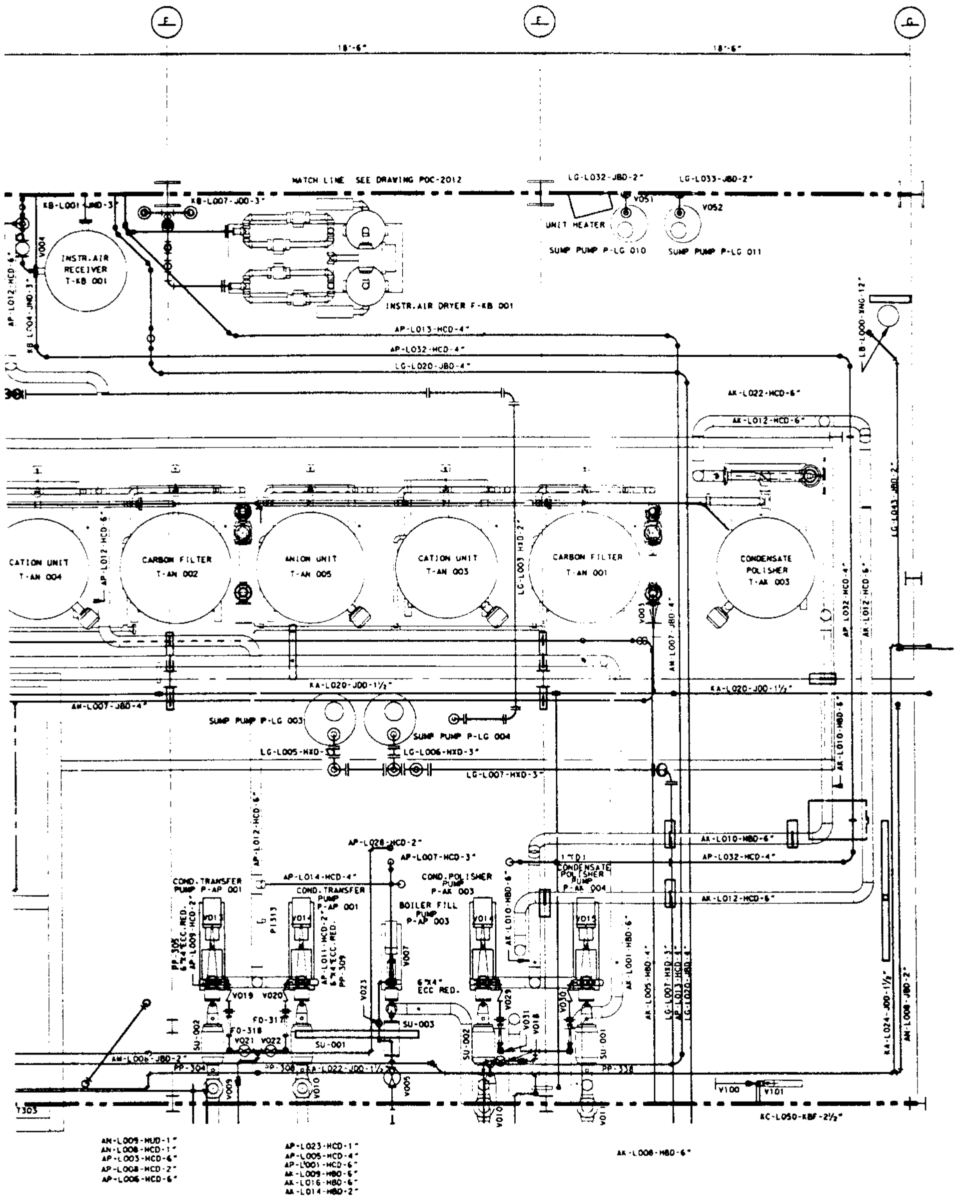


FIGURE B3.2 *(Continued)* Area piping composite.

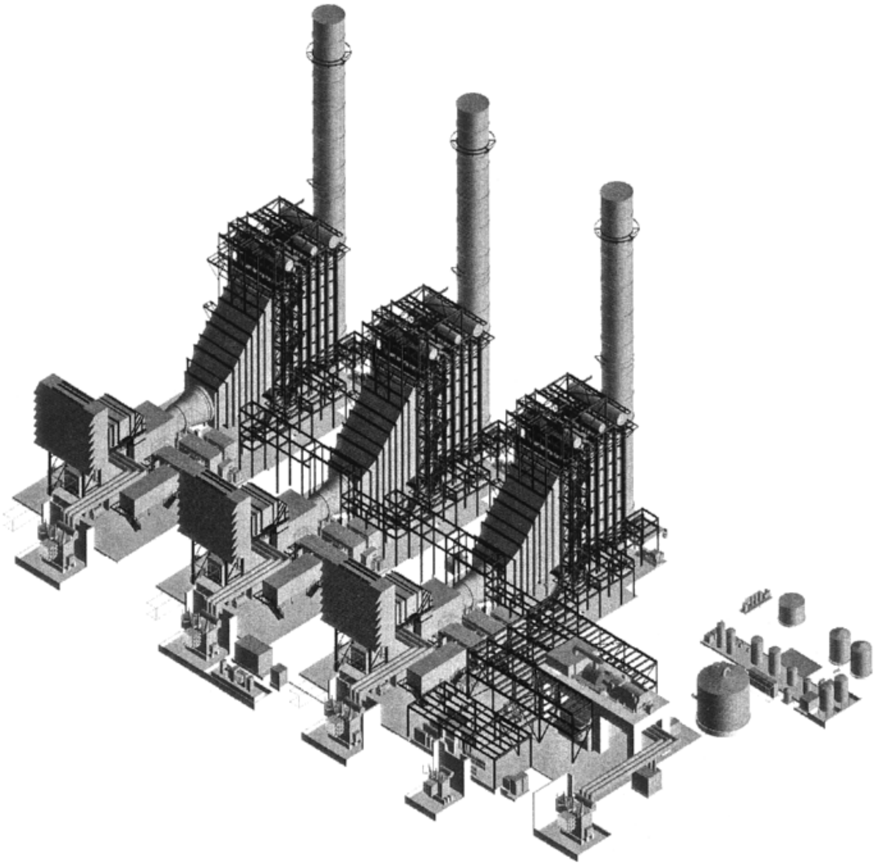


FIGURE B3.3 A 3D CAD model used for interferences, equipment layout, and pipe routing.

designing piping systems that are inherently flexible, was relied on to keep the number of computer iterations to a minimum. Today, this is much less of a problem with the advent of the personal computer and many computer programs for calculating stresses in piping systems due to thermal expansion and other static and dynamic loads. However, the piping designer must integrate piping flexibility considerations into the piping layout.

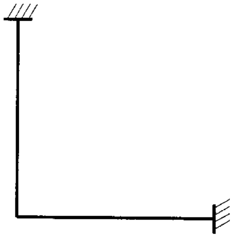
The piping designer should route piping with flexibility designed into it, using the minimum amount of pipe, fittings, and expansion loops by considering the following:

- Avoid the use of a straight run of pipe between two pieces of equipment or between two anchor points.
- A piping system between two anchor points in a single plane should, as a minimum, be L-shaped, consisting of two runs of pipe and a single elbow. This type of arrangement should be subjected to a ''quick-check'' analysis to determine if a formal computer stress analysis is required. A preferred solution in this case may be a series of two or more L-shaped runs of pipe.

- A piping system between two anchor points with the piping in two planes may consist of two L-shaped runs of pipe, e.g., one L-shaped run in the horizontal plane and another in the vertical plane. This arrangement should also be subjected to a quick-check analysis.
- A three-plane configuration may consist of a series of L-shaped runs and/or U-shaped expansion loops designed into the normal routing of the system.
- When the expected thermal expansion in any given run of pipe is high, consider the use of an anchor at or near the center of the run, thereby distributing the expansion in two directions.
- For systems consisting of a large-diameter main and numerous smaller branch lines, the designer must ascertain that the branches are flexible enough to withstand the expansion in the main header.
- Systems which are to be purged by steam or hot gas must be reviewed to ensure that they will be flexible during the purging operation.
- System or equipment bypass lines may be cold due to lack of flow while the main runs are at operating design temperature, resulting in excessive stresses.
- Temperatures during initial start-up and testing are often greater than those at operating conditions.
- Closed relief valve and hot blowdown systems should be given special attention due to rapid transients in temperature.

In addition, the piping designer may use a variety of single- and multiplane piping arrangements, such as the L-shaped, the U-shaped, and the Z-shaped configurations, in the normal routing of any system, as shown in Figs. B3.4 through B3.9.

Chapter B4, Stress Analysis of Piping Systems, discusses in detail pipe stress analysis including quick-check methods that may be used by the piping designer to determine whether the system is flexible enough and to determine if a more rigorous analysis is required.



FIGURES B3.4

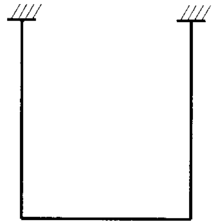


FIGURE B3.5

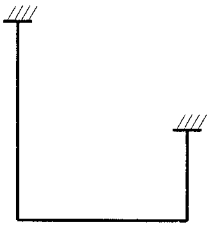


FIGURE B3.6

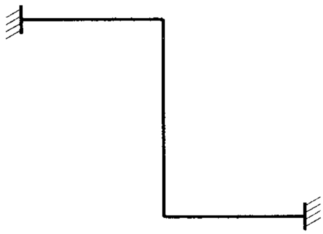


FIGURE B3.7

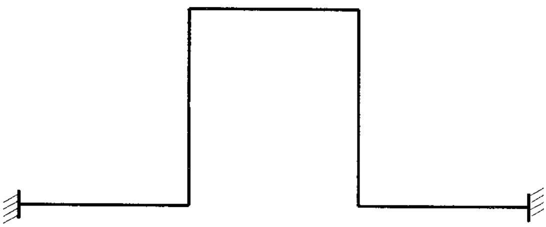


FIGURE B3.8

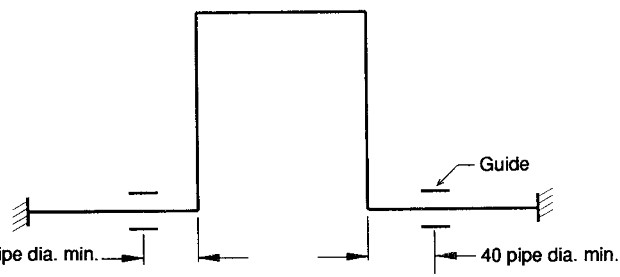


FIGURE B3.9

Valves

The piping designer must be familiar with proper application of all types of valves including gate, globe, plug, butterfly, ball, angle, diaphragm, check, pressure relief, and control valves and their methods of operation including manual, chain, gear, air, hydraulic, or motor. The following general guidelines should be applied when locating valves in any piping system:

- Valves should be installed with the stems between the vertically upward and horizontal positions with particular attention given to avoiding head and knee knockers, tripping hazards, and valve stems in the horizontal plane at eye level that may be a safety hazard. Large motor-operated valves should be installed in the vertical upright position where possible to facilitate support and maintenance.
- Valves in acid and caustic services should be located below the plant operator's eye level or in such a manner as to not present a safety hazard.
- The location of valves, with consideration for operating accessibility, should be accomplished in the natural routing of the system from point to point, avoiding the use of vertical loops and pockets.
- Valves in overhead piping with their stems in the horizontal position should be located such that the bottom of the handwheel is not more than 6.5 ft (2 m) above the floor or platform. Only infrequently operated valves should be located above this elevation, and then the designer should consider the use of a chain operator or a platform for access.
- Where chain operators are used, the valves should be located such that the chain does not present a safety hazard to the operating personnel.
- A minimum of 4 in (100 mm) of knuckle clearance should be provided around all valve handwheels.
- Valves should not be installed upside down.
- Space should be provided for the removal of all valve internals.

Improper application and placement of valves in the piping system can be detrimental to system function. This can result in malfunction of the valve and in waterhammer, and this can cause the valves to literally self-destruct. What follows are some specific recommendations and methods of avoiding these problems for some specific types of valves.

Control Valves. All control valve stations should be designed with the valve stem in the vertical upright position and a minimum of three diameters of straight pipe both upstream and downstream of the control valve, in order to reduce the turbulence entering and leaving the valve and to provide space for removal of the flange studs or bolts. Where applicable, this straight pipe will include the usual reduction in pipe size required to match the control valve size. Space must be provided for flange stud bolt removal where control valve bodies are designed for through-bolt installation.

Butterfly Valves. Butterfly valves should be provided with a minimum of five diameters of straight pipe upstream of the valve; and if this requirement has been met, the valve stem and operator may be oriented in the position best suited for operation and maintenance. When a butterfly valve is preceded by an elbow and this straight-pipe requirement cannot be met, the valve stem must be oriented in the same plane as the elbow. That is, if the elbow is in the vertical plane, the valve stem must also be in the vertical plane. This recommendation is based on the fact that the velocity profile of the discharge of an elbow is not symmetric. The result can be fluid dynamic torque that is twice the magnitude of that found for a valve with a straight run of pipe upstream. The resultant eccentric forces applied to valve disk produces excessive vibration and disk flutter which eventually may completely destroy the valve.

Check Valves. The preferred installation of any check valve is in a horizontal, continuously flooded run of pipe with cap up; however, swing check valves will function properly in vertical runs of pipe with the flow up. However, the velocity and the rate of flow must be adequate to move the valve disk away from the seat and to maintain the valve in the open position, as required.

Experience has indicated that check valves are highly susceptible to chattering due to upstream turbulence caused by elbows and branches. Therefore the designer should provide upstream straight pipe in accordance with the valve manufacturer's recommendations. However, where this information is not available, the preliminary design should include a minimum of five diameters of straight pipe upstream of all check valves. In addition, the designer should be aware that this requirement can be as much as 10 diameters of straight pipe depending on the type of valve and the manufacturer.

Safety Relief Valves. The arrangement for installation of safety and relief valves is very critical and involves the actual location of the valve itself, the design of the vent stack, and the design of any associated drain piping. The designer should adhere to the valve manufacturer's recommendations and the following guidelines; however, these guidelines relate to the power industry and may be used elsewhere, as applicable.

Valve Location

- All relief valves must be in the vertical upright position and fitting-bound to the top of a horizontal run of pipe, the pressure source, and must not be located less than one nominal header diameter from any butt weld.
- A safety valve inlet connection in a high-velocity steam line should be located at least 8 to 10 nominal header diameters downstream of any bend in the header, to minimize the possibility of acoustically induced vibrations. In addition, it should be at least 8 to 10 nominal header diameters either upstream or downstream of any diverging or converging T or Y fitting.
- No other header branch penetration, for any purpose, should be made in the same circumferential cross section containing the safety valve inlet nozzle.
- Where more than one safety valve or a service branch is to be installed in the same header run, a minimum distance of 24 in (600 mm) or 3 times the sum of the nozzle inside radii, whichever is greater, shall be provided between the nozzles.
- Where more than two safety valves are located in the same header run, the spacing between valves should be varied such that the distance between two adjacent valves differs by at least an inlet nozzle diameter.

Open Discharge. Open-discharge safety valve installations (see Fig. B3.10) should be in accordance with the following guidelines:

- Open-vent stack diameters shall be the calculated minimum flow diameter required for discharge venting without blowback, except as required to accommo-

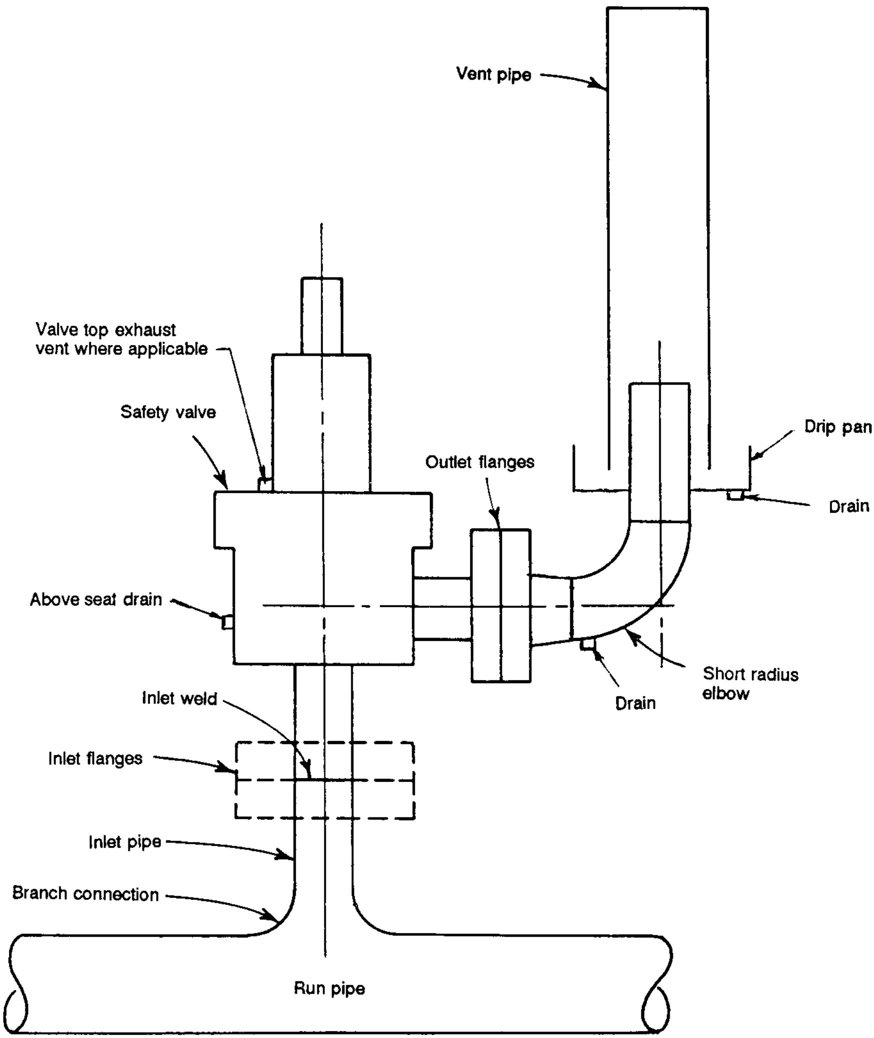


FIGURE B3.10 Open-discharge safety valve.

date the movement of the relief valve discharge from the cold to hot position such that the outlet pipe will be centered in the vent stack in the hot position. See Fig. B3.10.

- The vent stack entry diameter shall be maintained throughout the length of the vent stack; enlarged entry spools, later reduced in size to the calculated minimum flow diameter, are not acceptable.
- The relief valve outlet shall consist of the mating flange and a fitting-bound short-radius elbow, in order to minimize the moment and forces imposed on the valve body.

- Vent stacks should be routed, where possible, to provide a straight stack of minimum length. Where offsets or changes in direction are unavoidable, it is desirable to limit the change in direction to 30° or less; however, it could be more. The vent stack should terminate a minimum of 7 ft (2.2 m) or higher above the roof level.

Closed Discharge. Closed-discharge piping systems (see Fig. B3.11) are those piped continuously from the valve discharge flange to a closed receiver, such as a

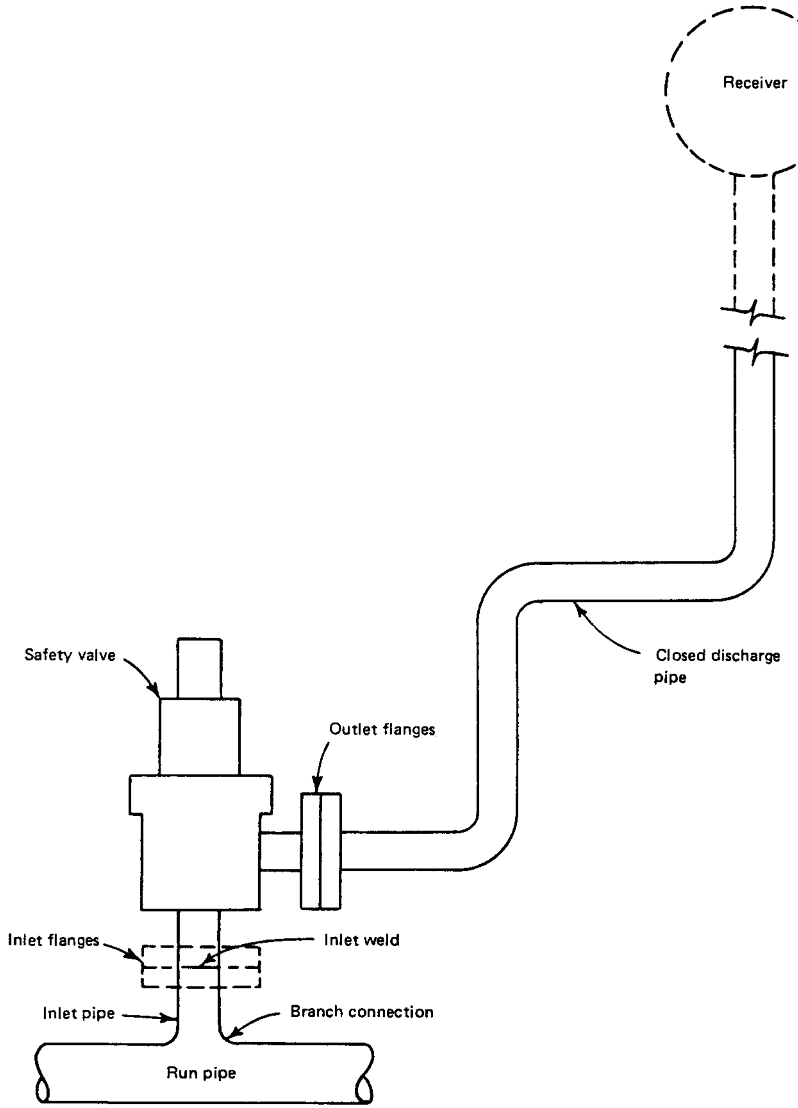


FIGURE B3.11 Closed-discharge safety valve.

condenser or blow-off tank. This type of system is required for feedwater heater shell side relief valves to provide protection against the effects of tube rupture, and may be used in other applications. Other than the normal considerations for designing pipe, there are no specific guidelines for the design of closed systems.

Drains. Relief valve and open-vent stack drains are important, in varying degrees, as discussed in the following:

- The discharge elbow and above seat body drain points are the most critical for safe valve operation. These drains should be collected into a common, closed drainage system and routed to a point where the drain can safely blow to atmosphere. This system must be sloped continuously downward and stress-analyzed to ensure that no strain is imposed on the valve body.
- Some relief valves now incorporate a relatively large valve top vent connection that is pressurized when the valve blows. This connection may be piped into the combined discharge elbow and valve body drain system and continued, at full-vent pipe size, to the point of the drain discharge.
- The open-discharge vent stack drip pan drain connection is of the least importance and is only intended to carry away any rainfall entering the stack and the residual condensate from the stack following a steam blow.

Piping of Centrifugal Pumps

The piping of centrifugal pumps, particularly the suction piping, can seriously affect the operating efficiency and life expectancy of the pump. Poorly designed suction piping can result in the entrainment of air or vapor into the pump and cause cavitation, which displaces liquid from within the pump casing, results in vibrations, and throws the pump out of balance. The cavitation alone can result in severe erosion of the impeller. The out-of-balance condition may result in a slight eccentric shaft rotation, which will eventually wear out the pump bearings and seals, requiring a pump shutdown for overhaul. When routing piping at pumps, the designer should follow the manufacturer's recommendations, the Hydraulic Institute Standards, and the following guidelines:

- The suction and discharge piping must be supported independently of the pump such that very little load is transmitted to the pump casing. The designer may consider the use of expansion joints on either the suction or discharge, or both, as necessary. However, expansion joints should be used only when it is unavoidable.
- The suction of any centrifugal pump must be continuously flooded, and the suction piping shall contain no vertical loops or air pockets.
- When a reduction in pipe size is required at the pump suction, provide an eccentric reducer flat side up. See Fig. B3.12.
- The suction side elbow in the piping at horizontal double suction pumps may be fitting-bound and in the vertical plane with the flow from either above or below the pump.
- When the suction piping is in the horizontal plane, provide a minimum of three to four diameters of straight pipe between the pump suction connection and the first elbow; the eccentric reducer noted above may be included in this straight section.
- Only long-radius elbows are to be used at or adjacent to any pump suction connection.

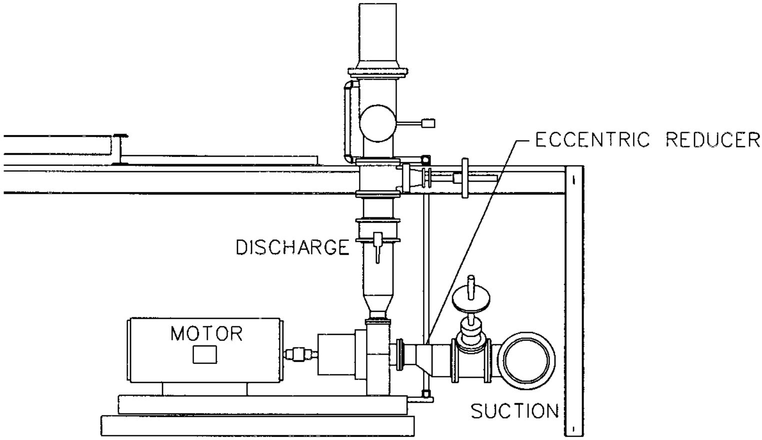


FIGURE B3.12 Pump suction reducer.

- All pump suction lines must be designed to accommodate a conical-type temporary strainer.
- A pipe anchor must be provided between any expansion joint or nonrigid coupling and the pump nozzle that it is designed to protect.
- When pump flanges are cast-iron flat-faced, the mating flanges must also be flat-faced and the joint made up with full-face gaskets and common steel bolts (ASTM A 307, Grade B), not high-strength bolts (ASTM A193, Grade B7).

Refer to the Hydraulic Institute Standards for arrangement of pump piping.

Vents and Drains

During the course of physical routing of any system, the designer should provide high-point vent and low-point drain connections for the following purposes:

- The filling of the piping system with water for hydrostatic testing and operation and the evacuation of entrapped air in the process
- The evacuation of all water used for hydrostatic testing and operation during periods of start-up and maintenance

High-point vents that will be used frequently should be piped down to an area where they can be accessed from the floor. When these vents are left out of reach, they tend not to be used. Systems subject to thermal expansion should be reviewed to ensure that they can be properly drained in both the hot and cold positions.

Buried Piping Systems

The economics of installing piping systems have proved that burying pipe in lieu of installing pipe aboveground provides a significant cost savings in both bulk footage and pipe supports. All system piping should be evaluated for underground installation if possible to decrease the TIC. Low-pressure and low-temperature systems such as for component cooling and demineralized water are good examples of piping that should be buried. Nonmetallic piping materials can be successfully used for buried applications in lieu of metallic piping, carbon steel, or stainless steel which need to be coated and wrapped to protect against galvanic corrosion, resulting in an expensive installation.

Pipe Racks

Pipe racks are structures designed and built specifically to support multiple pipes where adequate structure is not available. Pipe layout on pipe racks should follow the Pipe Planning Study concepts. Avoid designing one pipe at a time in order to avoid unnecessary overcrowding and fittings for pipes to enter and depart from the rack. Where possible, pipes should rest directly on the rack with the use of an insulation, if required. Steam piping should exit the rack with a vertical up-and-over to avoid condensate collection points, while water piping should exit the rack with a vertical down-and-under to avoid a high-point air pocket collection point.

Pipe Supports

Pipe supports require structural support, which means that piping should be located in close proximity to steel or concrete. Do not locate the pipe too close to the structure, so as to allow adequate space for the pipe support hardware to facilitate installation. Additionally the pipe insulation needs to be considered for clearances and insulation saddles. The most preferred location is either resting directly on structural steel for bottom support or using a single rod to the structure directly above the pipe.

The design and engineering of pipe support systems are covered in detail in Chap. B5; however, it is the responsibility of the piping designer to give serious consideration to the means of support during the piping layout, and in doing so, many pipe support problems may be either minimized or avoided altogether. For this reason, the piping designer should be familiar with the commercially available pipe support components and their application. Piping should be routed such that the support designer can make use of the surrounding structure to provide logical points of support, anchors, guides, or restraints, with ample space for the appropriate hardware. Banks of parallel pipelines at different elevations should be staggered horizontally and spaced sufficiently apart to permit independent pipe supports for each line. Piping on pipe racks should be routed using bottom-of-pipe (BOP) elevations. The piping designer should work closely with the structural engineer in the spacing of the pipe rack supports and the method of intermediate support to prevent pipe sagging.

Insulation

The engineering and selection of thermal insulation materials are covered in Chap. B7, and the piping designer should be familiar with these requirements and specifically with the thickness of insulation for any given system. In the location and spacing of piping systems, there must be clearance space between the insulation of one pipe and any adjacent pipe and/or other possible interference such as structural steel. The piping designer should also recognize that in some applications insulation may not be required for the prevention of heat loss but will be needed for personnel protection, and the spacing and clearances should be adjusted accordingly.

Heat Tracing

Heat tracing is required when there is concern that the pipe may be damaged due to freezing or that the line needs to maintain a temperature higher than ambient (i.e., caustic piping). The designer must provide the space and clearances for either electric or steam heat tracing and its outer insulation when routing the primary system pipe. The detail design requirements for these systems are covered in Chap. B6.

Operability, Maintenance, Safety, and Accessibility

Operability, maintenance, safety, and accessibility are interdependent, and certainly if any given piping component is accessible, it is also assumed to be operable and maintainable. However, maintenance may require additional space for dismantling the component, as noted elsewhere in this chapter. It is the responsibility of the piping designer to design a piping arrangement that satisfies all these (and other) requirements with the lowest total cost, i.e., resulting in the shortest pipe runs and the fewest fittings and pipe supports.

Operability, from the standpoint of operating personnel, means being able to perform daily functions in an efficient manner. This is done with consideration for the frequency of operation and the degree of physical effort required to perform it. The designer cannot make every valve and instrument ideally accessible, but will concentrate on those requiring the most frequent operation. Safety-related equipment and valves that are required to be operated during an emergency or to perform critical system functions must be accessible without exception. To ensure success, the designer, system engineer, and operating personnel work out the final arrangement. Sometimes input from construction, start-up, and vendor personnel is needed. Formerly in difficult cases, models or even full-size mock-ups have been used as design aids. Today the trend is toward virtual reality. Under today's conditions the whole process can be accelerated and, when done effectively, accomplished at lower cost than formerly. Additional considerations are discussed in other sections of this chapter. In general, an operable valve or instrument is one that can be readily reached when standing at grade or on an elevated floor or platform provided for that purpose. The position of the valve handwheel should be such that the force necessary to operate it can be applied without strain or undue contortions or interference from valves, lines, or other equipment. It is recognized that plant operating personnel will occasionally have to reach for a drain from a kneeling position or a vent valve from a ladder, but these are infrequent operations and as such can be tolerated.

Ease of maintenance actually begins with the development of the plant arrangement and equipment locations by providing sufficient space around each piece of equipment not only for the maintenance of the machinery alone but also for the pipe and the maintenance of the related components. These space allocations should include the pull spaces, laydown spaces, and rotor and tube removal spaces for the dismantling of all pieces of equipment. The engineering of the system P&IDs will indicate the need for maintenance facilities in the form of bypasses and block valves that would permit certain pieces of equipment or components to be worked on while the system is operating, or at least with a minimum of downtime. However, it is then up to the designer to design these facilities into the system and to provide the accessibility necessary to accomplish that maintenance, including the provision for any lifting gear such as cranes, davits, monorails, and hoists.

There are numerous national, state, and local codes and standards relating to safety, the most notable of which is the Occupational Safety and Health Act of 1970 (OSHA), which became law on April 28, 1971. Several thousand specific safety and health standards are being enforced under OSHA. These standards have been selected from the key safety standards developed by the American National Standards Institute (ANSI); the American Society of Mechanical Engineers (ASME); and the American Society for Testing and Materials (ASTM); and others, such as the American Water Works Association (AWWA), the American Petroleum Institute (API), and the National Fire Protection Association (NFPA).

Stairs, platforms, ladders, aisles, means-of-egress aisleways, and minimum headroom allowances designed in accordance with OSHA will provide a safe place to work. It is the responsibility of the piping designer to place equipment, valves, and other piping components in such positions that they do not create hazards. These hazards could include any piping components that presented themselves as ''head knockers,'' ''knee knockers,'' or trippers. The most common cause of these problems is valve stems, and common sense would say to place a valve in a horizontal run of pipe with the stem vertical, wherever possible. When this cannot be done, the designer should ascertain that the stem does not project into an access area and become a hazard. The designer should make every effort to keep such projections out of heights of 4½ to 6 ft (1.5 to 2 m), or specifically at face level. Steam system valves must not be placed at face level in the horizontal position since a packing gland leak may blow steam into the face of an operator; if this were a superheated steam leak, the vapor would not be visible. This same principle applies to hazardous and toxic fluids. However, this may be too restrictive, and it is not meant to rule out any perfectly safe arrangement of valves at face level if

- They are outside the limit of a platform.
- They are a part of a manifold of valves, all projecting about the same distance and with adequate access space in front of them.
- It is an isolated valve guarded by an adjacent pipe or structural steel.

Accessibility has already been discussed at length in terms of space and the normal platforms and stairways provided in any plant; however, the designer should review the layout and determine if there is a need for any platforms which access a remotely located valve or component.

Interfacing Disciplines and Organizations

Piping design requires coordination and cooperation with all interfacing disciplines including civil, electrical, instrumentation, and construction. Piping arrangements should blend with the layout design of interfacing disciplines. Pipes that require extensive support schemes in lieu of being conveniently located near structural support steel should be avoided. Pipes or electrical trays that twist and turn to avoid one another should be uniformly designed in a coordinated design effort which reduces congestion and reduces TIC. Most piping designs are not completed by a single designer or company, which makes the coordination between designers and different organizations critical. The best way to address this concern is to agree to specific divisions of responsibility in the planning phase of the project.

Electrical Tray and High-Temperature Piping Interfaces

High-temperature piping must not be located near electrical trays, wherever possible. This piping should cross over trays, not under them. The radiant heat could have an adverse effect on the cables. Electrical equipment maintenance space should be identified and accounted for in all piping passing near this equipment.

SPECIFIC SYSTEM CONSIDERATIONS

The power industry, through its many years of experience, has found that piping arrangements and layout can influence the functionality of a piping system. This section will present specific system guidelines and considerations that will enable the piping designer to minimize that influence.

Main Steam and Hot and Cold Reheat

In any power plant, be it a base-loaded electric power generation station or an industrial facility power plant, the main steam system is the backbone of the installation since it ties together the two most important and most costly pieces of equipment, the steam generator and the turbine, and is also usually the first system designed, giving it the preference in space allocation and routing. The recommendations of the following references should be incorporated in the design of the main steam and reheat steam piping systems.

1. ANSI/ASME TDP-1-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil),* American Society of Mechanical Engineers, New York.
2. ANSI/ASME TDP-2-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear),* American Society of Mechanical Engineers, New York.

Adherence to the following guidelines will ensure that the system performs its intended function:

- All piping in this service should be sloped down a minimum of ⅛ in/ft (10 mm/m), in the direction of flow. Extensive evaluation and design are required for lines that do not slope in the direction of flow to ensure that condensate is collected and drained adequately.
- The final design of the main steam and hot reheat lines should be reviewed, with consideration for thermal growth, to determine the location of any necessary low-point drains and to ensure that the system can be completely drained in both the hot and cold conditions. When these lines are split into more than one branch into the turbine, each branch should be reviewed for low points. Provide a drain

connection in each branch as close as possible to the turbine stop valve. All drain lines and large valve drain ports should have an inside diameter of not less than 1 in (25 mm), to prevent plugging. Main steam piping drains should not be piped together with any other drains from the boiler. In addition, this review should ensure that no condensate can collect in any undrained portion of the system during shutdown.

- Provide a drain pot at the low point of each cold reheat line, which should be fabricated from NPS 6 (DN 150) or larger pipe and be no longer than required to install the level-sensing devices. Each pot should be provided with a minimum NPS 2 (DN 50) drain line and a full-sized, full-ported automatic power-operated drain valve. Each drain pot should be provided with a minimum of two level-sensing devices.
- Steam lines that are fitted with restricting devices such as orifices or flow nozzles should be adequately drained upstream of the device.
- Valves in all steam services should be installed with the valve stem in the vertical upright position to prevent the entrapment of fluid in the bonnet. Where this is not practical, the stem may be positioned between the vertical and horizontal positions, but in no case below horizontal.
- Main steam safety relief valves should be fitting-bound to the main steam headers.
- Sufficient space should be provided around any steam line to allow for insulation, pipe supports and anchors, thermal growth, machine welding, and maintenance repairs and replacements.

Turbine Extraction Steam

Most steam turbines are provided with one or more low- to intermediate-pressure steam extraction points either for boiler feedwater heating or for industrial process service and heating. These systems are extremely critical, particularly from the standpoint of water damage, and must be designed in accordance with the following standards and guidelines:

ANSI/ASME TDP-1-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil),* American Society of Mechanical Engineers, New York (Ref. 1).

ANSI/ASME TDP-2-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear),* American Society of Mechanical Engineers, New York (Ref. 2).

- The routing should be as short and as direct as possible with consideration for thermal growth and piping flexibility.
- Extraction steam piping should be sloped down a minimum of ⅛ in/ft (10 mm/m), in the direction of flow. Extensive evaluation and design are required for lines that do not slope in the direction of flow to ensure that condensate is collected and drained adequately.
- Bleeder trip valves must be located as close to the turbine extraction point as possible, while at the same time keeping the total volume of the system within the turbine manufacturer's recommendations.

- When extraction steam piping is routed through the condenser neck, an expansion joint must be provided in each line and located at the turbine nozzle. The bleeder trip valves in these lines must be located just outside the condenser neck.
- A drain should be located at the low point in the extraction pipe between the turbine and block valve and routed separately to the condenser. A power-operated drain valve should be installed in this line that opens automatically upon the closure of the block valve in the extraction pipe.
- There should be no bypasses around the extraction line shutoff or nonreturn valves.
- Unavoidable vertical loops which create low points in the piping downstream of the bleeder trip valves must be provided with continuously drained drip pots.
- Provide a minimum of five diameters of straight pipe downstream of all bleeder trip valves.
- Provide maintenance access to all bleeder trip valves including any miscellaneous platforms, if needed.

Condensate

The condensate collection system from the condenser hotwell presents a unique set of parameters since we are dealing with water at slightly elevated temperatures and at a vacuum pressure. These conditions make the condensate pump suction piping susceptible to flashing and cavitation. The following guidelines apply to the design of condensate pump suction and discharge piping:

- Where two or more condensate pumps are used, the individual runs to each pump must be similar, and if a suction manifold or header is used, the individual pump suction lines from that manifold or header must be similar.
- When the manifold or header is larger than the pump suction size, the manifold or header should be made up of full-sized tees and eccentric reducers, flat side up.
- Each individual pump suction run should be sloped down a minimum of ⅛ in/ft (10 mm/m) toward the pump and be self-venting back to the condenser.
- Provide a minimum of three to four diameters of straight pipe in the pump suction line; in addition, these lines must be fitted with expansion joints and start-up strainers.
- The condensate pump discharge check valve must be located below the hotwell water level and be continuously flooded.
- The discharge header outlet should not be located between the pump discharge connections to the header, to avoid a counterflow condition.
- The condensate pump recirculation control valve should be located at the condenser nozzle.

Feedwater

The boiler feedwater pumps normally take suction from the deaerator storage tank, discharge to the feedwater heaters, and then supply the boiler. Here, too, the designer has to deal with the possibility of flashing fluid and must ensure that the deaerator storage tank is located at an elevation that will provide sufficient net positive suction head (NPSH) at the pump. The following guidelines apply to the design of this piping:

- The pump suction piping from the deaerator storage tank should drop vertically, avoiding any long horizontal runs of pipe. If short horizontal runs are unavoidable, they should be angled vertically down.
- A minimum of 3 diameters of straight pipe is required at the pump suction. The pump suction strainer may be located in this run of pipe.
- If a reducer is required at the pump suction, it must be eccentric and installed with the flat side up.
- The feed pump discharge swing check valves should be located in horizontal runs of pipe only.
- The feed pump recirculation line control valve should preferably be located at the deaerator storage tank. Horizontal runs are to be avoided in this line at the tank. If the control valve is located in a branch from the pump discharge, the line downstream of the valve must be continuously flooded.

Turbine Drains

This system consists of the turbine casing drains from the turbine to the condenser, a drain collection manifold at the condenser, or other drain vessel as indicated on the system P&ID. The designer should comply with the following standards and consider the guidelines listed below for the physical design of these drains:

> ANSI/ASME TDP-1-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil),* American Society of Mechanical Engineers, New York (Ref. 1).
>
> ANSI/ASME TDP-2-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear),* American Society of Mechanical Engineers, New York (Ref. 2).

- Turbine drain lines and valve ports should be sized for the maximum amount of water to be handled under any operating condition, but in no case may they be less than NPS ¾ (DN 20).
- Drain lines should be designed for both hot and cold conditions and should slope continuously downward in the direction of flow. Flexibility loops, when required, should be in the plane of the slope or in vertical downward runs.
- Continuous drain orifices, when used, should be located and designed so that they may be cleaned frequently and will not be susceptible to plugging by debris.
- Steam traps are not satisfactory as the only means of draining critical lines; however, they may be used in parallel with automatically operated drain valves.
- No part of any drain line may be below its terminal point at the condenser, drain collection header, or other drain vessel.
- Only drain lines from piping systems of similar pressure may be routed to a common manifold.
- All drain and manifold connections to the condenser must be above the maximum hotwell water level.

- Drainage from other vessels, such as feedwater heaters, steam jet ejectors, and gland steam condensers, that drain water continuously must not be routed to turbine cycle drain manifolds.
- Drain lines should be connected at a 45° angle to the manifold axial centerline with the drain line discharge pointing toward the condenser. Drain line connections at the manifold should be arranged in descending order of pressure, with the highest-pressure source farthest from the manifold opening at the condenser.
- Drain connections to flash tanks must be above the maximum water level in the tank.
- Drains from the upstream and downstream sides of shutoff valves must not be interconnected.
- Drain lines in exposed areas should be protected from freezing.
- All turbine drain drawings must be reviewed and approved by the turbine supplier.

Heater Drains

The heater drains system consists of the feedwater heater drains from one heater to another at a lower pressure, to a drain tank, or to the dump line to the condenser. The designer should comply with the following standards and consider the guidelines listed below for the physical design of these drains:

ANSI/ASME TDP-1-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil),* American Society of Mechanical Engineers, New York (Ref. 1).

ANSI/ASME TDP-2-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear),* American Society of Mechanical Engineers, New York (Ref. 2).

- Drain piping from feedwater heaters without an internal drains cooler must immediately drop vertically to provide as much static head as possible upstream of the heater level control valve. Thereafter any horizontal runs must be sloped down a minimum of ¼ in/ft (20 mm/m) in the direction of flow.
- Drain piping from feedwater heaters with an internal drain cooler may be routed horizontally without sloping upon leaving the heater.
- Heater level control valves should be located as close as possible to the receiving vessel, with consideration for ease of access and maintenance.
- The heater drain system arrangements must be coordinated with the system engineer for analysis to ensure that single-phase water flow is maintained upstream of the heater level control valves and to determine where downstream velocities may require tees and target plates in lieu of elbows for minimizing erosion.
- Heater drain dump lines should enter the condenser at approximately the horizontal centerline of the tube bundle. This location should be coordinated with the condenser manufacturer, who will provide the necessary baffle plates to prevent impingement on the condenser tubes.
- Only long-radius elbows should be used in heater drain piping.
- The use of reducers should be avoided, except at the control valves, which are generally smaller than the line size.

Compressed Air

The compressed-air systems provide service air and instrument air throughout the plant. The following guidelines apply to the design and layout of these systems:

- Refer to the compressor manufacturer's instruction manual for the recommended relative lengths of intake and discharge piping versus compressor revolutions per minute (rpm).
- The compressed-air system equipment arrangement and piping design should be such that the air receiver is the lowest point in the system and any condensate in the system will drain to the air receiver, particularly during periods of shutdown when large amounts of condensate can form. The point here is to preclude any possibility of condensates draining back to the air compressor, where it could cause extensive damage. The compressor discharge piping should be as short and direct as possible through the aftercooler and into the air receiver. The compressed-air system distribution lines and risers should originate from a separate outlet connection on the air receiver and should be sloped back to the air receiver.
- Compressed-air line header branches should have vertical risers and be drained at their terminations.
- Individual service branches should be taken off the top of the headers.

Floor and Equipment Drains

Floor and equipment drains in process plants are actually a process system and should be considered in the overall equipment layout design process. All equipment should be carefully evaluated for drain requirements, and a drain hub should be provided for pipes that produce continuous flow. The equipment drain system requires a thorough understanding of the equipment and system function because the drains are designed and issued for construction prior to receipt of finalized vendor information. Drain hubs should not be located more than 6 in (150 mm) away from the equipment pads, to prevent them from becoming tripping hazards.

Sump Locations and Pump Discharge

Piping and plant layout should always consider the sump locations as significant due to their impact on overall construction. Civil structural problems can occur when the sump size and location are not evaluated prior to determining a final sump location. Sump discharges should have a nonreturn valve to prevent the draining of the discharge piping. This is required to keep the discharge line solid and to avoid waterhammer.

Fire Protection

The fire protection system usually consists of two or more fire pumps taking suction from the fire water source with the discharge of each pump independently connected to the underground fire main and as widely separated as possible. The underground fire main loop shall completely encircle the plant and may serve multiple sites if cross-connected between units. The National Fire Protection Association codes and the following guidelines may be used to design and lay out the yard fire main loop:

- Locate the yard fire main such that all fire hydrants will be a minimum of 50 ft (15 m) from any building or structure whenever possible.
- The underground fire main shall be sectionalized in accordance with NFPA code using post indicator valves.
- Post indicator valves shall be provided on each side of any fire pump discharge connection into the fire main loop.
- All fire protection system branches from the yard fire main loop shall be provided with a shutoff valve located not less than 40 ft (12 m) from the building or structure being served.
- Two-way fire hydrants with individual curb boxes should be provided at 250- to 300-ft (75- to 90-m) intervals along the yard fire main loop.

Water fire-extinguishing systems within any building may consist of automatic sprinkler systems, spray systems, deluge systems, and hose stations, as determined by the project engineering group. The following guidelines shall apply to the design of these systems:

- Large areas, such as below the turbine operating floor, should be divided into sectors each served by an individual branch from the yard fire main loop.
- Each sector should be controlled by an exterior post indicator valve and an alarm check valve or automatic valve located inside the building.
- The maximum area served by any one alarm check valve or automatic sprinkler valve shall not exceed 25,000 ft^2 (7620 m^2).
- The maximum number of sprinkler heads in any sector shall not exceed 275.
- Provide automatic wet sprinkler systems in the area of the tube oil system below the turbine operating floor and in the ceiling of the clean and dirty tube oil storage tank room.
- Separate water spray systems should be provided in the area of the tube oil system, in addition to the wet sprinkler system noted above, and in the area of the hydrogen seal system.
- Standpipes and hose stations should be provided in accordance with the NFPA code as a complement to the automatic suppression systems noted above.
- The hose stations on any given floor should be fed from above to avoid creating a series of unvented high points.

Cooling Water Systems

There are several types of cooling water systems utilized today in the engineering and design of power generation, petrochemical, and industrial plants. The most common system in use for many years in power generation was the direct use of the water from the nearby river, bay, or ocean. In this system a water intake structure is located along the shoreline and includes as a minimum circulating water pump(s), piping, both fixed and traveling intake screens, and the necessary crane facilities for the removal, replacement, and maintenance of the pumps and their motors. The intake screens are provided to prevent fish, crabs, and other debris from entering and damaging the pumps. In addition to this main cooling water system, there may be one or more service water systems for other equipment throughout the plant. The following guidelines apply in the design and routing of these systems:

- Where butterfly valves are used, follow the guidelines provided for valves. Any given heat exchanger inlet and outlet valves should be located close together for balancing the system.
- Avoid unnecessary vertical loops in any closed cooling water system. This type of system will usually include an expansion tank, which should be located at or above the highest point in the system, and the outlet from this tank should be piped directly to the pump suction.
- For piping at centrifugal pumps, follow the guidelines provided for piping of centrifugal pumps.
- Consult the Hydraulic Institute standards and the pump manufacturer's guidelines for layout and arrangement of deep-well type of pumps.

Since the temperature in these systems is not high and does not vary widely, piping offsets to accommodate thermal expansion and/or contraction are not of paramount importance.

APPLICATION OF COMPUTER-AIDED DESIGN TO PIPING LAYOUT

The piping industry today is very diverse in its use of computer-aided design. This diversity is shown by the various levels of sophistication of the CAD applications in use by different segments of the industry. Even within the same company, the sophistication of CAD use can vary widely from discipline to discipline, department to department. This diversity ranges from a surprisingly large portion of the industry in which there is little use of CAD to a few who claim to be approaching a paperless office. Between these two extremes, most of the industry appears to be using CAD as computer-aided drafting. In this sense, CAD becomes an electronic pencil, not necessarily a design tool.

The meaning of the term *CAD* has evolved as quickly as the technology itself. From its original use as an acronym for computer-aided drafting, it has spawned a whole family of related acronyms: CADD (computer-aided drafting and design), CAE (computer-aided engineering), CAM (computer-aided manufacturing), and so on. Many of these terms have been applied when describing the design and layout of piping systems. In the minds of many people, CAD and its related acronyms are still envisioned as simply automated drafting, where CAD is basically the substitution of drawing boards with CAD terminals. While computer-aided drafting represents a significant portion of the application of CAD to piping layout, this is changing rapidly. In this section, applications beyond simple drafting will be discussed. Therefore the acronym *CAD* will mean *computer-aided design* and will refer to both design and drafting activities related to piping layout.

The entire field of design automation, including CAD, is changing so rapidly that it would be of little value to make recommendations regarding specific hardware and software systems. What may be the best or most cost-effective system today may be out of the picture tomorrow. However, there are some fundamental issues associated with the selection and implementation of a CAD system which should be considered, regardless of the specific supplier of hardware and software.

Computer-Aided Drafting

Currently, as indicated previously, the most significant use of CAD for piping layout is for drafting. Many software systems exist which can function on nearly every type of computer hardware available, including mainframe computers, minicomputers, workstations, and personal computers. Today, the use of CAD for two-dimensional drafting is dominated by CAD software for personal computers. In selecting a system for producing piping drawings, there are several issues which must be considered, regardless of the hardware to be used.

User-Definable Symbols and Menus. Any CAD software, if it is to be of long-term benefit, must provide the capability to define its own drafting symbols and menus (e.g., tablet, on-screen) for selecting these symbols. Since piping drawings make extensive use of symbology, defining symbols is of critical importance for significantly increasing drafting productivity. This capability allows the user organization to create and manage libraries of its own symbols, standard details, and standard notes, which can be easily and automatically included in any drawing.

Use of Standard Hardware. Traditionally, many CAD systems were provided by the vendor as a turnkey system that included both hardware and software. In these cases, the CAD software was designed to operate specifically on the hardware provided by the vendor. Today, however, many vendors have decoupled the hardware and software, which allows the software to run on a number of hardware platforms. In fact, most of the major providers of CAD software for drafting provide only software, with the users acquiring the hardware and operating system independently. This is particularly true for the personal-computer-based CAD systems. By selecting software which can function on a number of types of hardware, the user has the flexibility to more fully take advantage of rapid changes in the hardware market, i.e., decreasing prices with improved performance. If the CAD software can function only on the hardware from one specific vendor, then the user must rely on the hardware vendor to keep pace with the rest of the industry.

Availability of Third-Party Software. Certainly not every user can have the luxury of developing dedicated software, particularly beyond the development of symbol libraries and menus. Therefore, before selecting a CAD system, the user should determine how much application software is available from the vendor or from third parties. For piping layout, the most important applications to look for are those intended for generating orthographic piping drawings and piping isometric drawings. Application software, specific to piping layout, can significantly increase the productivity of the application of CAD. If little or no applications software exists for the CAD system under consideration, then the user will likely have to develop his or her own applications software or fail to realize the full value of the CAD system.

Support of User-Developed Software. In cases where no applications software exists, perhaps due to the uniqueness of the user requirements, the user needs to ensure that application software can be developed for the specific CAD system. As a minimum, the system should support developing simple "macro" commands which execute a series of commands in response to a single command. Many systems have macro languages which offer much of the functionality of general-purpose programming languages. For more sophisticated applications, the system should provide interfaces to software written in other programming languages, such as Fortran or C.

Support for Multiple Users. Piping layout is not done in isolation and must interface design information and drawings from other piping designers as well as other disciplines. Therefore, the CAD system must support this type of activity. The CAD system should provide the capability for a designer to have read-only access to the CAD files of other designers for reference, interference checking, or use as background information for the piping drawings. Systems which have this capability often refer to it as a *reference file* capability. This allows one designer to see the file of another designer, as if it were part of his or her file; however, the data cannot be changed. For personal-computer-based CAD systems, this requires that they be part of some type of local or wide-area network. Without this capability in the CAD software or for personal computers which are not in a network, the data from other designers must be copied and incorporated into the designer's file. This does not allow the designer to see the active data of other designers. In addition, it also greatly increases the storage requirements since many drawings are duplicated, perhaps numerous times. Most importantly, this introduces a more complicated file management problem, making it more difficult to (1) know which file has the most up-to-date information and (2) ensure that everyone references the current data.

Database Capabilities. To utilize the CAD system for more than just drafting requires that the system have the ability to create drawings which, in addition to the drawing graphics, contain (or reference in database) other information which can be extracted from the drawing, such as valve numbers and/or line numbers. With this type of capability, bills of material can be generated automatically from the piping drawings. It is even possible to generate the input to the piping stress analysis program from a piping isometric. However, note that merely having a basic database capability does not mean that it can be effectively used for extracting data from piping drawings. This is the role of applications software developed specifically for piping which automatically generates and manages this information during the creation of the drawing. In the absence of piping applications software, the designer would be required to key in a significant amount of data while generating the drawing. This not only dramatically decreases the productivity of the drawing production process, but also greatly increases the possibility of errors.

Training and Implementation. In the past, much of the cost of implementing the traditional turnkey CAD systems was in the hardware and software. Today, as the cost of hardware and software continues to decline, the majority of the cost is shifting from hardware and software toward training and support. Therefore, the costs associated with the training and implementation of a CAD system, even for two-dimensional drafting, should not be underestimated. In fact, experience has shown that the relative effectiveness of a CAD system is directly related to the amount of training and support the individual users receive.

The precise method of implementing a CAD system is dependent on the company's current organization and method of executing work. Centralized CAD groups working multiple shifts were often the norm with the installation of the large turnkey systems. Now, however, as the cost continues to decrease and the piping design industry in general increases its sophistication in the use of CAD, more effective uses of CAD are being made by placing the workstations right in the piping design groups. Many companies started by training their drafting personnel. But again, experience has shown that even more effective use can be made of the CAD system by training senior-level piping designers. Instead of creating sketches which are then passed on to a drafter, the designer, using the CAD system and piping layout applications software, can create an electronic sketch which is very nearly a finished drawing, leaving very little to do in the way of drafting. This approach can greatly increase the productivity of the whole design and drafting cycle.

Computer-Aided Design

While the use of CAD for two-dimensional drafting in support of piping layout can provide a number of productivity benefits, there are inherent limitations as to overall benefits to the entire design, fabrication, and construction cycle. While providing benefits in producing the piping drawings (e.g., drafting quality, drafting productivity) and possibly in generating bills of materials, it offers little in the way of improving design productivity. Also, the cost and effort required for interference detection are only marginally improved. Thus two-dimensional drafting, while improving drafting quality and productivity, does little for improving design quality and productivity.

The use of three-dimensional (3D) modeling offers a significant step forward in improving piping design productivity and quality. Systems for 3D piping modeling have existed since the 1970s in a variety of forms. The early systems were geared primarily toward interference detection and materials management and really were not used as design tools per se. Today, a number of systems exist which address the entire piping design cycle. In selecting one of these systems, all the issues which applied to computer-aided drafting apply to 3D piping design systems. However, there are a number of other issues which must also be considered.

Interactive Design. To truly improve piping design productivity, the software should provide the capability to interactively lay out the piping systems directly in the 3D computer model. This allows the piping designer to sit at the graphics workstation, viewing the 3D model, and directly add new piping or modify existing piping. Without this capability, the system can provide other benefits, such as in interference detection, but will not necessarily improve the piping design productivity. In fact, without interactive design capabilities, another step is added to the process for entering the data into the 3D model from the 2D design drawings. Many CAD systems provide interactive 3D modeling capabilities, but these are not usually sufficient for 3D piping design. Applications software, specifically aimed at piping design, is required to realize gains in design productivity. Without this type of applications software, 3D modeling is probably only effective for early conceptual design and perhaps detailed modeling of very specific problem areas.

Interference Detection. A major advantage of using 3D computer modeling for piping layout is the ability to automatically check for interferences. This alone can provide a significant improvement in design quality by making it possible to issue a "provable" design, i.e., an interference-free design. Many CAD systems, particularly those originally developed for mechanical design, can detect interferences between two 3D objects; but this is not sufficient for checking plant models for interferences in a production environment. As a minimum, the software should provide the following capabilities:

- The software should be able to check interferences for all or part of the plant in a batch mode. This check should include not only piping but all other disciplines as well. The software should have a method of reporting interferences which is easy to interpret and makes it possible to quickly locate the interferences in a large and complex model. Some systems also offer the capability to check for interferences as the piping is being designed. This is especially useful for designing pipe in very congested areas.

- The software should check for not only ''hard'' interferences, i.e., metal-to-metal, but also ''soft'' interferences, such as personnel access areas, equipment removal spaces, insulation, and construction access.
- The software should provide some capability for managing interference resolution over the life of the project. This includes the ability to suppress certain types of interferences and flagging certain specific interferences as acceptable which will not be reported in the future.

Drawing Generation. To fully realize the benefits of 3D modeling, the system should provide the capability to automatically or semiautomatically produce the piping drawings, both orthographic and isometric, directly from the 3D piping model. These drawings should be generated in the form of 2D CAD drawings so that they can be managed along with the 2D drawings not generated from the 3D model. For orthographic drawings, the system should be able to represent the piping in the format required by the user, e.g., single-line; it should be able to automatically remove hidden lines from the model; and it should have some basic capability to automatically place annotation, such as component callouts, into the drawing. For piping isometrics, it is not unreasonable to expect the software to generate the piping isometric automatically.

Bills of Material. As a minimum, the software should have the capability to produce a bill of materials for any of the components included in the model. If a user requires stringent control of piping materials, the system should also provide a piping materials control system or an interface to a third-party materials control system.

Interface to Other Systems. Since many disciplines utilize 3D geometry data, the software should have the ability to interface the 3D geometry data with other computer systems. For piping design, this would include the piping stress analysis systems. This could also include interfaces to fabrication equipment, such as numerically controlled pipe-bending systems.

Design Review. The use of 3D modeling for piping design impacts the design process in a number of ways. First, the design evolves in the 3D model—not on the drawings, as in the case of 2D design. The drawings are not usually produced until the design is completed. This means that the drawings cannot be used as a means of reviewing the design while the design is in progress. Second, since in some companies the use of 3D design has virtually eliminated the plastic model, the plastic model is also no longer available as a design review tool. Thus the 3D software system should provide, either directly or through an interface, the means of reviewing the 3D computer model on a high-performance graphics terminal. These types of systems provide the capability to ''walk through'' solid shaded models in real time for the purposes of design review.

Training and Implementation. Once again, the issues related to computer-aided drafting apply here as well. The primary difference is one of degree. Systems for

3D computer modeling of piping require more training, more support, and a longer learning curve. Also, these types of systems are more pervasive than simple 2D CAD drafting in that they require a higher level of integration between disciplines and departments and thus a higher level of management attention and support. For these systems to be effective, it is imperative that senior-level design personnel are trained in the use of the system and can use it effectively for piping layout.

Conclusion

Computer-aided drafting and computer-aided design have been used effectively and productively for piping design for a number of years. One of the most important lessons learned from the application of CAD to piping layout, particularly the use of 3D modeling, is that design firms are no longer tied to the same design process and design documentation as when the design was performed manually. The use of 3D piping design provides a number of opportunities for improving the way in which plant design is performed, over and above simply the increase in design productivity. In fact, experience has shown that force-fitting 3D piping design into a project organization and design process geared to manual design actually leads to some inefficiencies.

There appear to be several factors which are important to the continued effective application of this technology. Perhaps most important is the fact that being able to effectively apply this type of software requires training—not only for the individual designers and engineers but also for the supervisors, project engineers, and project managers who control the project work. This type of software opens up new possibilities for improving the way project work is performed, but being able to take advantage of these requires that people at all levels of the project understand the software capabilities as well as its limitations.

REFERENCES

1. ANSI/ASME TDP-1-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Fossil),* American Society of Mechanical Engineers, New York.
2. ANSI/ASME TDP-2-1985, *Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation (Nuclear),* American Society of Mechanical Engineers, New York.

FURTHER READING

ASME B31, Code for Pressure Piping, Section B31.1, *Power Piping,* 1998 ed., American Society of Mechanical Engineers, New York.

ASME Y32, Code for Graphic Symbols, Section Y32.2.3-1953, *Graphic Symbols for Pipe Fittings, Valves and Piping,* American Society of Mechanical Engineers, New York.

Hydraulic Institute Standards, 1994 Edition, Hydraulic Institute, Cleveland, OH.

National Fire Protection Codes, vols. 1 to 11, 1998, National Fire Protection Association, Quincy, MA.

OSHA Regulations, Code of Federal Regulations, Title 29, Part 1910.

Pipe Fabrication Institute Standards, Pipe Fabrication Institute, Springdale, PA.