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Designing a Process Flowsheet

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Piping and instrumentation diagrams belong to a family of flowsheets that includes block flow diagrams and process flow diagrams. Technology advances have transformed these resources into intelligent documents, capable of storing layers of digital information.

The appearance and form of piping and instrumentation diagrams (P&IDs) have changed little over time, despite decades of technology improvements. A P&ID created 60 years ago on the drawing board, using ink pens on linen sheets, describes a process the same way as one created today using modern computer-aided design (CAD) software. P&IDs continue to be fundamental references for any process facility.

This article discusses what makes a good P&ID, and how technology can improve its quality, usability and effectiveness.

Flowsheets

The terms *flowsheet* and *flow diagram* are often used in the context of engineering and design applications. Although this terminology is not the most accurate way to describe P&IDs, it is sufficient to describe the overall family of process-based diagrams to which P&IDs belong.

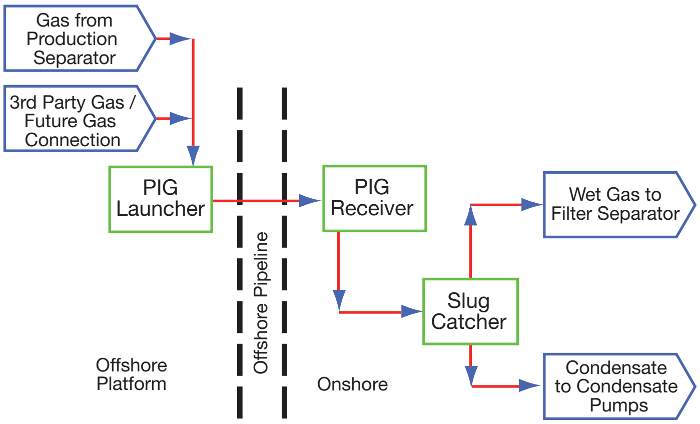
The *block flow diagram* (BFD) (Figure 1) is a very simple diagram that can condense an entire process onto as little as a single sheet. More detailed information can be found in the *process flow diagram* (PFD), which is considered the precursor to the P&ID. Typically, the PFD is used by plant designers to conduct initial layout studies of a plant's process systems and major pipework. Since PFDs use many of the same symbols as P&IDs, they allow viewers to more easily identify items and processes by sight. This is in contrast to the BFD's standard block and line diagram, which emphasizes the descriptions contained in those blocks.

P&IDs provide the most detail of the three types of diagrams, using standard nomenclature and symbols to fully describe the process. Some regulatory agencies mandate their use during design and construction, as well as throughout ongoing operations and decommissioning.

The main purpose of each document is to convey the right amount of process information, as needed, during the various stages of the bidding, engineering, design, procurement, construction, operation, and decommissioning phases of a facility's lifecycle.

Block flow diagrams

The beauty (and advantage) of a BFD is its ability to outline the complete process on little more than a single sheet. These diagrams usually resemble an organizational chart, containing mainly text enclosed by boxes, interconnecting lines and the process commodities they transport, and flow



▲ **Figure 1.** A block flow diagram can illustrate an entire process on one sheet.

arrows to indicate process flow directions.

A good BFD typically contains the following:

• large individual pieces of equipment, or equipment as part of a combined process, that are denoted by a single symbol, typically a rectangle

• clear labels illustrating function (since no equipment or package numbers appear on this document)

• the order of process flow arranged from left to right and, if possible, with a gravity bias, *i.e.*, if hydrocarbons are shown entering a separation process, then gas leaving the process should be shown exiting from the top of the block and condensate from the bottom

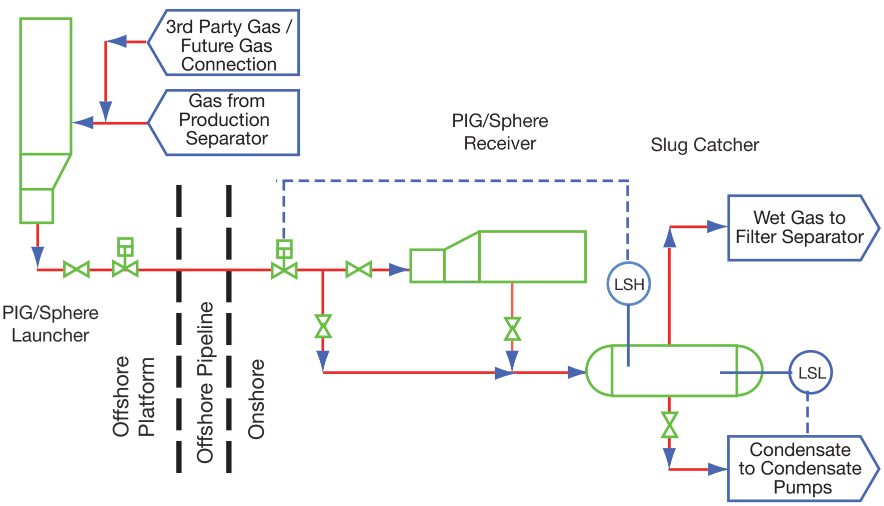
• lines linking equipment or processes to show flow direction

• wherever more than one line leaves a process, then the processed commodity in each line should be clearly marked.

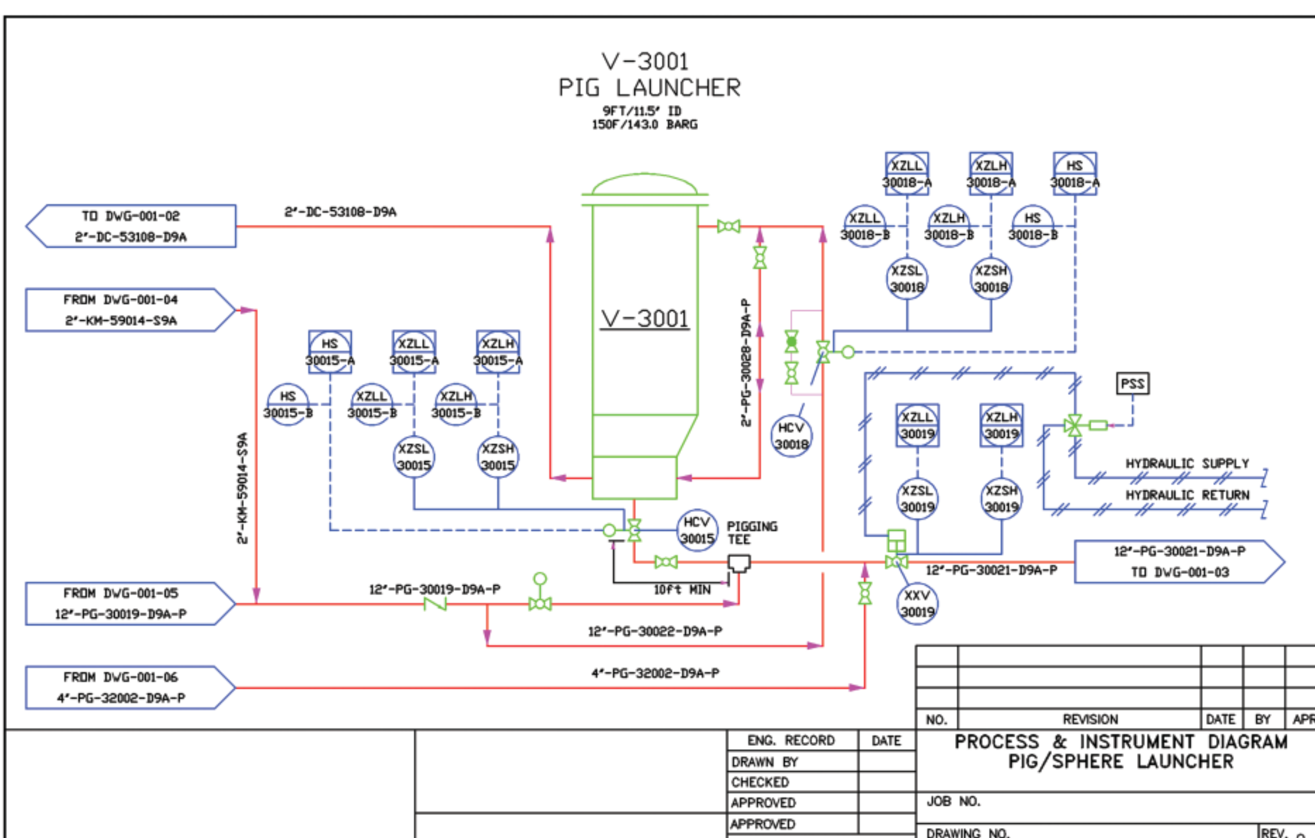
Process flow diagrams

Process flow diagrams (Figure 2) carry more information than the block flow diagrams from which they are derived. They show more detail about major equipment and subsystems and the flow of product between them.

PFDs include information on the



▲ **Figure 2.** Process flow diagrams illustrate major equipment and subsystems and the product flow between them.



▲ **Figure 3.** A piping and instrumentation diagram serves as an important reference that is useful at any stage of the process lifecycle.

pressures and temperatures of feed and product lines to and from all major pieces of equipment, such as vessels, tanks, heat exchangers, pumps, etc. Also indicated are main headers and points of pressure, temperature and flow control, plus the main shutdown points in the system.

For rotating equipment, PFDs carry important information, such as pump capacities and pressure heads, and pump and compressor horsepower. For tanks, vessels, columns, exchangers, etc., design pressures and temperatures are often shown for clarity.

A typical PFD shows the following items:

- process piping
- process flow direction
- major equipment represented by simplified symbols
- major bypass and recirculation lines
- control and process-critical valves
- processes identified by system name
- system ratings and operational values
- compositions of fluids
- connections between systems.

Piping and instrumentation diagrams

A P&ID (Figure 3) carries a wealth of information that spans engineering disciplines to define a process. It is the best way of accurately documenting the operation of a process, and it is truly a coordinating document.

P&IDs are also required health and safety documents. The U.S. Dept. of Labor's Occupational Safety and Health Administration (OSHA) mandates that P&IDs be accurate and kept up-to-date throughout the life of the plant. As a result, P&IDs take center stage in discussions of plant and process operations and product lifecycle management.

P&IDs take the conceptual aspects of the PFD and expand them by adding:

- detailed symbols
- detailed equipment information
- equipment order and process sequence
- process and utility (non-process) piping
- process flow direction
- major and minor bypass lines
- line numbers, pipe specifications, and pipe sizes
- isolation and shutoff valves
- maintenance vents and drains
- relief and safety valves
- instrumentation
- controls
- types of process component connections
- vendor and contractor interfaces
- skid and package interfaces
- hydrostatic vents and drains
- design requirements for hazardous operations.

Standards and rules

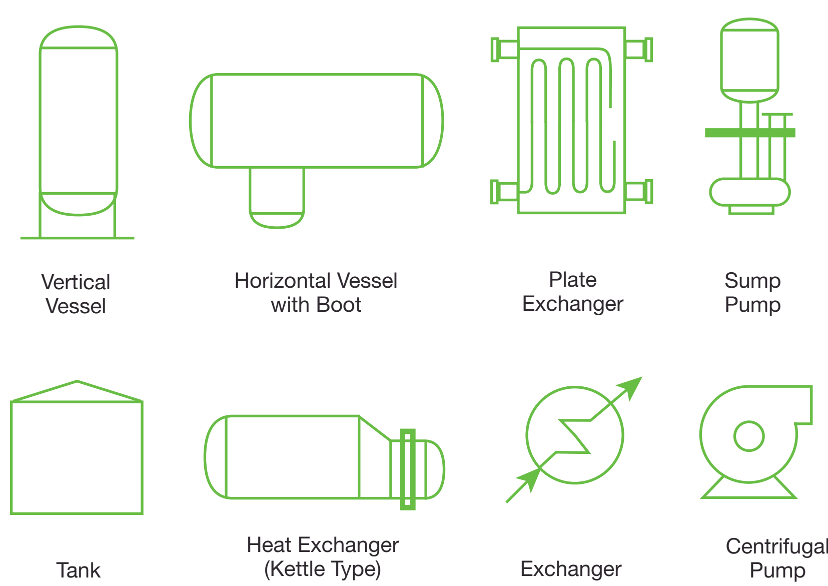
P&IDs are prepared according to a set of rules established to maximize the documents' usefulness. Standard symbols that are easily recognized must be used to represent the items on a P&ID. Each line, instrument, piece of equipment, etc. (Figures 4-6), must be labeled using specific conventions of nomenclature. These rules may seem strange and complicated, but, like any new language, once learned, they becomes second nature.

To demonstrate the use and importance of these rules, let's look at three of the most important named items on a typical P&ID: equipment, process lines, and instrumentation.

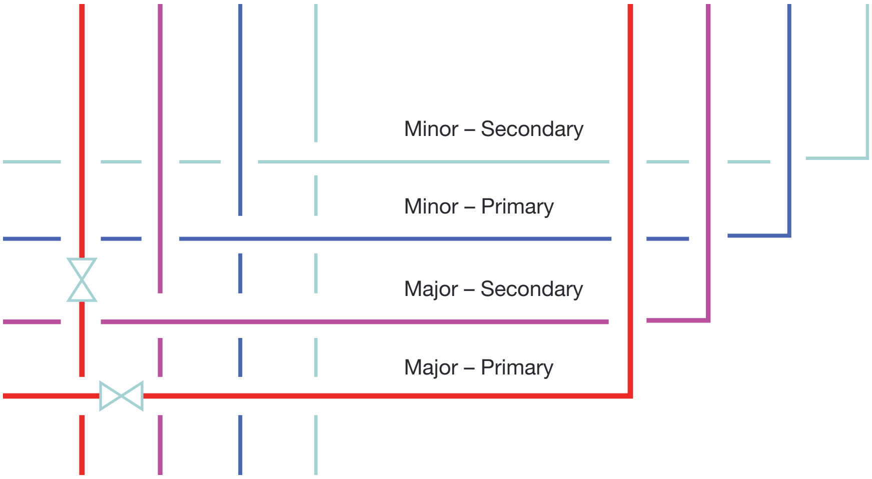
Equipment designation

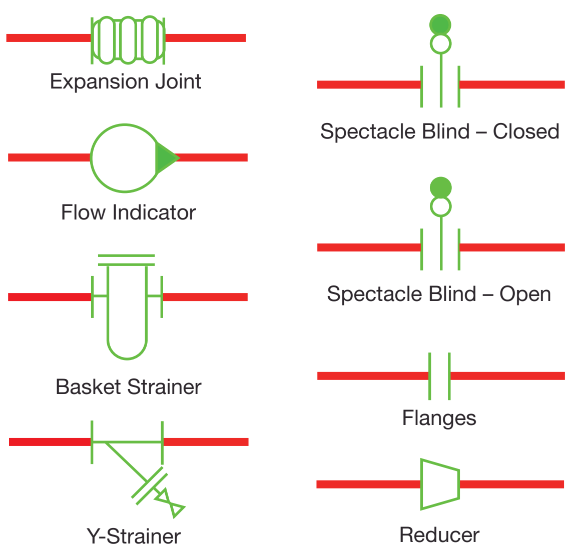
Equipment numbering allows instant identification of equipment by its unique number. For example, an equipment identifier may consist of a letter and five numerals — *e.g.*, X-00000. The letter designates the type of equipment, such as: V = vessel, E = heat exchanger, HE = heater (electrical), P = pump, and T = tank. The first two numerals could be the system code, for example: 30 = process gas, 60 = fuel gas, and 33 = gas dehydration.The final three numerals are a sequential identification number, from 001 to 999.

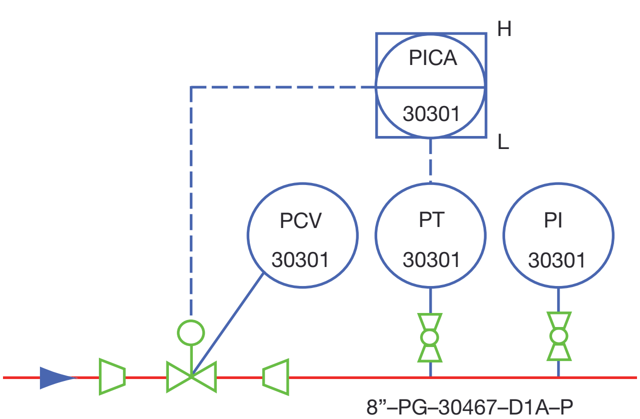
Thus, a piece of equipment identified as V-30456 is a vessel (V) in the gas processing service (30), and is uniquely indentified with a sequential number of 456.



▲ **Figure 4.** So that flowsheets can be universally understood, typical equipment configurations have both standardized equipment symbols and numeric means of identification.







▲ **Figure 5 (top).** When process and instrument lines cross, they are broken based on hierarchy.
Figure 6 (middle). Lines are broken where inline symbols are inserted into a flow line.
Figure 7 (bottom). Instrument loops show instruments working together.

Line designation

Similar nomenclature rules apply to process and utility lines (Figure 5), which are accompanied by an identification number, such as 00˝-XX-00000-X0X-X0˝. These fields convey a wealth of information at a glance. In this example, the first field is the line size (*e.g.*, 24˝). This is followed by two letters that indicate the process commodity in the line — for example, VA = vent, CU = condensate, PG = process hydrocarbons gas, etc. The third field is a five-digit number, the first two a gas system code (30 = process gas, 60 = fuel gas, and 33 = gas dehydration), and the last three a sequential identifier from 001 to 999. The next segment is an alphanumeric sequence indicating the type of pipe specification (X0X), (*e.g.*, A1, B1B, D1A, etc.). The last segment designates insulation information, with a letter indicating class (*e.g.*, P = personnel protection, H = heat conservation, and T = tracing), followed by a number indicating thickness (*e.g.*,1˝).

Thus, a line labeled 24˝-PG-30123-D1A-P1˝ is a 24-in.-dia. pipe carrying gaseous process hydrocarbons (PG) in the process gas system (30) with a unique identification number of 123; the line is to be designed to piping specification D1A with 1-in.-thick personnel protection insulation.

Instrument lines

Instrument lines show both the flow of information between instruments and how that signal is passed from instrument to instrument. Examples of different signal lines include equipment-to-instrument connection lines, electrical, hydraulic, pneumatic, capillary, etc. These use various solid and dashed lines or have particular modifiers added to them to denote their service.

Instrument designations

Instrument nomenclature is very complicated, but once mastered, can become intuitive. Instrument balloons contain two main identifiers: the top indicates the role of the instrument (Table 1), and the bottom is a unique identification number that could also display the instrument's process service. By looking at a combination of these top and bottom strings, one can easily determine the instrument loop to which the instrument belongs.

The instrument nomenclature that appears in the top portion of an instrument balloon has between two and four letters which define its function. The first letter describes what factor of the process it is measuring or indicating (*e.g.*, pressure, temperature, level, flow, etc.). These measuring or indicating factors are denoted by a single letter (in this case, P, T, L and F, respectively).

If the next letter is the last letter, it typically indicates either its passive function (*e.g.*, indicator), or its output function (*e.g.*, switch). So, PI represents a pressure indicator, LC a level controller, and TS a temperature switch. However, the second letter is not always the last letter, and this is where things get tricky.

The second letter can be a modifier of the first letter. For instance, TI is a temperature indicator. To show that the indicator was measuring temperature differentials instead of the actual temperature, D is added as a modifier to yield TDI. Modifiers are always placed before the passive or output function, so TID would be incorrect.

It is possible to have both passive and output functions in the same instrument. For example, PDIC represents a pressure differential indicating controller.

The letters after the final passive or output function can label the range of an instrument. LSH denotes a level switch high, whereas LSHH (level switch high high) points to a level switch working at a higher fluid level than LSH.

Sometimes, text may be placed outside the instrument balloon to indicate the range of operation of an instrument. In the instrument loop example in Figure 7, PICA (the pressure indicating controller alarm) operates in both the high and low range, indicated by the H and L placed just outside the instrument balloon.

Instrument loops. Since instruments work mostly in concert with other instruments, and serve as a vital part of controlling and monitoring a facility, it is important to identify which process control group each belongs to. These groupings are known as instrument loops. By looking at the combination of the top and bottom strings in the instrument designation, one can determine the instrument loop to which the instrument belongs.

Instrument loops (Figure 7) are also conveyed on the P&ID. The instrument loop number identifies items that work together or are to be used in concert. Looking at the examples above, it is tempting to assume that 30302 is the loop number for both PIC-30302 and LSHH-30302; this would be a mistake. Both share the same process system code (30) and have the same sequential number (302), but because their measuring and indicating services are different, they cannot be considered to be in the same loop — PIC-30302 is part of a pressure loop 30302, whereas LSHH-30302 is part of a level loop 30302. Therefore, it would be more accurate to identify them as loop P-30302 and loop L-30302, respectively.

Standard symbols

It is important to use symbols that clearly identify the equipment lines and inline items that appear on P&IDs.

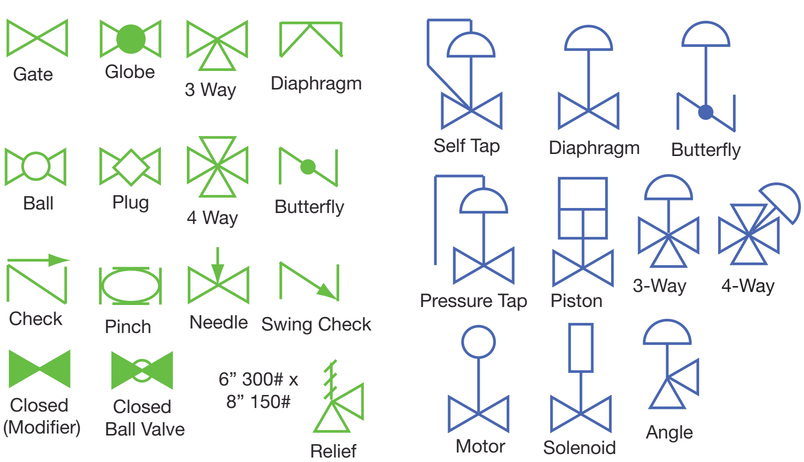
Table 1. Typical instrument functions follow nomenclature that is common for all P&IDs.

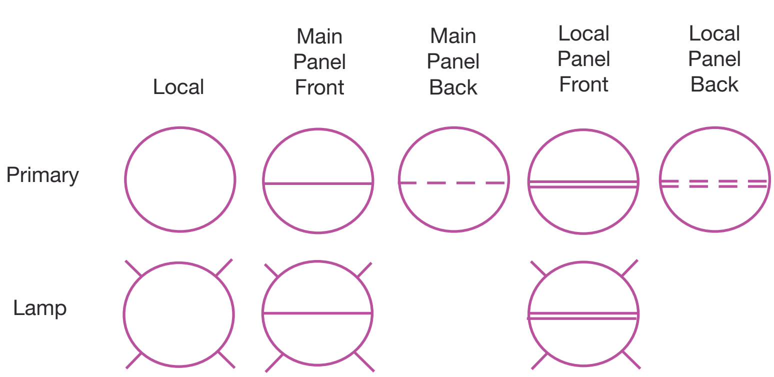
PS	**Pressure**	**Switch**		
PSL	▼	▼	Low	
PSH	▼	▼	High	
PSLL	▼	▼	Low	Low
PSHH	▼	▼	High	High
PSXL	▼	▼	Extra	Low
PSXH	▼	▼	Extra	High
PAL	▼	Alarm	Low	
PAH	▼	▼	High	
PC	▼	Controller		
PI	▼	Indicator		
PIC	▼	▼	Controller	
PICA	▼	▼	▼	Alarm
TS	**Temperature**	**Switch**		
TSL	▼	▼	Low	
TSH	▼	▼	High	
TSLL	▼	▼	Low	Low
TSHH	▼	▼	High	High
TSXL	▼	▼	Extra	Low
TSXH	▼	▼	Extra	High
TAL	▼	Alarm	Low	
TAH	▼	▼	High	
TC	▼	Controller		
TI	▼	Indicator		
TIC	▼	▼	Controller	
FA	**Flow**	**Alarm**		
FAL	▼	▼	Low	
FAH	▼	▼	High	
FI	▼	Indicator		
FIC	▼	▼	Controller	
FISL	▼	▼	Switch	Low
FSL	▼	Switch	Low	
FSH	▼	▼	High	

Although no two companies use exactly the same symbols, they are generally easily recognized.

P&ID symbols, even those used in CAD systems, are derived from the symbol stencils developed for a 0.125-in. grid and used on the drawing board. These symbols, especially frequently drawn inline symbols such as valves (Figure 8), are usually additive. For example, a gate valve is represented by two triangles with touching apexes, a ball valve by a gate valve symbol with an open circle in the center of the valve, a globe valve by a gate valve with a blocked-in circle in its center, and so on.

Modifiers are used extensively in P&IDs to create multiple symbols without "re-inventing the wheel." This makes the addition of a few lines or a circle to a standard symbol one of the easiest ways to differentiate between two items on a P&ID. Examples of equipment modifiers are the addition of filters, vanes or mist eliminators to vessels, and the addition of tubes to exchangers. Instrument symbols (Figure 9) make the best (and most extensive) use of modifiers. When used in concert with nomenclature modifiers, instrument balloons indicate not only an instrument's function, but also its type and location, (*e.g.*, local, local panel, behind a local panel, control panel, etc.) and the type of indication (*e.g.*, local lamp or control panel lamp, etc.).





▲ **Figure 8 (top).** Since P&IDs typically contain information on piping systems, block valves (left) and control valves (right) have their own standard sets of symbols.
Figure 9 (bottom). P&IDs depict these common instrument types.

Computer-aided design

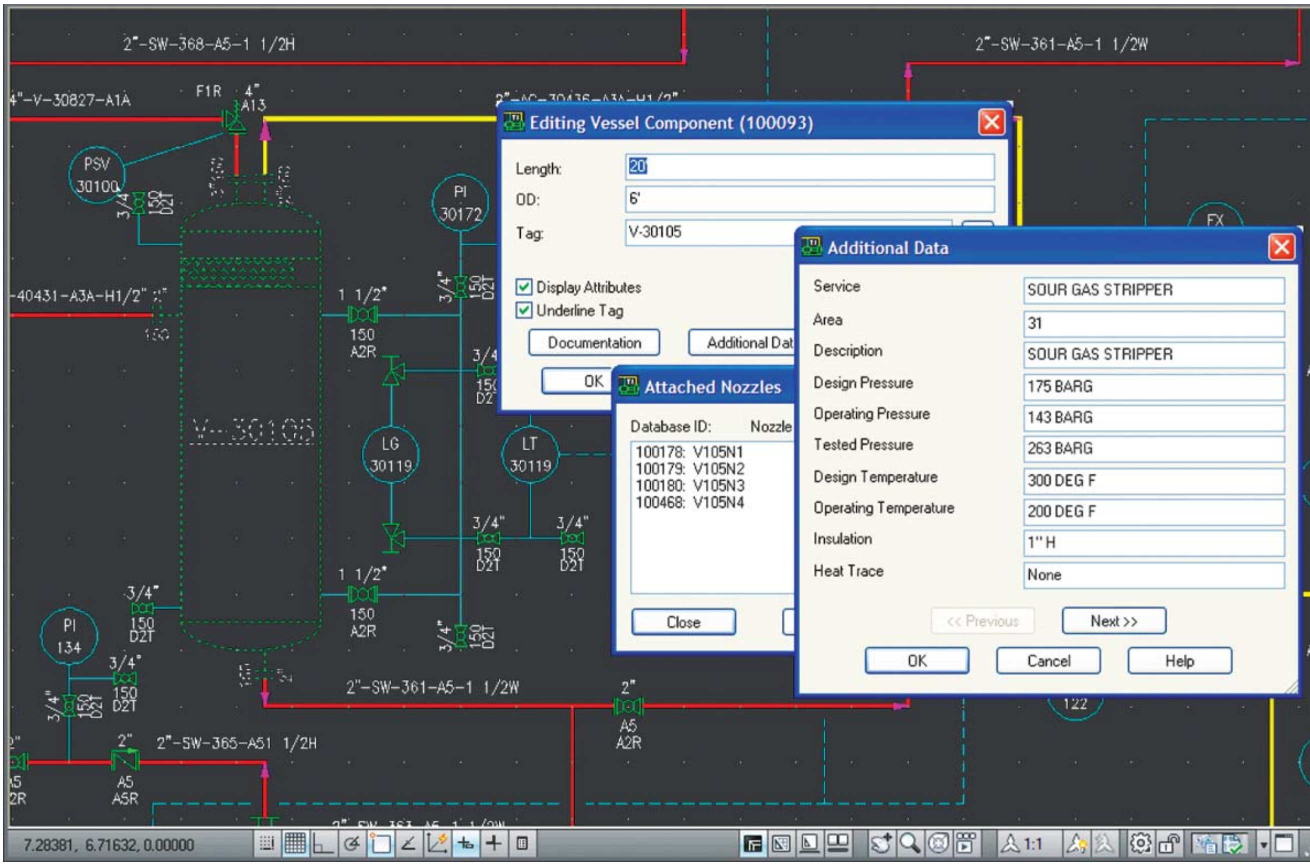
Since P&IDs consist mainly of lines, arcs and standard symbols, CAD systems are ideal for producing them. CAD-produced P&IDs are far more legible than their hand-drawn counterparts, with the added benefit of being easier to update and maintain.

Another benefit of using CAD tools to produce P&IDs is the ability to automate much of the drafting functionality. Such functionality includes the ability to automatically: break process lines when they cross; remove a section of a process line when a valve is inserted, or close a line when a valve is removed; check that a valve is the same size as the line into which it is being inserted; make global changes, such as changing the size of a line (with a prompt asking if those changes should be applied to all inline components); and change line types without redrawing.

Intelligent P&IDs. There are many definitions of intelligent P&IDs (Figure 10), which range from delivering some of the drafting enhancements mentioned above, to P&IDs linked to 3-D models. Here we will define an intelligent P&ID as one whose components carry extra information that cannot be seen by looking at the printed drawing. For example, looking at a valve on a P&ID may reveal its size, tag, and specifications (and its type, due to the symbol used), but on an intelligent P&ID, the valve could also have additional background information attached to it, such as vendor name, part number, material of construction, port size, top works, etc. Similarly, operating pressures and temperatures and design pressures and temperatures could be added to the lines that represent process piping.

This addition of extra information for each component makes the P&ID even more valuable. Intelligent P&IDs allow users to store and extract a wealth of information that could be useful throughout the life of the project, such as line lists, bills of material, valve counts and equipment and instrument lists.

Specification-driven P&IDs. One benefit of using CAD for 3-D plant design is the ability to perform specification-driven designs. Once a designer sets the size and piping specification for a line, to ensure accuracy, the CAD system checks the piping specification each time a component is selected for placement into a line. This ensures that someone does not place a carbon steel welded tee in a stainless steel line or use a non-reinforced stub-in branch connection where a welded reducing tee is specified.



▲ **Figure 10.** Intelligent P&IDs contain additional information that is not accessible or apparent from a printed P&ID.

Although there are many things that do not need to be indicated on a P&ID, there are still benefits to having P&IDs that, like a 3-D model, are specification-driven. With specification-driven P&IDs, users can set pipe sizes and specifications, and place items into process lines with the knowledge that these inserted items are correct. With this capability, they know that they are receiving the same benefits as their downstream colleagues and delivering more-accurate lists and reports much earlier in the engineering and design process.

A more-significant benefit of a specification-driven P&ID that uses the same data as a 3-D model is that 3-D designers can verify their designs against the P&ID. This allows line checks to be performed much more quickly.

Another benefit of specification-driven P&IDs is that, in some systems, the 3-D designer can have both the P&ID and the model displayed on the computer screen at the same time, and can drag-and-drop a valve or other inline item from the P&ID directly into the model. Doing this ensures that the designer has the latest information, and that the system checks whether the item is in the model.

The ability to make these integrity checks at any time during the design process, performed by those creating the design, is a large step toward leveraging the power of P&IDs and all of the information associated with them.

In closing

P&IDs have always been very valuable and useful tools, yet it has taken modern technology to release their true potential. P&IDs are no longer limited to holding information that only skilled CAD operators can access. Take a fresh look at your P&ID systems, and you might find that, for just a little more effort, they can be used to their full potential in the design process. CEP

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