Using Process Flowsheets as Communication Tools

Graham Nasby
Eramosa Engineering, Inc.

Piping and instrumentation diagrams (P&IDs), process flow diagrams (PFDs), and block flow diagrams (BFDs) are essential tools for documenting processes and promoting interdisciplinary understanding and communication.

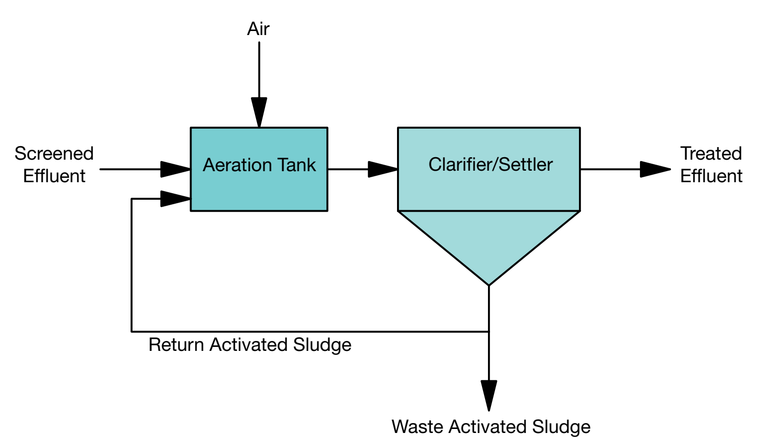
Effective plant design, construction, and operation are team undertakings. In this environment, ensuring clear and concise communication among team members, especially if they are from different disciplines, can be an ongoing challenge.

Of the many communication tools available to engineers, the piping and instrumentation diagram (P&ID, referred to as a process and instrumentation drawing by some) plays an important role in promoting communication and understanding. A P&ID is a type of engineering drawing that provides an overview of a process, its physical components, and how it is controlled. P&IDs are graphical representations of a process that show piping, vessels, valves, pumps, instrumentation, and other pieces of process equipment.

P&IDs, block flow diagrams (BFDs), and process flow diagrams (PFDs) are different types of flowsheets that advance plant design, support construction, and facilitate interactions among all parties involved in building and operating a plant. The terminology for these drawings varies; depending on the segment of the chemical process industries (CPI) in which they are used, they may be called flow diagrams, process schematics, or process sheets. Despite differences among industry sectors and their various terminologies, the contents of these three types of drawings are relatively consistent. This article provides an overview of what BFDs, PFDs, and P&IDs are, who uses them and for what purposes, and how they can be drafted effectively.

The project lifecycle, from predesign and construction to operation to decommissioning, involves a large number of people with different backgrounds. Engineers from various disciplines are among the design professionals. The project team from the sponsor company (*i.e.,* the facility owner) can include personnel from operations and maintenance, regulatory affairs, quality control, information technology (IT), and upper-level management, as well as health, safety, and environmental specialists. Each construction partner will also have its own specialists, estimators, and project managers. The project staff can expand even further to include representatives from operating companies, upstream and downstream operators, suppliers, various service providers, and equipment vendors.

With this large group of workers involved in plant design, construction, and operation, P&IDs effectively com-



▲ **Figure 1.** This BFD of a secondary treatment process shows major material and energy flows, but omits details such as pumps, valves, and small vessels.

municate a plant's inner workings, and serve as a reference tool for all parties involved. Individual disciplines can then develop their own detailed documents, drawings, and specifications based on a common set of P&IDs.

Block flow diagrams

BFDs (sometimes called block diagrams) show unit operations, material and energy flows, and inputs and outputs as a collection of rectangles, arrows, and pointed rectangles, respectively (Figure 1). Only the major energy and material flows are displayed, and details such as individual vessels, pumps, and valves are omitted. BFDs are often used in preliminary design work, when the main energy and material flows are still being determined, because they can be created, revised, and redrawn with minimal effort.

Follow these guidelines to draw an effective BFD:

• Don't use elaborate symbols. Use simple rectangular boxes for equipment or unit operations, arrows for material or energy flows, and connectors for inputs and outputs to other systems.

• For flow-oriented BFDs, show the process flowing from left to right and top to bottom. For density-based equipment such as columns or separators, show the dense products leaving the bottom and the lighter and/or gaseous products leaving from the top.

• For site-oriented BFDs, place large pieces of equipment in their approximate physical locations onsite and use arrows to show the flows between them.

• Label the rectangles representing major pieces of equipment or unit operations in plain English with text inside the rectangles.

• Label the lines representing major energy and material flows with their direction clearly shown. Label the off-sheet connector rectangles clearly.

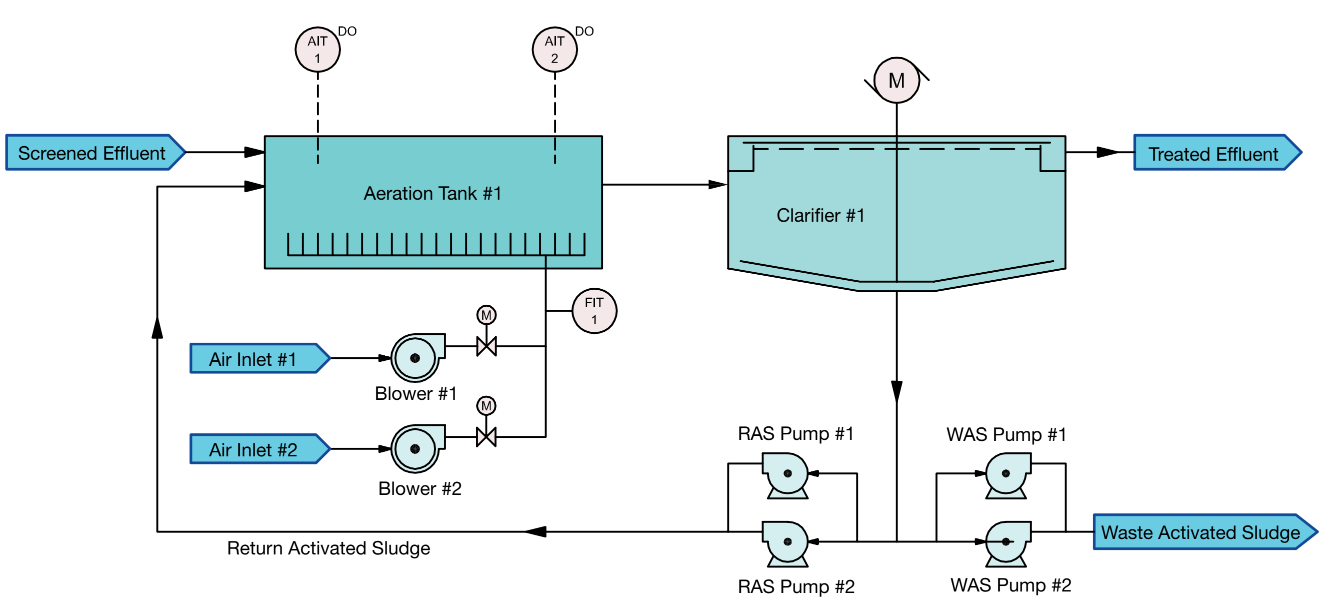
• Keep it simple, and avoid unnecessary detail as much as possible.

A good BFD can be quickly created and just as easily understood.

Process flow diagrams

PFDs show more detail than block flow diagrams, but less detail than P&IDs. PFDs display major pieces of equipment, important pumps and valves, main flow paths, and key pieces of instrumentation (Figure 2). Process details such as flowrates, flow contents, and energy and mass balances are often included, but instrumentation details, utility details, and smaller secondary piping are rarely shown.

A PFD may use tags on certain pieces of equipment, but these act only as reference tools to facilitate discussion in the design phase; the equipment tagging scheme used in the finished plant is based on the P&ID. Process flow diagrams are useful communication tools because they are not as complex as P&IDs, and it takes much less time to create a PFD; this is especially useful when a plant's design has not been finalized, and it would be too costly to draw and redraw a detailed P&ID multiple times. In many sectors of



▲ **Figure 2.** A PFD displays major pieces of equipment, important pumps and valves, and key pieces of instrumentation. The simplified tagging scheme promotes communication during the plant's design phase.

the CPI, process flow diagrams are also used in regulatory filings, safety studies, and budgeting for both new construction and retrofit projects. The PFD can also be a powerful tool for conducting feasibility studies and for making go/no-go decisions.

Follow these guidelines to draft an effective PFD:

• Represent major equipment, such as vessels, heat exchangers, large pumps, and significant control valves with simple P&ID symbols (discussed later).

• Label equipment with simplified tags based on P&ID standards (for discussion purposes only, not to be used for construction).

• Show process piping for primary flow paths, as well as pertinent bypass and recirculation piping, with the flow contents and direction clearly indicated. Do not show ancillary or subsystem piping.

• Include the pressure and temperature ratings for piping, vessels, and heat exchangers, as well as pump capacities, pressure heads, pump horsepower ratings, and expected control valve flow coefficients.

• Show the major pieces of primary instrumentation that are used for normal steady-state process control and shutdown in a simplified manner.

• Do not show utility operations or interconnections for very complex processes.

• If a process control narrative or functional specification does not yet exist, add explanatory notes to describe how the process functions under normal steady-state conditions.

In the iterative discipline of process design, PFDs fill an important niche between the high-level BFDs and the detail-oriented P&IDs.

Piping and instrumentation diagrams

P&IDs provide the highest level of detail of the three types of flowsheets. A well-drawn P&ID (or set of P&IDs) will show every pipe, valve, pump, vessel, and instrument within the plant. P&IDs will also show all process-connected equipment and packaged equipment skids, along with key input, output, and interfacing details (Figure 3). P&IDs do not show specific information such as materials of construction, physical layouts, pipe-wall thicknesses, and wiring connections; these details reside in other drawings and specification documents. Even as new instrumentation technologies are developed, the basic contents, symbols, and line types used on P&IDs has stayed relatively constant.

P&IDs contain a wealth of information that is used by many different individuals on the project team. In many industries, P&IDs are also a mandatory requirement for workplace safety, environmental, and hazard-analysis regulatory filings.

Follow these guidelines to prepare an effective P&ID:

• Use a consistent layout that distinguishes field-mounted, control panel, and computerized functions.

• Use a fully developed tagging scheme in which every piece of plant equipment, instrument, control element, and instrumentation function has a uniquely assigned tag.

• Represent equipment such as vessels, heat exchangers, valves, and pumps with standardized symbols.

• Use simple line drawings for more complex equipment like conveyors, mixers, clarifiers, etc.

• Represent piping, ducts, and flow channels that convey process materials or gases and liquids with lines.

• Represent instrumentation, control, and automation equipment with small circles or boxes with tags.

• Use dashed and other specialized line types to show instrumentation connections (*e.g.,* electrical wiring, pneumatic tubing carrying control signals to valves, network bus connections, etc.).

• Off-sheet connectors should be used to show process or utility connections to external systems.

• Various other pieces of key summary information about normal process conditions, expected flows in process lines, design pressures/temperatures, and equipment and piping sizing, as well as process and skid boundaries, should also be shown.

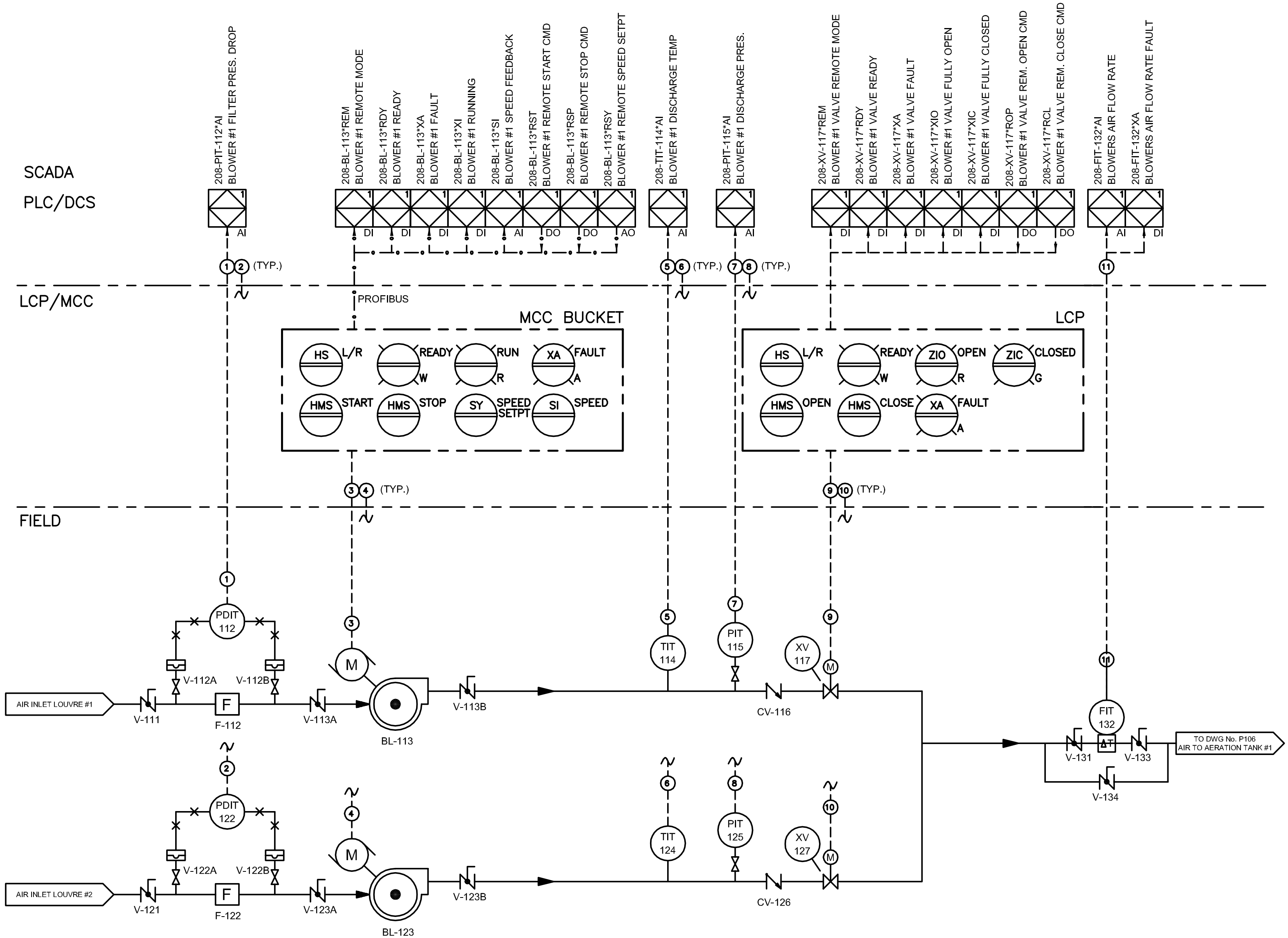
Using PFDs and P&IDs together

For large, complex processes that cannot fit onto a single P&ID, it is often helpful to pair a block flow diagram or process flow diagram with a set of P&IDs. The BFD or PFD can be used as an overview for the set of P&IDs. A well-thought-out flow diagram can act as an excellent visual index to a group of detailed P&IDs. Some drafters will put dotted boundary lines and P&ID drawing references on the flow diagram to help guide the reader to the right drawing in the P&ID drawing set.

P&ID drawing styles

The way that symbols and piping are arranged on a P&ID can vary considerably by CPI sector. Some sectors show instrumentation, motor controls, and computer functions arranged throughout the drawing, while others segment the drawing so that the process is shown on the bottom with control panels and computer functions shown as separate layers. Sometimes a combination of the two approaches is used.

The P&ID in Figure 3 employs a layered approach: the bottom layer describes the process equipment (FIELD), the next layer shows local control panels and motor control centers (LCP/MCC), and the top layer shows the computerized control system (SCADA/PLC/DCS). The P&ID layout approach depends on the norms for the particular industry and the company's P&ID drawing standards. For example,



▲ **Figure 3.** This layered P&ID is much more complicated than a PFD, as it shows all vessels, piping, instrumentation, and control instruments.

the P&ID layout in Figure 3 is often used in the municipal wastewater-treatment sector.

Good drawing practices

To facilitate effective communication among team members, engineers must ensure that their drawings can be easily understood by others. Some on the project team may not be familiar with the drawing numbering scheme, the tagging standard employed, or the symbols and line types that are used. At the beginning of the drawing set, the drafter should provide:

1. a lead sheet drawing that states what facility and project the drawings are for
2. an index drawing that lists every drawing in the set and its corresponding drawing number
3. a set of standardized legend drawings that defines the symbols, abbreviations, line types, and tagging schemes that are used in the drawing set.

To avoid potentially costly communication misunderstandings and reduce the chance of mistakes, every drawing must:

• have a unique number that can be easily referred to

• have a revision number and a revision date; if a drawing is a work-in-progress or preliminary, clearly mark it as such and include the in-progress printing date

• use a standardized title block, so the reader can quickly determine what each drawing is for

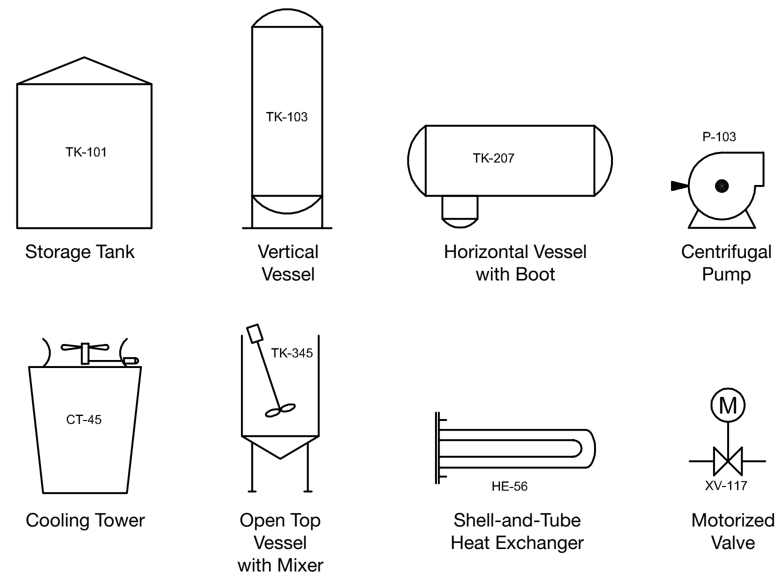
• be the same size — oddly sized drawings often get lost or misplaced

• adhere to company drawing standards (*e.g.,* computer-aided design [CAD] details such as standardized title blocks, line types, and layers, etc.).

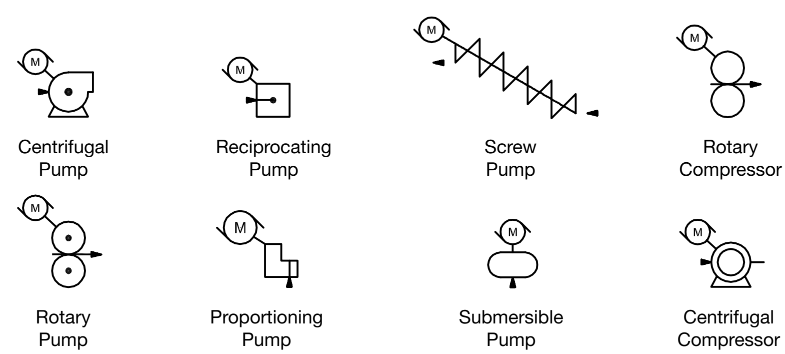
Tagging

To ensure precise communication about specific parts or functions of the plant, every significant piece of equipment, piping, and instrumentation on a P&ID should carry a unique tag. Due to their simple graphical nature, P&IDs act as coordinating documents that show all tags throughout a plant in an easy-to-read manner. Tags, which consist of alphanumeric codes, should be assigned in a logical, flow-oriented manner so that the reader can easily follow the tags through individual processes.

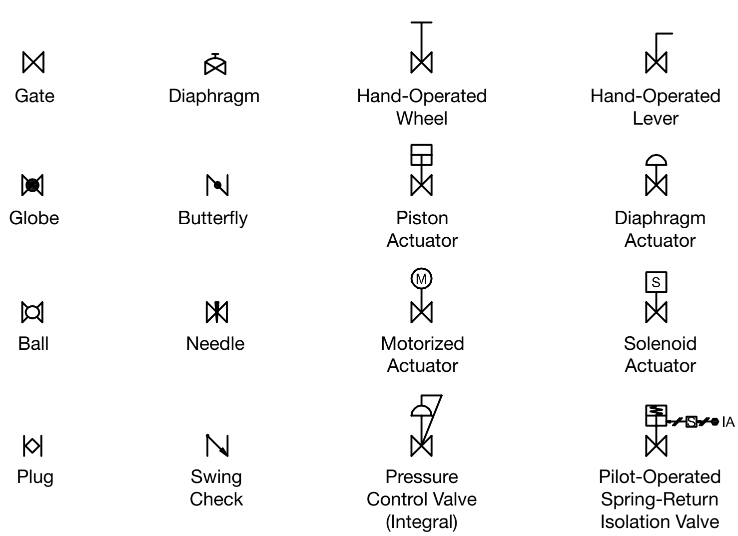
It is important that tags follow a consistent and standardized format. For equipment and



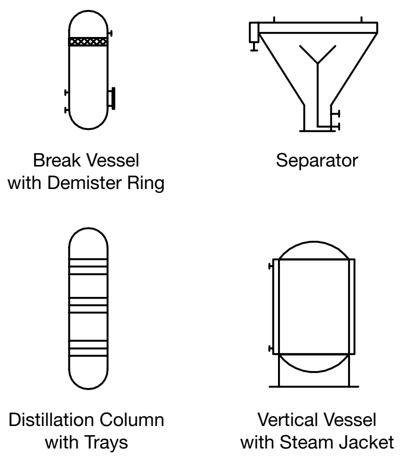
▲ **Figure 4.** Commonly used equipment is depicted as simple line drawings with alphanumeric labels.



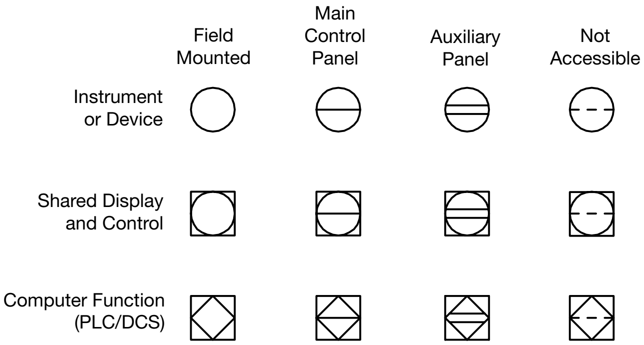
▲ **Figure 5.** Pump type is distinguished by simple line drawings.



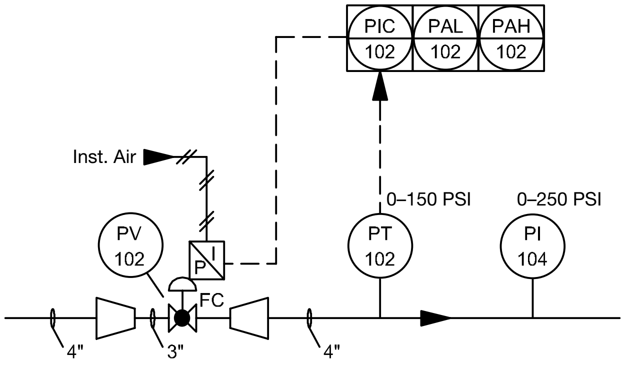
▲ **Figure 6.** Each type of valve and actuator is represented by a unique symbol.



▲ **Figure 7.** More-complex equipment is represented by simple line drawings.



▲ **Figure 8.** In a typical P&ID, circles represent individual instrument functions, and squares or diamonds represent panel-mounted and computerized functions.



▲ **Figure 9.** In this example of a pressure control loop, the system has both high and low alarms.

piping tagging, the Construction Industry Institute's PIP PIC001 standard, or a similar internal company standard, is often used. For instrumentation tagging, the most common is the ANSI/ISA-5.1 standard, or some variant thereof. This article employs the commonly used combination of the PIC001 and ANSI/ISA-5.1 tagging schemes. These two standards also define a set of popular symbols and line types for P&IDs.

Regardless of the tagging scheme, tags usually consist of several fragments that are assembled together to create a complete tag. In some schemes, tag fragments are separated by dashes; in others, no dashes are used. One widely used scheme is: facility code – site area code – equipment or instrumentation code. In some tagging schemes, additional fragments are added to show that instrumentation is associated with parent pieces of equipment. On individual P&ID drawings, either the entire tag or just the last tag fragment (with a note on the drawing stating the assumed prefixes) may be shown.

Equipment symbols and tagging

Figure 4 shows some common equipment symbols and tags. The equipment symbols are typically simple line drawings, and equipment tags have letter identifiers and a number. For example, in a letters-plus-number tagging scheme, a tank would be TK101, a heat exchanger HE56, a pump P103, an isolation valve XV117, and so on. In another tagging scheme, the type of service may be incorporated into the tag as well; the tag V-30560 consists of V for valve, 30 for process gas service, and 560 for the unique valve number.

Some ingenuity is required to develop symbols for different types of pumps (Figure 5) and valves (Figure 6). In each case, a baseline collection of symbols is slightly modified to show the possible variations in that equipment class. For more-complex equipment such as conveyors, screens, and distillation columns, simple line drawings (Figure 7) usually suffice.

Instrumentation symbols

Instrumentation symbols, and the tags that go with them, can be confusing to the uninitiated, but once mastered allow the reader to quickly and easily read any P&ID. Circles, often called bubbles or balloons, represent individual instrument functions, whereas squares and diamonds typically represent panel-mounted and computerized functions. Some of the most common circle, square, and diamond symbols for instrumentation are shown in Figure 8.

Figure 9 illustrates a 4-in. pipeline with a pressure control valve, pressure controller, and pressure transmitter, along with an unrelated pressure gage. The pressure control valve is indicated by a globe valve symbol (two triangles with a black dot the in the middle) and is tagged with the bubble PV102. The pressure control valve is controlled by a pressure controller (PIC102), and a dashed instrumentation line indicates the relationship between the two.

The pressure controller PIC102 is shown as a circle within a square to indicate that it is a combination display and controller; the single horizontal line in the square means that it is panel-mounted in the control room (the absence of such a line would indicate that it was located in the field). The letter I in the PIC102 tag stands for indicating — *i.e.,* it has a readout display. The pressure controller receives its process variable from the pressure transmitter (PT102), as denoted by the dashed line between them. The range of the pressure transmitter, shown beside the PT102 tag, is 0 to 150 psi. The pressure transmitter's tag does not have an I because the device does not have a local pressure readout. The pressure gage beside it is labelled PI104 to show that it is a pressure indicator.

Beside the pressure controller PIC102 in Figure 9 are two symbols — one is labelled PAH and the other PAL. These illustrate that the pressure controller has both a high-pressure alarm (PAH) and a low-pressure alarm (PAL). The depiction of alarms on P&IDs can vary depending on the segment of the CPI; in some sectors, alarm details are outlined in a plant's functional specification documents rather than shown on the P&IDs.

Instrumentation tagging

Instrumentation tags have two parts: a sequence of alphabetic codes and a loop number. When an instrument is tagged with an instrumentation circle on a P&ID, the alphabetic code appears on the top row and the loop number appears on the bottom. For example, a pressure indicating transmitter would be tagged PIT201 — PIT on the top row of the circle and 201 on the bottom row. The loop numbers (sometimes called sequence numbers) are unique for every process area.

The alphabetic portion of an instrumentation tag consists of several parts, each containing one or more letters. Table 1 shows some of the more commonly used letter codes. An instrumentation tag can include: the measured or initiating variable, an optional variable modifier, an optional readout/passive function, the output function, and an optional function modifier.

Table 1. Instrumentation identification letters are an important part of instrument tagging.

	First Letter		Succeeding Letters		
	Measured or Initiating Variable	Modifier	Readout or Passive Function	Output Function	Modifier
A	Analysis		Alarm		
C				Controller	
D		Differential			
E	Voltage			Sensing Element	
F	Flowrate	Ratio (Fraction)			
G			Sight glass		
H	Hand				High
I	Current		Indicator		
K		Rate of Change			
L	Level		Light		Low
M		Momentary			Middle
P	Pressure				
Q	Quantity	Integrate, Totalize	Point (Test) Connection		
R	Radiation		Recorder		
S	Speed	Safety		Switch	
T	Temperature				
V	Vibration			Valve, Damper	
Z	Position			Actuator	

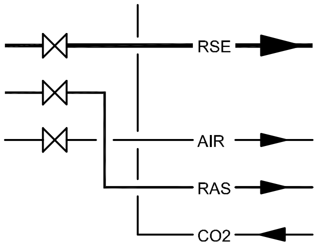
Measured or initiating variable. The measured or initiating variable represents the type of measurement the instrument performs. For example, in the tag PIT, the P refers to pressure. Other possible first letters include T for temperature, F for flow, and L for level. For chemical analyzers, A is commonly used as the first letter, and a flag is often added to the instrument circle to show what kind of analyzer it is. Therefore, an instrumentation circle containing the text AIT101 with a pH flag beside it would represent a pH analyzer that has local indication and transmits a signal back to the distributed control system (DCS).

Optional variable modifier. An optional variable modifier is used when a base measurement has an integrating, differentiating, or mathematical function applied to it. For example, a second letter of D in a tag stands for differential. Thus, an instrument that measures the temperature difference between two points could be tagged TDIT745 (where 745 is the loop number). Other possible second letters include F for ratio, K for rate of change, and Q for totalization.

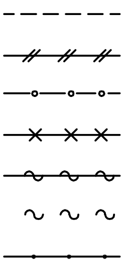
Optional readout or passive function. The most common optional passive function is indication, denoted by the letter I. Other passive functions include E for sensing element, G for sight glass, and R for recorder. Sometimes more than one optional passive function is shown. For example, a device with a tag of PIR201 would be a pressure indicating recorder for loop 201.

Output function and modifier. These terminating letter sequences can take on several formats. A terminating sequence that starts with an A represents an alarm, and typically has a suffix to indicate what type of alarm it is. For example, the tag FAH224 signifies a flow alarm – high, whereas LALL305 signifies a level alarm – low-low. Terminating sequences that start with an S after the measured or initiating variable usually indicate a switch. Thus, FSL205 is a low-flow switch, and TSH341 is a high-temperature switch.

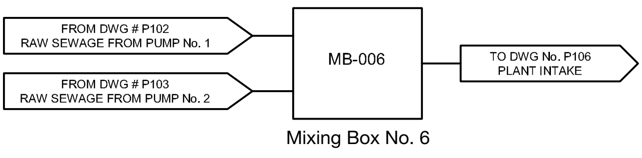
This article is not intended to be a detailed tutorial on instrumentation tagging, but these examples should give the reader a taste of how instrumentation tagging works.



▲ **Figure 10.** Line thickness and alphabetic coding denote piping size and service.



▲ **Figure 11.** Special line types denote instrumentation and control signals.



▲ **Figure 12.** Through the use of off-sheet connectors, large processes can be divided into several separate P&IDs.

Line types and connectors

Process and utility piping. On P&IDs, pipes are typically depicted as lines. Line thickness, and occasionally line color, is used to indicate whether the piping is for a primary flow path or a secondary connection (Figure 10). Flow direction is usually indicated by arrows, and pipe size is often shown either in piping tags or small labels. Piping on a P&ID may also have three-character abbreviations inserted at regular intervals on the drawing to indicate what the pipe is carrying.

In some parts of the CPI, piping tags are placed along the pipes to convey additional information about the piping, such as its service, size, piping material, wall thickness, and other physical characteristics. These tags usually consist of various alphanumeric fragments separated by dashes. For example, the piping tag 18-PG-60456-D2A-P1 may be interpreted as 18 = pipe diameter (in.), PG = process gas, 60 = gas subsystem identifier, 456 = line identifier, D2A = the piping specification code, P = class P polyethylene insulation, and 1 = insulation thickness (in.). The meanings of these codes would be described in other specification documents associated with the plant. Piping tags are usually industry- and site-specific.

Lines on P&IDs are not necessarily confined to just pipes. Special line styles may be used to represent other conveying means, such as open channels, ducting, long conveyors, and permanently attached hoses.

Instrumentation and control signals. Other special line types, such as those in Figure 11, are used for instrumentation and control signals. On a well-drawn P&ID, the types of instrumentation and control signals will be clearly shown and defined in a corresponding set of standardized legend drawings. Modern control systems often include a combination of electrical, pneumatic, and various other types of industrial network communications, which must all be clearly defined in order to avoid compatibility problems.

Off-sheet connectors. The last major component of P&IDs is the off-sheet connector. Off-sheet connectors link piping from one drawing to another. An example is shown in Figure 12. Through the use of off-sheet connectors, large processes can be divided into several separate P&IDs and utility connections to the processes can be shown. Off-sheet connectors are small, open, rectangular block arrows that typically contain text indicating the drawing that they link to plus a unique identifier to indicate their corresponding process connection on the other drawing. The unique identifier is usually a piping tag and process label for the flow path involved.

Using and maintaining drawing standards

It is important for every organization to establish good tagging, symbology, and drafting standards. Standards can take many forms. These can include referencing external standards documents, developing sets of typical drawings (*i.e.,* typicals), creating a set of standardized legend drawings, or developing written specifications. Often a combination works best. Only by laying down clear standards across the organization, and by making the standards available to all members of the project team, can the communication benefits of P&IDs, BFDs, and PFDs be fully realized.

Software for drawing P&IDs

Today, P&IDs and PFDs are almost exclusively drawn with the help of CAD software. Such software can range from a simple 2-dimensional drawing tool to a fully integrated 3D plant design suite. Most 2D drawing software has the advantage of being relatively inexpensive and fairly easy to use. Many packages also have libraries of reusable drawing blocks that greatly reduce drafting time. In addition, industry-standard commercially available drawing file formats now make exchanging 2D drawing files a relatively routine undertaking.

For larger process design projects or for designing entire plants, more-sophisticated drawing tools are often worth the investment. With these advanced tools, symbols on the P&ID can be assigned attributes and equipment and piping can be entered into a live database in the plant design software package. This database can then be used to generate a bill of materials, create instrument data sheets, assist with 3D pipe routing, and automatically create instrument loop drawings. Sophisticated plant design tools often have macros that automatically check for common design mistakes. The power and flexibility of these advanced software design tools continue to increase.

P&IDs as living documents

In order for P&IDs to be truly useful tools, it is imperative that they be kept up to date. Every time a plant's equipment is modified, whether during a planned upgrade or as a result of maintenance or operations activities, the corresponding P&IDs must also be reviewed and modified accordingly. Out-of-date P&IDs can lead to miscommunications, operational mistakes, and even accidents, as project personnel may be misled as to how a plant functions. To be effective communication tools and viable resources, P&IDs must always be kept updated to reflect the plant's current state.

Good drawings encourage good communication

BFDs, PFDs, and P&IDs are powerful tools that are used throughout the lifecycle of a plant. From designers and construction personnel to operations and maintenance staff, these drawings are vital communication tools that help every team member understand what a plant does and how it does it. P&IDs are also a key component in the larger group of engineering specifications and drawings that are used to design, build, operate, and maintain plants. By keeping the project team and its many diverse members in mind, today's process designer and instrumentation specialist can create a valuable coordinating document for the entire plant. CEP

Additional Reading

Construction Industries Institute, "Piping and Instrumentation Diagram Documentation Criteria," Process Industry Practices (PIP) PIC001, Univ. of Texas, Austin, TX (2008).

International Society of Automation, "Instrumentation Symbols and Identification," ANSI/ISA-5.1-2009, ISA, Research Triangle Park, NC (2009).

McAvinew, T., and R. Mulley, "Control System Documentation. Applying Symbols and Identification," 2nd ed., ISA, Research Triangle Park, NC (2004).

Meier, F., and C. Meier, "A Standard P&ID, Elusive as the Scarlet Pimpernel," presented at ISA TECH 1999, ISA, Research Triangle Park, NC (Oct. 5–7, 1999).

GRAHAM NASBY, P.E., PMP, (Phone: (519) 763-7774; Email: graham.nasby@eramosa.com) is a senior member of the International Society of Automation (ISA) and a licensed professional engineer who has worked in various industries, ranging from IT and software development to pharmaceuticals and semiconductor manufacturing. He currently designs automated control and monitoring systems for the municipal water and wastewater sector at Eramosa Engineering, Inc. He is also a contributing member of the ISA18 Alarm Management standards committee, and director-elect of the ISA's Water/Wastewater Industry Division. In 2011, he was named among *Control Engineering* magazine's Leaders Under 40, Class of 2011 award winners, and he received the ISA's Keith Otto Award for best article of the year in *InTech* magazine for his article entitled "SCADA Standardization."

Acknowledgments

The author thanks Associated Engineering for its assistance with the figures. He also thanks Joseph S. Alford and Thomas C. McAvinew for their assistance with reviewing and revising the draft manuscript.