Understand Pilot-Plant Design Specifications

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Although pilot- and commercial-scale plants may appear similar, they must be designed with different objectives in mind. Find out how the design criteria for pilot and commercial plants differ, and why commercial specifications should not be applied to pilot plants.

Pilot and demonstration plants can behave like, and even look like, large-scale commercial plants, just at a smaller scale. This misconception of sameness can lead engineers to design their pilot facilities with the same equipment and specifications as commercial-scale plants. However, while this choice may seem rational, considering that both types of plants need to be designed and fabricated in accordance with federal and local codes and standards, use the same engineering principles, and have similar electrical and control systems, this line of thinking is actually a trap that can deliver subpar research results and incur unnecessary expenses.

Contrary to the intuition of many engineers, commercial plant specifications should not be applied to pilot plants.

Pilot plants vs. commercial plants

The differences between the specifications for pilot plants and those for commercial plants can be attributed to their different objectives. Pilot plants are designed and built so that engineers can learn more about a process to make decisions regarding new technologies or other process configurations. Data collection is central to achieving this goal, as it provides process engineers with boundary conditions for scale-up. Pilot plants expose potential problems, and allow alternative solutions to be engineered and tested before continuing to scale up or transferring technology to full-scale operation.

To achieve its purpose, a pilot plant needs to be flexible and adaptable so that operators can quickly make modifications to test configurations and operating conditions to establish optimal operation. Owners of pilot plants are less concerned with efficiency of operation and more so with proof of concept. For example, recovering heat from hot streams is not required, nor is it practical; instead, controlling the reactor temperature is the critical issue. Though commercial-scale operations run continuously with a few weeks of shutdown per year, pilot plants operate intermittently for one to ten days a campaign.

Commercial plants are built to produce a set volume of a well-defined product of consistent quality to maximize profits. To achieve economies of scale, the plants are large and typically require a high capital investment, which incurs high fixed operating costs in the form of depreciation. Operating at a high utilization maximizes the value of the assets, which controls costs and protects profit margins. Because quality is an important component of maintaining strong sales, standard procedures that break tasks into discrete steps — that are reproducible and uniform — are implemented.

Assuming sales and the order backlogs are stable, it is the responsibility of plant management to ensure that

Table 1. Pilot-plant and commercial-plant objectives are different, so the specifications used to design them should also be different.

Pilot-Plant Objectives	Commercial-Plant Objectives
• Collect data to aid in scale-up	• Produce product to maximize revenue and minimize costs
• Accurately model the full-scale process at a smaller scale to obtain representative results	• Maintain consistent and reproducible product quality
• Expose problems and try alternative solutions	• Maintain efficient operation
• Assess the effect of the buildup of impurities in recycle streams	• Use resources efficiently
• Test multiple configurations and operating conditions	• Reduce costs through preventive maintenance
• Maintain flexibility for frequent reconfigurations	• Troubleshoot without shutting down
• Enable easy startup and shutdown	• Account for continuous operation
• Account for intermittent operation	

▲ **Figure 1.** Different control valve positioners can be added to (a) a simple control valve, such as (b) a mechano-pneumatic positioner or (c) an electro-pneumatic positioner, but they can drastically increase the cost. Because pilot plants shut down regularly and their footprint is generally small, expensive control valve positioners are not necessary. Photos courtesy of Badger Meter (a, b) and Emerson Process Management (c).

the plant is well maintained to maximize uptime. Unlike pilot-scale operations, preventive and predictive maintenance is paramount. In commercial plants, plant layouts can be sprawling, necessitating the need for smart devices to alert personnel when equipment replacement is required. Controlling costs is equally as important as maintaining the plant. Some methods of cost control include: recycling solvents and gases that can be reused, recovering heat from effluent streams, and capitalizing on the energy value of waste gases.

Design criteria

Design specifications for pilot plants are primarily driven by the need for flexibility and representative data collection. Flexibility allows the order of unit operations to be reconfigured, new unit operations to be added, and a range of operating conditions to be tested. Other criteria that help define design specifications for pilot plants include:

• complete design and fabrication quickly to minimize time to market

• maintain the accuracy of small-scale metering and measurements

• minimize the layout space of the plant

• represent process conditions accurately

• ensure the system is safe

• minimize the cost of the system.

These criteria are often very different from those that drive the specifications for commercial plants, which underlines how misguided it is to apply commercial specifications to pilot plants (Table 1). The examples that follow detail situations where commercial specifications are unnecessarily or incorrectly imposed on pilot plants.

Control valve positioners

The objective of a commercial plant is to gain economies of scale and keep the process running for as long as possible, while minimizing operational costs. Preventive maintenance greatly contributes to effective control of a plant's efficiency, and replacing parts at the optimal point in an instrument's lifecycle can prevent more-costly repairs in the future, as well as downtime. This explains why an electro-pneumatic positioner would be used for a commercial-plant application. In this context, the diagnostic capabilities offered by smart control valve positioners can have a huge payback.

But in the context of a pilot plant, the payback is less clear and the value is questionable (Figure 1). Pilot plants typically run for one to ten days a campaign and are shut down at regular intervals, during which preventive maintenance tasks can be accomplished. Provided that the control valve can accurately maintain the desired output, the "smartness" of the positioner should not matter. Also, since the total footprint of a pilot plant is small and distances across the entire plant are short, operators can easily inspect a valve's stem position visually to confirm whether trims are working properly or need to be replaced.

Figure 1 shows three control valve positioner options with different levels of complexity and cost. The valve with no positioner would cost approximately $1,000. With the mechano-pneumatic positioner added, the cost increases by about $500 to $700. The cost of the total valve assembly could easily jump to more than $2,000 by adding the electro-pneumatic positioner. In most pilot plants, especially for processes with mild pressures and temperatures and low flowrates, valves without expensive positioners can be installed to minimize costs.

Piping

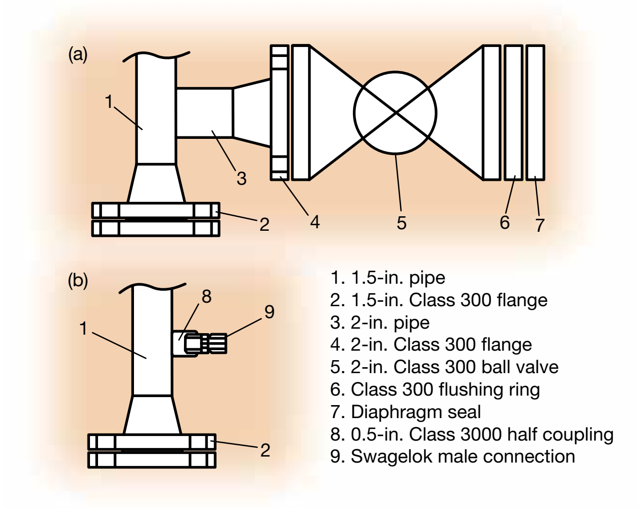
Figure 2a illustrates a situation in which a piping specification for a commercial plant has been inappropriately applied to measure differential pressure across a 1.5-in.-dia. pilot-plant reactor that is 40 ft long. The specification calls for a 2-in. Class 300 flanged nozzle with a Class 300 ball valve, a flushing ring, and a diaphragm seal. The volume of the assembly is a significant volume of the reactor, and although it does not necessarily contribute to increased residence time, the assembly creates dead space where a large volume of reactants can accumulate, which can affect product quality. Temperature would also be difficult to control because the volume of the assembly is about one-third of the volume of the reactor.

The appropriate pilot-scale solution is to replace the entire assembly with a Class 3000 half coupling and a compression fitting (Figure 2b). This minimizes the dead volume and allows for easier control of the reactor temperature profile, which provides more representative data and a higher-quality product. Operators are able to disassemble these types of fittings more quickly with less effort, enhancing the flexibility of the setup. Minimizing the size and number of fittings used throughout the plant lowers costs.

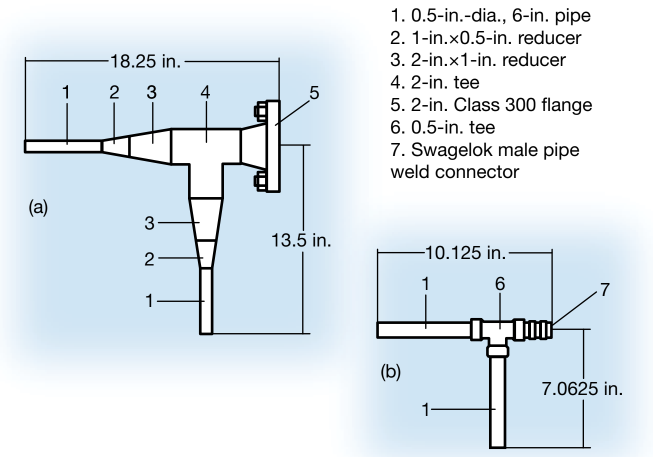
Thermowells

Owners of pilot plants commonly request that a thermowell be included in a process line that requires temperature measurement, but this specification is inappropriate for pilot plants. Thermowells are typically used in full-scale commercial plants; when a thermocouple within a thermowell fails, the thermocouple can be easily replaced without the need for production interruptions and draining of the piping or vessel. Commercial processes will run at equilibrium for long periods of time with very few changes in process conditions. In this environment, a thermocouple within a thermowell will accurately represent the process fluid temperature.

However, a large flanged thermowell will introduce residence time issues in pilot plants, which have smaller lines. In Figure 3a, the pilot-plant piping needs to be expanded to accommodate the bulky thermowell. The time to achieve equilibrium following a temperature change will be significantly delayed at the pilot-plant scale because the



▲ **Figure 2.** (a) When piping specifications for a commercial plant are applied to measure differential pressure across a pilot-scale reactor, the incompatible piping creates a large dead volume that affects product quality and the ability to control temperature. (b) Replacing the entire assembly with a smaller-scale solution minimizes the dead volume and helps to control the reactor temperature profile.



▲ **Figure 3.** (a) Large flanged thermowells introduce residence time issues in pilot plants, which have smaller piping. (b) Swaging the thermocouple directly into the process line is a more appropriate and scale-specific method of temperature measurement that lowers residence time because of the smaller volume.

Mechanical technicians can install flexible tubing lines in a fraction of the time it takes to install an equivalent metal line, which reduces costs.

bulky assembly produces low process fluid velocities and a high volume relative to the flowrate. This will adversely affect temperature and quality control.

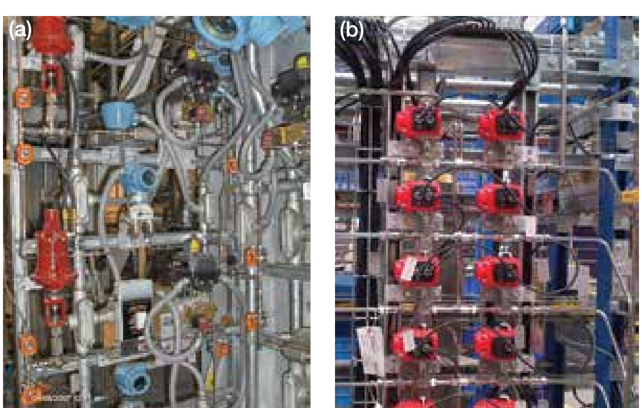
The best solution at this scale is the use of a thermocouple by itself without a thermowell. Nonfunctioning thermocouples can be changed out during a planned shutdown. In Figure 3b, the thermocouple is swaged directly into the process line, which is a more elegant, scale-specific method of temperature measurement. Temperature changes are more responsive and the smaller volume creates a lower residence time and enables better control.

There are instances where thermowells are useful at the pilot scale, but a more scale-appropriate tubing-style thermowell can be designed. In this case, an expansion in the tubing will still be required to accommodate the thermowell, but it will not be as bulky as the expansion shown in Figure 3a.

Modification and flexibility

Figure 4 shows two types of valve banks and instrumentation that could be considered for a pilot facility: a bank of valves and instrumentation that are installed with metal tubing and electrical conduit; and a bank of automatic valves that are actuated through plastic air lines and push-type quick-release fittings. However, the latter is more appropriate for pilot plants.

The plastic lines will facilitate flexibility, allowing the system to be reconfigured or modified quickly. Furthermore, this system is equally as safe as the metal-tubing installation — if a fire were to occur in the plant, the plastic lines would melt, releasing air from the actuators and causing the valves to fail to the safe position. Mechanical technicians can install flexible tubing lines in a fraction of the time it takes to install an equivalent metal line, which reduces costs. If a new instrument were to be added to the assembly in Figure 4a, a stainless steel tubing line would need to be run between the air header and the new instrument, which would cost more and take more time to install compared to the costs and time required to add that same instrument to the assembly in Figure 4b.



▲ **Figure 4.** (a) Banks of valves and instrumentation installed with metal tubing and electrical conduit are expensive and difficult to alter if additional equipment or connections are needed. (b) Valves connected via plastic air lines and push-type quick-release fittings are less expensive, easier to install and change, and do not compromise safety.

Closing thoughts

There are many more examples where commercial-scale specifications have been inappropriately applied to pilot plants beyond the four described in this article *(1)*. Specifications for commercial-scale operations often involve welded pipe and the American National Standards Institute (ANSI) flanges, whereas tubing can be substituted in most instances at the pilot scale. Unique pilot-plant specifications reduce layout space and costs, and improve product quality.

Before initiating a pilot-plant project, the project management team should review the objectives of the plant and choose criteria for specifications that are aligned with those objectives. Ideally, specifications should be written specifically for each project. However, if that is not possible, the next best scenario is to exclude commercial specifications and follow codes, standards, and best practices for pilot plants, and incorporate only logical specifications that have solid support for inclusion. Applying these principles to your next pilot-plant project will lower costs and improve performance. CEP

Literature Cited

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