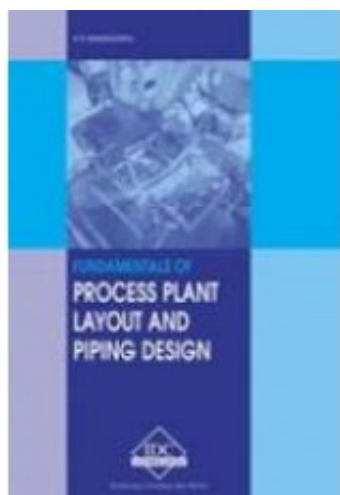


# PT-E - Fundamentals of Process Plant Layout and Piping Design



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## **Short Description**

Plants, such as refineries and petrochemical plants, are complex facilities consisting of equipment, piping systems, instruments, electrical systems, electronics, computers, and control systems. The design, engineering and construction of process plants involve a multidisciplinary team effort. Plant layout and design of piping systems constitute a major part of the design and engineering effort. The objective is to design safe and dependable processing facilities in a cost effective manner.

This manual will cover the fundamental principles and concepts used in process plant layout and piping design. It will provide you with a clear understanding of the design and engineering principles used in plant layout and piping design.

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## **First Chapter**

### **Chapter 1: Introduction to Process Plant Layout and Piping Design**

1

#### **Introduction to Process Plant Layout and Piping Design**

*This chapter provides a brief introduction to Process Plant Layout and Piping Design. The fundamental aspects of process plant layout and piping design are discussed. An overview of the procedures and workflow methods used in plant layout and piping design is also provided and the physical quantities and units commonly used are presented.*

#### **Learning objectives**

- Understanding the fundamental aspects of process plants, plant layout and piping design.
- Understanding the procedures and the workflow methods used in designing process plants and piping systems.
- Understanding the physical quantities and units used in process plant layout and piping design.

#### **1.1 Plant layout fundamentals**

Process plants encompass all types of facilities involved in the chemical/physical

processing of raw materials into desired finished products or intermediates for further processing. Examples of such processing facilities include the following:

- 
- Chemical/Petrochemical Plants.
- Fertilizer Plants.
- Offshore Processing Facilities.
- Power Plants.
- Pulp and Paper Mills.
- Food/Beverage Industries.
- Pharmaceutical Plants.
- Water Treatment Plants.
- Waste Treatment Facilities.

The processing facilities included in the preceding list play a vital role in meeting the basic needs of humanity. Therefore, a proper design, maintenance and operation of such facilities is necessary to ensure steady, dependable supply of materials and products required for comfortable and productive living in the contemporary modern world.

Process plants are complex facilities consisting of equipment, piping systems, instruments, electrical systems, electronics, computers and control systems. Figure 1.1 is a picture of a section of a refinery that illustrates the complexity of the equipment, piping and other entities.

### **Figure 1.1**

*A small section of a refinery showing equipment, piping system and other items.*

The design of process plants is a complex team effort involving different disciplines of engineering: process (chemical), mechanical, piping, electrical, instrumentation, controls, materials and project. It also requires considerable management and coordination skills.

The objective is to design and construct a plant in a cost-effective manner that will meet the process requirements and client specifications and that will operate in a safe reliable manner. Other factors to be considered in the design of process plants are:

- Short design, engineering and construction schedules and getting the plant on stream as quickly as possible.
- Minimizing or even eliminating field rework, which significantly increases plant construction costs.
- 
- 
- Satisfying environmental requirements.
- Minimizing costs.

Figure 1.2 illustrates the interaction and teamwork between different disciplines in the plant layout and piping design effort.

## **Figure 1.2**

*Plant Design and Piping Design Effort – Contributions from different disciplines*

### **Tasks involved in plant layout and piping design**

Plant Layout and Piping Design involve multiple tasks, which include:

- Development and refinement of “Plot Plans”. Plot plans are representations of precise location of equipment and their associated infrastructure (foundations, ladders, platforms etc.). Plot plans are developed taking into consideration process, client and safety requirements. Plant coordinates are used extensively in specifying equipment locations. Plot plans are discussed in more detail in Chapter 4.
- Establishing equipment nozzle locations. Nozzles are components of equipment that connect to pipe.
- Routing of pipes. This is a dynamic and iterative process until the equipment and nozzle locations are finalized.
- Designing equipment ancillaries such as foundations, platforms, and stairways.
- Location of safety equipment such as fire hydrants and safety showers.
- Being cognizant of the location of structures, instruments, control valves, electrical raceways and miscellaneous plant items while routing pipe.

## The salient skills and qualities required for plant layout and piping design are as follows:

- Sufficient knowledge of the process being used including function of each equipment. This information is obtained from the process group in the form of “Process Flow Diagrams (PFDs)”. PFDs are discussed in detail in Chapter 2.
- Knowledge of the operating and maintenance procedures used for equipment.
- Common sense and attention to detail.
- Ability to think creatively to solve layout problems and challenges.
- Ability to think and visualize spatial relationships between plant items in three dimensions.
- Ability to effectively use computer tools such as 3D modeling software and pipe stress analysis software.
- Excellent communication skills.
- Ability to function effectively as a member of a multi-disciplinary project team.
- Effectively communicate and resolve layout issues and problems with project management.
- Ability to produce, maintain and update project drawings and documents.
- Awareness that conscientious, quality effort during the design and engineering phase can shorten project schedules resulting in economic benefits and client goodwill.

## Data used in plant layout and piping design

Massive amounts of data is generated and used in plant layout and piping design. Proper management of plant data is necessary to ensure data accessibility and data integrity, which in turn contributes to the overall quality of the project. Plant data can be classified into three categories.

- **Project data** consists of information such as plant location, local codes and regulations, access roads, waterways, railways, seismic conditions, climate data (average temperature, wind speed and direction, and rainfall).
- **Design and engineering data** is internally generated during the design and engineering phases of the project. Examples of such data include equipment sizes, service conditions (temperature, pressure etc.), and mass flow rates.

- **Vendor data** consists of information provided by equipment vendors by means of vendor drawings and data sheets.

## **Rules of thumb for plant layout and piping design**

The approach to plant layout and piping design can vary depending on the nature of the plant and the project. For example, the design philosophy for an offshore facility is quite different from that for an onshore chemical plant simply because of limited space available on offshore platforms. However, there are a few useful rules of thumb that can be followed.

- Knowledge and understanding of project requirements and project documents.
- Conservation of space and resources.
- Arrangement of equipment in a neat, organized manner taking into account process needs and safety.
- Attention to detail including adjacent equipment, supports and other items, which can cause potential clashes between piping and equipment/supports.
- Consideration of constructability, operability and maintainability of the plant.
- Routing of pipe in a neat, orderly and symmetrical manner keeping in mind the future needs of the plant.
- Avoiding excessive changes in elevations and directions.
- Ensuring consistency in design.
- Avoiding excessive amounts of relocations and revisions by “doing it right the first time”.

## **Common abbreviations used in plant layout and piping design**

- N,S,E,W: North, South, East and West
- CL: Centerline
- El: Elevation
- TOS: Top of Steel
- BOP: Bottom of Pipe
- POS: Point of Support
- BBP: Bottom of Baseplate
- ISBL: Inside Battery Limits

- OSBL: Outside Battery Limits
- AG: Above Ground
- UG: Underground
- f: Diameter
- OD: Outside Diameter of pipe
- ID: Inside Diameter of pipe
- TL: Tangent Line
- TYP: Typical
- PFD: Process Flow Diagram
- P&ID: Piping and Instrumentation Diagram

Abbreviations used in PFDs and P&IDs are explained in Chapters 2 and 5 respectively.

## 1.2 Procedures and workflow methods used in plant layout and piping design

**Front end engineering and design:** The complex task of designing and building process plants consists of several phases – design, engineering, procurement and construction. The design phase itself consists of conceptual design, design study and detailed design. The conceptual design phase starts with the Process Flow Diagram (PFD) and client specifications. The project scope is also defined during this phase. The working documents used during this phase are the PFD and the Conceptual Plot Plan. Based on the PFD, a large chemical plant or offshore production facility is sub-divided into several small, manageable areas. A Plot Plan is then generated for each area. Boundary limits for each area are specified using spatial coordinates. The boundaries are known as match lines and play an important role in combining the smaller areas. In offshore platforms, plot plans are generated for each deck of the platform. The outcome of the conceptual design phase is usually preliminary sizes and locations of major equipment, which results in the plot plan for use during the design study phase.

The design study phase plot plan is reviewed and discussed by the client and by the project disciplines. Vessel supports and ancillaries are located during this phase. Preliminary routing of major lines also takes place during this phase. The outcome of the design study phase is a final plot plan and a preliminary Piping & Instrumentation Diagram (P&ID). The P&ID contains details and specifications of all equipment, piping, fittings, instrumentation and control valves. The P&ID also contains references to detailed drawings of equipment. The P&ID serves as the primary reference document in communication between engineering and design

personnel in all disciplines. Thus, the P&ID is an important working document in the design and engineering of process plants and piping systems. The final plot plan and the P&ID must be approved by all disciplines including safety and loss control.

The conceptual design and design study phases together constitute the Front End Engineering and Design (FEED) phase of the project. The P&ID, plot plans and elevations are used in building a three dimensional electronic model of the process plant. This 3-D model will contain all the components of the plant including equipment, piping, fittings, control stations and support structures. In recent years, the ability to build 3-D electronic models has been greatly enhanced due to advancements in computer hardware and software.

**Detailed design and engineering:** The FEED phase is followed by the detailed design and engineering phase where every piece of equipment and every component of piping systems is finalized and specified for procurement. During this phase, piping isometric drawings known as “Issued-For Design (IFD)” drawings are generated for analysis and comment by piping engineers and engineers from other disciplines whose input is required. The IFD drawings are pictorial representations of the piping system and allied components containing all dimensional information. Piping engineers primarily use the IFD drawings for the following purposes:

- **Pipe Stress Analysis:** The piping systems are analyzed for stress and load to ensure that the pipes are not overstressed (both under installed and operating conditions) and are adequately supported. In many cases, piping systems need to have enough flexibility to allow for thermal expansion. Pipe stress analysis also includes computing loads and stresses on equipment nozzles and ensuring that they are within the allowable limits specified by applicable standards and codes. Pipe stress analysis is performed with the aid of stress analysis software.
- **Code compliance:** The code that governs the design of piping systems for process plants is ASME B31.3: Process Piping. Piping engineers are responsible for interpreting the code using sound engineering judgment to ensure that the proposed design meets the code requirements.
- **Piping material specifications:** The piping engineer is responsible for specifying appropriate materials for the pipes. In accomplishing this task, the piping engineer takes into account operating conditions such as the pressure and temperature and also the chemical nature of the fluid being transported. Piping material specification is a very time consuming task but it is very important to specify the right material to ensure the safe and efficient operation of the plant.



The 3-D model is an extremely useful design tool that can be used by all disciplines during the detailed design and engineering phase. The 3-D model is constantly referenced during design review meetings and discussions. These meetings occur frequently and involve all the engineering disciplines and the client. The 3-D model is also useful in clash detection and interference checking. This process saves considerable money and effort by minimizing field rework and field rerouting of pipes. An engineering database is also generated as part of the electronic model. This database is useful in purchasing and procurement functions. As the design is reviewed and updated, so is the 3-D model.

After the detailed design and engineering phase, piping isometric fabrication drawings (also known as spool drawings) along with material specifications are issued for creating the required piping spools. Simultaneously, procurement lists are generated for fittings, instrumentation and other items in the piping system from the engineering database. The procurement lists are used for purchasing the items and contain all the information required to accomplish this task. The procurement lists are also known as “Bill of Materials (BOM)” or “Material Take-off”.

Foundations, structural members and major equipment are put in place using civil/structural drawings, equipment drawings, the 3-D model and other documents. Now the stage is set for the installation of the piping system. Drawings and documents known as “Issued for Construction (IFC)” are used for this purpose. Construction personnel assemble and install the piping system by using IFC drawings and documents.

Figure 1.3 illustrates the workflow methods used in process plant layout and piping design. It should be noted that workflow methods could vary depending on client and company preferences. It should also be noted that the entire process is iterative in nature. There is continuous interaction between the different phases of the project.

### **Figure 1.3**

*Procedures and Workflow Methods Used in Plant Layout and Piping Design*

**Organizations involved in providing standards and guidelines for plant layout and piping design**

Some of the organizations that provide standards and guidelines for plant layout and piping design are listed here along with their web addresses.

- American Society for Mechanical Engineers (ASME): Publishes and updates codes for piping design. The code relevant to the design of piping systems is **ASME B31.3 – 2004 Process Piping**. ([asme.org](http://asme.org))
- Center for Chemical Process Safety (CCPS): Publishes documents and guidelines related to process safety. The focus is on preventing or mitigating catastrophic releases of chemicals, hydrocarbons, and other hazardous materials. CCPS has published guidelines for “Facility Siting and Layout”. ([aiche.org/ccps](http://aiche.org/ccps))
- Construction Industry Institute (CII): Provides guidelines for cost effective and safe construction methods and has several publications on constructability. ([construction-institute.org](http://construction-institute.org))
- Society of Piping Engineers and Designers (SPED): Promotes excellence and quality in the practice of piping engineering and design. SPED emphasizes education and training and has certification programs for piping designers. ([spedweb.org](http://spedweb.org))
- Occupational Safety and Health Administration (OSHA): Provides regulations and safety standards for the operation of process plants. ([osha.gov](http://osha.gov))
- National Fire Protection Association (NFPA): Provides fire protection standards for process plants and for gas storage and handling. ([nfpa.org](http://nfpa.org))

### 1.3 Physical quantities and units in plant layout and piping design

The physical quantities and units used in plant layout and piping design are summarized in Table 1.1. The units are specified both in the SI System and in the US Customary System (USCS).

**Table 1.1**

*Physical Quantities and Units Used in Plant Layout and Piping Design*

Physical	Symbol	SI System	USCS
<b>Quantity</b>			
Length	L	Meter (m)	Feet (ft)
Diameter	D	Millimeter (mm)	Inch (in)
Thickness	?x	Millimeter (mm)	Inch (in)

Mass	m	Kilogram (kg)	Pound mass (lbm)
Time	t	Seconds (s)	Seconds (sec)
Temperature	T	Degree Celcius (°C)	Degree Farenheit (°F)
Area	A	Square meter (m <sup>2</sup> )	Square feet (ft <sup>2</sup> )
Volume	V	Cubic meter (m <sup>3</sup> )	Cubic feet (ft <sup>3</sup> )
Velocity	v	Meters/sec (m/s)	Feet/sec (ft/sec)
Acceleration	a	Meters/sec <sup>2</sup> (m/s <sup>2</sup> )	Feet/sec <sup>2</sup> (ft/sec <sup>2</sup> )
Force	F	Newton (N)	Pound force (lbf)
Pressure	P	Pascal (Pa)	Pounds/in <sup>2</sup> (psi)
Stress	s	Megapascal (Mpa)	Pounds/in <sup>2</sup> (psi)
Strain	?	Mm/mm	in/in
Work	W	Newton-meter (N.m)	Foot pound force (ft-lbf)
Energy	E	Joule (J)	British thermal unit (Btu)
Energy flow		kilowatts (kW)	Btu/sec or Btu/hr
Enthalpy	H	kilojoules (kJ)	Btu
Mass flow		kg/s	Lbm/sec
Volume flow		m <sup>3</sup> /s	ft <sup>3</sup> /sec

Notes: The unit of force in the SI system is Newton (N). A Newton is defined as the force required to produce an acceleration of 1 m/s<sup>2</sup> on a body of mass 1 kg. The unit of force in the US Customary System (USCS) is Pound force (lbf). One pound force is the force required to accelerate 1 lbm at 32.2 ft/sec<sup>2</sup>. This leads to the use of a conversion constant,  $g_c$  in USCS. The following equations are useful in understanding the units of different physical quantities.

Unit Prefixes:

$$\text{kilo (k)} = 10^3$$

$$\text{Mega (M)} = 10^6$$

$$\text{Giga (G)} = 10^9$$

$$\text{milli (m)} = 10^{-3}$$

$$\text{micro (}\mu\text{)} = 10^{-6}$$

$$\text{nano (n)} = 10^{-9}$$

## Figure 1.4

*Workflow model*

### 1.4 Summary

The objective of process plant layout and piping design activities is to design and construct a plant in a cost-effective manner that will meet the process requirements and client specifications and will operate in a safe, reliable manner. This chapter provides an understanding of the tasks involved and the skills required in these activities. It also provides brief guidelines for plant layout including some general rules of thumb. In addition to adequate and safe design, designers and engineers must consider issues such as constructability, maintainability and operability of a process plant. An overview of the tools, documents, workflow methods and procedures used in plant layout and piping design is also included in this chapter. Organizations that provide guidelines for plant layout and piping design are mentioned in this chapter along with their web addresses. Physical quantities typically used in plant layout and piping design are discussed along with their units both in the SI System and the US Customary System (USCS).

## Fundamentals of Process Plant Layout and Piping Design

### Practical Exercise 1

1. What are the main tasks of a plant layout designer? (Name just three)
  
2. Select the correct order of progress during a project.
3. Conceptual Plan, PFD, P&ID, Plot Plan.
4. PFD, Conceptual Plan, Plot Plan, P&ID.
5. PFD, P&ID, Conceptual Plan, Plot Plan.
6. Plot Plan, PFD, Conceptual Plan, P&ID.
  
3. Besides the design and engineering phases of a project, what other aspects of the project should a good designer be concerned about? Explain.
  
4. Expand the following abbreviations:
5. IFD:
6. TOS:
7. PFD:
8. ANSI:
  
5. Psi stands for \_\_\_\_\_ and is a unit of \_\_\_\_\_ and kPa stands for \_\_\_\_\_.
  
6. The unit of pipe stress in the SI system is \_\_\_\_\_.
  
7. The unit of force in the US customary system is \_\_\_\_\_.
  
8. What are the possible consequences of not knowing maintenance

requirements for a particular piece of equipment?