PLANT LAYOUT

1. Introduction

Plant layout can be the single most important part of the overall design. A good layout can result in significant savings amounting to millions of dollars in erected plant cost. A layout can make the difference between a facility that is easy to operate and maintain, and a plant that is a nightmare. This article presents an overview of the many concepts that go into a good layout and includes a step-by- step procedure to aid the designer in developing the layout. A list of commonly used layout terms with the corresponding definitions is provided. A discussion of the particular equipment layout requirement is also included. Many layout considerations are concerned with the piperack, which is the arterial system of a plant. There are several different modeling concepts, including plastic scale models, three- dimensional (3D) computer-aided design (CAD) models, and isometric and orthographic presentations.

2. Definitions

Battery limit defines the boundary of the unit equipment, which is used in a processing facility, by an imaginary line that completely encompasses the defined site. The term distinguishes areas of responsibility and defines the processing facility for the required scope of work.

Inside battery limit (ISBL) is the limit of the processing facility and the equipment contained therein.

Outside battery limit (OSBL) defines the work and responsibilities outside the battery limit. The OSBL includes auxiliaries required for the chemical process unit, including tank storage for feedstock and refined products, waste treatment, cooling towers, flares, and utilities that are not included in the battery limit, but are required for the unit. Also included are the pipeways, racks, and sleepers, which are used to convey all of the utility‘s interconnecting process piping to and from the processing facility.

Plot plan is the scaled plan drawing of the processing facility.

Site plan is a scaled drawing, including the roadway system for adjacent areas and auxiliaries and the space requirements for the processing facility.

Piperack is the elevated supporting structure used to convey piping between equipment. This structure is also utilized for cable trays associated with electric power distribution and for instrument trays.

Sleepers comprise the grade-level supporting structure for piping between equipment for facilities to tank farms or other remote areas.

Paving is the surface preparation in a processing facility which may be concrete, asphalt, gravel, crushed shell, or brick.

Equipment-handling facilities include any device used to convey or temporarily support equipment, or provide access for plant maintenance, eg, portable ladders, davits, A-frames, monorails, forklift vehicles, and cranes.

Alloy piping comprises all piping that is stainless steel, carbon–molybdenum, or chrome alloys.

Shutdown or turnaround is the period when an operating plant or a significant portion of it is out of service, during which replacement of catalyst, mist eliminator pads, or sections of piping; repairs to rotating equipment; or cleaning of exchangers is performed. Generally, a shutdown or turnaround is any period during which production is curtailed and maintenance is necessary.

3. Importance of a Good Layout

Once the process design optimization has been completed, it is estimated that $> 75\%$ of the capital cost has been established. The next significant cost-controlling opportunity is in the selection and purchasing of the equipment, which depends on having a good set of equipment data sheets and general specifications that define the level of equipment quality desired. After purchasing has been initiated, the next area in which substantial plant cost savings can still be realized, or lost, is in the plant layout. The plant layout also has profound implications on both the operability and maintainability of the plant. Obtaining the recommendation of an experienced layout consultant in the early phases of the design can make the difference between a highly successful and a bad project.

Equipment layout and the design of the associated piperacks are critical elements of the plant design and require interfacing among many disciplines, including operational and maintenance staffs, as well as various design disciplines. Low plant cost is favored by a tightly spaced layout; operations and maintenance (qv) are favored by a more spread-out layout. A compromise between these two extremes needs to be reached early in the process. Some high pressure alloy piping can easily run $> \$1000$ a linear foot. Pipe fittings can be even more expensive. Shutdown time can also be costly, running into hundreds of thousands of dollars per day in lost product revenues when the plant is shut down for maintenance. Providing adequate maintenance space for quick turnarounds can help reduce the down- time cost.

The reengineering cost for making design modifications as a result of moving equipment after the design layout has been started can be expensive. A firm layout can help keep changes to engineering design to a minimum. It is important to spend a little extra time early in the design to get the equipment located and spaced so that it does not have to be moved in the middle of the design. This keeps engineering on schedule and costs within budget. For this reason, it is undesirable to squeeze equipment together too closely in the early part of the design and then to have to spread it out at a later time. A good layout engineer or designer can help provide realistic spacing and select equipment locations that do not need to be changed throughout the design.

A cost-effective layout that provides for easy operability and quick turnarounds is often designed by someone with a background in the piping discipline. This is most likely because of their ability to think in 3D and their familiarity with visualizing 3D piping (see Piping systems).

The layout can only be started after a process flow diagram is available. The process flow diagram includes information, eg, the principal equipment items and order of the process flow. A sized equipment list is also useful from the standpoint of knowing what spaces are required to fit the equipment. Availability of a preliminary piping and instrumentation drawing (P & ID) provides more information to aid in spacing equipment and thinking about piperack requirements.

Development of a preliminary layout requires the following information: (*1*) process flow diagrams; (*2*) plot limits; (*3*) process unit rough area requirements; (*4*) storage and tankage requirements; (*5*) expected expansion requirements; (*6*) waste treating area, usually located at the low point of the plot; (*7*) rerun and product storage location (preferably close to process unit); (*8*) locations of roads, rail spurs, and pipeline tie-in points; (*9*) product and blending area (best if located close to product sales loading area); (*10*) product tankage and loading (should be located near blending); (*11*) plant roads and access ways for considerations of maintenance access and plant constructability; (*12*) utility and steam generators (should be adjacent to process plot) if a significant requirement exists; and (*13*) cooling towers and electrical distribution substations (must be at plot periphery).

4. Plot Plans

Figure 1 shows an overall plot plan for a grassroots plant. A grassroots plant design differs from a retrofit design in that it allows the designers full latitude in the plant layout and subjects only them to the overall limitations of the new plant site boundaries and safety-in-design considerations. The process facilities usually occupy a small fraction of the overall plant site area, typically ~25%. However, the process facilities generally cost about one-half of the overall plant expenditure and the off sites cost the other one-half. Most petrochemical facilities provide large plot areas for feed and product storage. Feed storage is usually at least 30 days, and product storage can be 60 days or more. Tankage can be quite spread out due to diking requirements for fire control containment of fluids for safety reasons. Space also needs to be provided for all the other facilities that are required to make a plant self-sufficient. These facilities include general office space; parking for employees and contractors; engineering services offices; laboratories; wastewater-treating facilities; product loading racks; shops; warehouses; fire stations; laydown areas for construction; off sites, including boilers, water treating, cooling towers, and electrical distribution; change rooms; railroad spurs; control room; and safety headquarters and equipment. These need to be laid out in a logical manner that considers site terrain, accessibility to roads, soil bearing capability of land, and the climate, including wind directions, winter conditions, hurricanes, and other unusual weather conditions.

Few grassroots facilities, however, are being built in the 2000s. Most companies are adding on to or expanding their existing facilities. These projects are often more challenging because space limitations can frequently be the limiting considerations. Part of a good grassroots layout is to consider what the requirements for future expansion might be, and to provide not only the space anticipated within individual units for expansion and for debottlenecking, but also open areas in the overall site for the addition of new process units. Access to utilities and tie-ins in existing piperacks are critical to avoid moving existing facilities and prevent costly shutdowns in order to provide for new additions.

The preliminary plot plan is the first step in the layout process. The plot plan shows the location of the following items that are known or approximated: main equipment, main pipeway, major structures, housed electrical switch, control room, and tie-in connection locations. Individual unit plot plans may also need to be developed. The scale is often increased on the unit plot plans to make it easier to read. By using a CAD system, unit plot plans are easily developed from the plot plan file. Unit plot plans are necessary, mainly as background information, for such uses as equipment location plan drawings, foundation locations, excavation drawings, paving plan drawings, fire system, underground drawings, and shop model concept. The overall plot plans are usually drawn to scale one- eighth in. ft^{-1}(1 mm/m).

4.1. Initial Sketch. Figure 2 shows a process flow diagram for a petrochemical plant (1,2). This drawing shows the feed and products so the designer knows what to allow for these lines in the interunit pipeway routing. The process engineer has indicated with notes that pieces of equipment will be located in elevated structures, eg, the overhead condensers, and has also shown which equipment should be located close by other equipment, eg, the reboiler next to its column. Primary instrumentation is shown to indicate that room is required for instrument drops to these control valves. All this additional information provides the designer with data to make a good start on the first cut of the layout in a rough sketch form.

The first-cut sketch is usually not drawn to scale, but is roughly spaced out. Figure 3 shows a first-cut layout. The utilization of CAD on the first-cut layout can be beneficial when optimization of the plot is necessary. Several important things should be noted in the first-cut layout sketch derived from key information provided by the process engineer. These items are indicated in the legend for Fig. 3.

4.2. Scaling the Sketch Example. Once the initial sketch is completed, it can be refined to include space requirements and shown to the approximate scale. This is where the designer uses knowledge of spacing and clearances for safety and maintenance considerations. There are several rules of thumb on how much space to leave between each type of equipment. There is also a way of approximating the amount of total space needed in a plot area to provide for all the equipment. For additional assistance, inside as well as outside battery limit equipment spacing charts have been compiled. Figure 4 shows how this information has been converted into a scaled drawing.

Adding the estimated dimensions of equipment and spacing, the designer finds an overall dimension of 65 m (Fig. 4). As more firm information is developed, some of the dimensions may vary slightly, but if so there is no more plot length available; the designer would then have to adjust other dimensions to suit, perhaps by combining some foundations. Alternatively, the air coolers can be located above the piperack to reduce the plot length by >13 m. Other considerations include the following: wind direction, which is a key factor in the location of stack and fired heaters; the location of pumps that have autoignition or that create extreme fire hazards, which should be away from under the piperack; soil conditions at plant site, which determine the size and type of foundations;

room for loading and unloading catalyst for reactors using solid catalyst; and the use of extremely large pipelines between equipment, which can dictate the location of equipment (piping stress engineers should be involved in the decision).

4.3. Cut-and-Paste Method. Some experienced layout people bypass all the previously discussed preliminary procedures and go directly to a scaled preliminary plot plan. The cut-and-paste method is giving way to new CAD models, which automatically route piping and determine capital costs for a specific equipment layout. However, the cut-and-paste method is another viable way of creating a first rough plot plan. In this method, the background of the plot area is sketched on a blank drawing to scale. This background shows plot limits as well as existing roads and other objects within the facility of the proposed plot. All the equipment items are then cut out to a scale that matches the background plot scale. In order to apply this method, the following information is desirable: process flow diagram for unit; plot size and locations of boundaries; rough equipment sizes, which should be conservative and err on the high side; location of control building and other existing structures can be ignored if off plot; and knowledge of the rough sizes of the lines and which of the piping is critical from a materials standpoint, for example, alloy lines should be kept as short as feasible.

The way the equipment is located on the background is based on the process flow sequence. Again, certain equipment such as fired heaters can be situated first to put them at a safe distance from other equipment. Other large equipment may have to be located where the soil-bearing load is best.

When alloy piping or large bore piping is required, the associated equipment is located together as much as possible to keep the pipe runs short, preferably nozzle-to-nozzle to avoid the piperack. Items, such as elevated overhead condensers, are located near the source and destination. Similarly, thermosiphon reboilers need to be placed adjacent to the column they reboil. Where gravity flow is required, these lines must be kept short and sloped. Space allocation for future additions must also be considered.

Once the equipment has been located on the plot, it can be photographed for reference. Because many cases can be evaluated, references to these need to be documented. Client approval is also needed. One way of making a record is to trace over the various arrangements for future reference. Once the plot is finalized, a first pass can then be made at transposing the principal piping lines to determine if any significant piperack problem exists and whether equipment relocation is required. Figure 5 shows a simple flow diagram used to transpose the piping on the preliminary plot plan (2). This is done line by line starting with large bore and critical material piping. A simple example has been used for illustration. The transposition effort can be much more complex with a more detailed unit.

5. Equipment Considerations

Every type of equipment requires certain layout considerations. These requirements address both operational and maintenance issues. Practical rules have been provided to guide the designer on the spacing requirements needed to address these concerns. Most of these are rule-of-thumb information based on reviews of existing designs from a maintenance and operation standpoint as well as practical engineering design rules and safety-in-design practices. The following equipment items have been evaluated in detail and are covered by Ref. (3–14). Only summary information is provided here for the most common equipment items: fractionating towers; vessels, including drums, separators, and surge tanks; reactors; heat exchangers, including shell-and-tube, double-pipe, and plate-type exchangers; fired heaters, both box and vertical cylindrical; compressors, including reciprocating and centrifugal; storage tanks, including fixed roof, floating roof, and open roof; cooling towers, including side- and top-draft fans; pumps, including centrifugal, reciprocating, and in-line; control room; and electrical switch gear.

5.1. Fractionating Towers. Most petrochemical facilities include the use of multiple fractionating towers to perform separation of the products by boiling range. Special types of towers include strippers, absorbers, reboiled absorbers, and articulated fractionators. These towers are usually vertical vessels that contain trays or packing to perform the separation. These towers are supported by skirts or other structural means to provide the vertical height required for the bottoms pump net positive suction head (NPSH) as well as the vertical height needed by the reboiler to produce enough hydraulic head to make thermosiphon reboilers circulate. These towers usually include overhead condenser systems and sometimes side strippers.

From a practical layout consideration, the fractionating towers are usually grouped together. In some eastern European countries and in Russia, towers are always grouped together so that personnel access is by platforms with stairs; no ladder access is allowed. Common structures are often used for the overhead condenser systems. These towers need to be spaced so that platforms can be located to provide an entrance area for inspection and tray repair. Towers $> 16\,\text{m}$ high need to be provided with davits for handling vessel trays and with a clear vertical drop underneath and away from the piperack so that trays can be replaced. Generally, ladder access (if allowed) to the towers is located on the piperack side for easy access by the operators. Towers should all be located on a common center line having $\sim 4–5\,\text{m}$ separation away from the piperack column supports for access clearance.

Figure 6 shows a typical plan and tower elevation drawing (6). The piperack is located to the right, and the access to manholes is to the left. Clear access to the pumps is required at the bottom. Piping headroom clearance is provided below the unit pipeway and grade for equipment access. The designer needs to be aware of the various types of tower internals (8). The spacing between these internals is critical from both a process and accessibility standpoint. The feed inlet, the overhead reflux return, the reboiler drawoff nozzle, the reboiler return nozzle, and the intermediate draws all have to be oriented by the layout person, and this information must be passed on to the vessel designer so that the vessel nozzles can be oriented properly. A liquid draw nozzle that leaves from a tray with a boiling liquid should immediately turn down in order to allow any vapors to work their way back into the tower. If a horizontal run is required, this can be made at some lower elevation after the vapors have been eliminated. Overhead lines again should be routed so that there are no low spots or pockets in the line where liquid can collect. The layout designer has to be aware of these critical situations and provide the clearances and open spaces in the plot area to allow for these important piping considerations. The process engineer needs to call these out on the process drawing or P & ID, so that they are not overlooked by the piping designer.

Most towers contain trays or packing required to perform the separation of feed into products. The various internals provide the means of taking material from the column or introducing feeds. Most column problems are a result of improper selection of feed distributors, or using the wrong type of internal in a column to make a transition from one type of tray to another (single pass to double pass). Flooding problems at the transition zone are caused by not providing enough vertical space for gravity flow of liquid between the internals. It is good design practice to provide a manway for access at each important internal. It is also good practice to provide a manway about every 10 trays to minimize the number of trays a person needs to pass through to access all parts of the tower. Manways should be 60 -cm diameter where possible. Small-diameter towers may not be big enough to allow such large manways. Sufficient vertical distance should be provided between the trays at the manway to allow access, eg, 1 m minimum if the internal occupies significant space.

5.2. Vessels and Drums.

Vessels and drums have been discussed in detail (7). Vessels are oriented either in the vertical or horizontal position. The vertical position is preferred if the plot space is tight. Horizontal vessels are easier to support and are preferred when large liquid surge volumes are required. The liquid level displacement height for a unit volume is much less for a horizontal vessel than for a vertical vessel, which makes the control range shorter than for a vertical vessel. The displacement height per unit volume is only approximately linear on a horizontal vessel when the level is near the center line, however. This can be a problem if the normal liquid level is too low or too high and the instruments are not tuned for quick response.

Figure 7 shows nozzle locations and support arrangements for a typical horizontal vessel (7). The saddles used for support are sustained by concrete pedestals or steel structures. Sufficient clearance between the bottom nozzles and the support saddles needs to be provided for access to the nozzle flange bolts. The manway can be located on the end head of the vessel, the topside of the vessel, or the side of the vessel. The preference is for an end manway wherever possible for accessibility, except when it is limited by the level gauges and controls that are commonly mounted off the heads.

The vessel can be supported off the structure and sometimes off the rack. Some economy may be possible by combining two or more services into a common vessel by using a single vessel that has an internal head. Differential pressure as well as concerns over internal leakage need to be considered for these services. This can be done with vertical vessels as well. A knockout section can be provided below or above the main vessel.

5.3. Reactors.

Reactors are a special type of vertical vessel. Some reactors are also in horizontal vessels, but this is rare. Reference 7 covers reactors in more detail (see also Reactor technology). Reactors provide the means by which chemical reactions occur to transform feedstocks into products. Typically, reactors require some type of catalyst. Reactors with catalyst can be of the fixed-bed style or fluid-bed types. Fixed-bed reactors are the most common. The feed often enters the reactor at an elevated temperature and pressure. The reaction mixtures are often corrosive to carbon steel and require some type of stainless steel alloy or an alloy liner for protection. If the vessel wall is < 6 mm, the vessel is constructed of all alloy if alloy is provided. Thicker reactor walls can be fabricated with a stainless overlay over a carbon steel or other lower alloy base steel at less cost than an all-alloy wall construction.

Reactions are either endothermic and require heating to complete the reaction, or exothermic and raise the temperature, thus requiring some type of cooling, eg, quenching or an internal heat exchanger to remove reaction heat. The reactors are provided with various types of internals to support the catalyst and distribute the reaction components uniformly across the catalyst area; collection internals remove the products and provide other distribution.

Figure (8) shows a typical vessel sketch for a vertical reactor with a fixed-bed catalyst (7). The top nozzle is frequently used as an access manway. Below the inlet nozzle, a distributor is used to spread the reactant uniformly across the reactor cross section. Below this is a rough distributor of some other type, eg, a bubble cap tray, that provides for more uniform distribution. Whatever is used, a good means of distribution of feed over the catalyst is required for an effective reaction and efficient use of the catalyst. A good vapor liquid distributor is usually required if the flow is two-phase going into the top of a reactor bed; vapors find the easiest path available. Good mixing requires good uniform distribution of the phases (see Mixing and blending). The top bed of catalyst often contains some type of trash baskets to localize the collection of feed impurities so that this part of the catalyst bed can be removed and replaced during the run cycle if required without unloading the whole reactor. This reactor can also include an internal quench system to control reactor temperature in the case of exothermic reactions. The quench media is cooler than the fluid in the bed and thus thermal expansion of the distributor should be considered so as to avoid excessive thermal stress. Some part of the internal needs to be free to expand and contract with temperature changes.

Distribution balls are frequently used on the top of each bed; they are often employed to support the catalyst bed from below. The outlet of the reactor needs to include some type of collector in order to retain the catalyst and support balls while allowing the products to leave the reactor.

Figure 8 shows a plan and elevation view of the piping and valving between a typical reactor and furnace in a catalytic reforming unit. In this typical catalytic reforming system, there are multiple reactors that have interreactor heaters to reheat the reactants in order to increase the reaction conversion. The valving shown allows for each reactor to be taken off line and regenerated while another reactor is put on line in its place. The arrangement of piping between the heater and reactor is made compact because these pipe runs and fittings are constructed of expensive alloy steel. Access platforms are provided to enable the operators to reach the isolation valves. Sufficient clearances are provided under the lowest piping that connects the furnace and reactor to allow adequate headroom for the maintenance of equipment. The reactors are typically supported from a common structure. Either individual heaters or separate coils within a single heater firebox are used for the reheaters, depending on the size of the unit.

5.4. Heat Exchangers. Heat exchangers are special types of pressure vessel that include internal tubes used to transfer heat between two streams. The hot stream (heat source) is used to heat the cold stream (heat sink). Generally, heat exchangers are of the shell-and-tube type of construction. However, other types of heat exchangers are often used, including double-pipe exchangers, plate heat exchangers, spiral heat exchangers, and air coolers. The other types of exchangers have been described (8).

Typically clustered in groups that shorten the length of the interconnecting piping (3), heat exchangers are located in a row with all of the channels in a line similar to the center-line lineup used for aligning fractionation columns. The channels always face away from the pipeway and an open area is provided to remove the heat exchanger tube bundles periodically for cleaning. There must be enough space in between the exchanger bundles to provide for the clearances and room occupied by insulation and the interconnecting piping. Access has to be provided to the channel flanges for unbolting the tube cover plate for removal during cleaning. The Tubular Exchanger Manufacturers Association (TEMA) head type influences the space required. Whenever a shell cover is present it must be removed as well. The TEMA Type S construction, which uses a floating head attached to the exchanger bundle with a split ring, requires that the rear shell cover plate be removed, the split ring disconnected from the floating head, and the floating head cleared away before the tube bundle can be removed (pulled) from the shell. This operation requires an access area to the rear shell cover and is the main disadvantage of this type of construction. However, it provides for a less costly design than the TEMA T (pull-through design) and also allows for more surface area to be included for a given shell diameter. The V-tube and pull-through construction are often preferred designs for the reason that they do not require additional maintenance to function every time the exchanger is cleaned.

The exchanger piping elevation drawing for a typical exchanger shows the piping connections to and from the channel, the piperack, the shell, and the piperack again (Fig. 9). Also, the double-block valve and bypasses, which are included on certain heat exchangers, must be included on both the tube side and the shell side in order to isolate the exchanger from the rest of the system.

This piping, shown located at the end of the pipeway, is required in order to take the exchanger out of service for cleaning while the rest of the unit is operating. Minimum clearances must be provided for the piping, including the necessary dimensions to make turns (90° elbows) and allow room for the isolation valves. Water-cooled heat exchangers are supplied with cooling water from a cooling-water main usually located underground. The cooling-water main is lined up with the channel inlet flange so that a line can be run directly up to the inlet of the tubeside and includes space for a cooling-water supply shut-off valve. The tubeside outlet is also piped back to the cooling-water return header, which is located underground but further away from the channel outlet nozzle.

Where possible the exchanger piping should run nozzle-to-nozzle to minimize the amount of pipe rack piping and shorten piping runs. Heat exchangers are grouped together and located relatively close to other equipment for this reason. Energy conservation favors maximum heat recovery consistent with the associated savings in fuel and cooling cost reductions.

Locating the heat exchanger bundles in elevated structures is often done where plot space is tight, as shown in Fig. 10 (15). These heat exchanger systems are often complex and the piping between the heat exchanger bundles is tightly compacted. Elevated heat exchangers often require special provisions to be able to remove the heat exchanger bundles. Figure 10 shows the complexity of the piping when a heat exchanger system is located in the structure. Heat exchangers can also be stacked vertically on top of each other with no intermediate platforms or supports. In this case, the stacking is done so the exchangers are connected nozzle to nozzle. No valving can be included between exchangers in this type of arrangement. This means that if the exchangers are to be cleaned, they must all be removed from the operating service in banks of stacked exchangers. Typically, heat exchangers can only be stacked so that the center line of the top bundle is $< 5\,\mathrm{m}$ from the grade which limits the number of bundles in the stack to three (sometimes two) high.

In high pressure services, where 10 MPa (1500 psig) of pressure flange ratings are required, considerable savings in nozzle bolting and head closure space can be achieved by using two types of special connections. The exchanger nozzles can be connected to the process piping by using a Graylock flange (16), a compression type of fitting that requires only two or four bolts rather than the large number of bolts for a conventional flange. When Graylock (Gray Tool Company) flanges are subjected to lateral stresses due to thermal expansion as the piping heats up, the alignment can change and cause internal displacement and potential leakage from the flange. The piping has to be designed with enough flexibility so that the thermal squirm does not result in undue stresses and cause a flange to become misaligned.

The other space-saving approach is to use the Kobe (Kobe Steel) type of channel enclosure, which does not have all the external head bolts of typical TEMA Type B or Type C head enclosures. These exchangers require special tools to remove the tube bundles and trained maintenance personnel to do the work. These exchangers should never be located in structures because of the need to be able to access the channel from grade as it is difficult to remove the channel cover plate by using special equipment.

Heat exchangers are usually supported by two pedestals attached to the exchanger saddles. The saddle closest to the channel is the fixed support, which has the saddle bolted tight to the foundation pedestal. About two-thirds of the exchanger weight usually rests on this pedestal because it carries the weight of both the channel and part of the tube bundle as well as one-half of the shell. The rear end support saddle carries the rest of the weight, which is one-half of the shell weight and part of the tube bundle. The saddle on the end away from the channel end is usually bolted loosely to the pedestal to allow the exchanger shell to grow thermally and expand as the unit heats up. On some heavier exchangers, a Teflon slide plate is required between the top of the pedestal and the support saddle in order to provide reduced friction, so that the saddle can slide on top of the foundation pedestal to reduce the horizontal stress on the pedestal and prevent it from cracking. This is commonly used on exchanger support foundations either in high temperature service, when the exchangers are heavy, or when they are stacked.

Stacking heat exchangers so that the center line is > 5 m or more than three stacks high can be a problem for maintenance. If more exchangers are required, eg, four, then the exchangers must be stacked in two pair two bundles high, because the surface area exceeds that which can be fabricated into three bundles.

Overhead condensers sometimes need to be located in the structure. Usually, partial condensers need to be elevated above the reflux accumulator. Considerable structure cost reduction can be achieved if the process can use grade-mounted condensers. Mounting the exchangers at grade may require them to be designed with subcooling so that the reflux accumulator can be located above the condenser. This should be considered as part of the process design.

Reboilers need to be located next to the tower they serve, except for the pump-through types, which can be located elsewhere. Fired heater reboilers are always located away from the associated tower and use a pump to circulate the bottoms. Kettle-type reboilers are preferred from an operational and hydraulic standpoint because they can be designed without the worry of having to ensure sufficient head for circulation required by thermosiphon reboilers. However, kettle reboilers require a larger- diameter shell that is more costly, and the reboiler must be supported at a sufficient elevation to get the product to the bottoms pump with adequate NPSH.

Horizontal thermosiphon reboilers are popular because they are less costly than kettle types and because they can be supported close to grade. The piping must be designed to provide enough liquid hydraulic head to overcome the recirculation loop pressure drop. Typically, an elevated draw tray provides the head and a large, low pressure drop inlet line runs from the reboiler draw nozzle to the reboiler inlet nozzle located on the bottom side of the shell. The reboiler outlet nozzle and piping are smaller than the inlet piping to keep the return-line velocity high enough and prevent separation of liquid from vapor and the resultant slug flow from occurring. Space needs to be provided for this piping.

The vertical thermosiphon reboiler has a particular advantage in that the reboiled fluid flows inside the tubes. This permits the use of alloy on the tubeside only if the reboiled fluid is corrosive or requires a noncarbon steel construction. However, the vertical thermosiphon reboiler also has two principal drawbacks. First, the vertical shell must be supported off the column or in some other way. Second, the removal of the tube bundle can be difficult because of the need to remove the outlet piping and provide the access room for pulling the bundle out vertically. The location of the vertical thermosiphon is usually put on the backside of the piperack because of the access room requirements for pulling the bundle vertically for cleaning. Many columns require multiple reboilers because the size of a single reboiler cannot be fabricated in a single shell. This service requires the allocation of space on both sides of the tower and a symmetrical piping design to ensure evenly distributed heat input loads and equal flows to each unit. Side reboilers are often useful inclusions on towers that make separations of mixtures with widely differing boiling points. Side reboiling is sometimes a preferred alternative to preheating the feed if the preheat temperature levels get too high and result in too much vaporization of the heavy component. Side reboilers require special considerations from a plot area and support consideration. They need to be supported in the structure at or near the section of the tower from which they withdraw liquid and return the reboiled mixture of vapor and liquid to the tower. Space needs to be provided for both the piping runs to and from the column and the pipe runs for whatever fluid is used as the heat media.

The location of exchangers is the key to maintenance. Usually, the back head is kept at a distance of about three meters from the piperack support columns. Access equipment must be able to get in and remove the shell cover and flange head. Access area must also be provided to handle and remove the shell cover usually located under the piperack. The tube-pulling or rodding-out area must be kept clear to allow access to the channel end. This space should be at least equal to the tube length and about two meters from the tube sheet location. Tube removal space should be allowed for but is not mandatory if grade-mounted heat exchangers are used and mobile maintenance equipment employed to pick up the entire unit and transfer it to the repair shop.

5.5. Fired Heaters. In many European refineries, the overall plant layout is designed so that all heater exhaust gas is ducted to a centrally located 100-m high stack; in this manner release to the atmosphere is dispersed more broadly. Usually, fired heaters are located a minimum of 15 m from the hydrocarbon-containing equipment. When reactor-heater systems are used, the distance can be shortened if certain safety precautions are included in the design. The piperack can be used to provide part of the separation between the reactor and the heater. Reference 10 covers the various types of heaters and their components. Heaters basically come in two types. The vertical cylindrical heater, which is usually bottom-fired and often has a self-supporting stack, is popular from a space-saving standpoint and the capital cost is usually low for this type of design on small units. Vertical heaters use vertical tubes in the radiant section, which can be a process disadvantage in some two-phase systems because of the higher pressure drop and the tendency for vapor and liquid to separate in the upward flow path. The tubes are pulled and removed from the top side of the heater usually by using a pull ring attached to the heater stack. This ring provides a way of removing the tubes without the need for a tall crane. A space of 3 m longer than the tube length needs to be provided above the heater to pull the tubes. A lightly traveled road at the access side of the heater is preferred for equipment access. The tube-pulling area must be kept open during maintenance.

Larger-sized heaters are usually horizontal box heaters. The radiant coils can be located either on the side walls so that the units are fired from underneath, or in a center row of tubes in which the heater is fired from both sides to provide a higher heat flux for reducing the radiant surface. An access area at one end of the box is required in order to remove the tubes. Sometimes multiple coils are included in the same box, which may require access to both ends of the box.

Most high efficiency fired heaters include either a convection coil to generate low pressure steam or some other low temperature coil in the convection section. The other option to improve heater thermal efficiency is to include an air preheater. The air preheater makes the layout much more complex for several reasons. First, the stack can no longer be self-supporting. Second, space needs to be provided to accommodate the forced draft fan, the induced draft fan, and the air preheater itself. Some heaters can share a common stack to simplify the addition of convection coils by having all coils in one convection box. A steam coil in the heater convection section requires that a steam drum and the associated piping for natural circulation be provided. This requires a support structure. Environmental considerations may also require a structure to provide a sampling access platform on the stack and the necessary analyzer housings.

Piping for snuffing steam injection into a heater firebox is required to help put out a fire if a tube rupture occurs. The snuffing steam isolation valve needs to be located at an accessible spot remote from the heater. Also, a remote fuel shutoff valve should be located adjacent to the snuffing steam valve so that both valves can be accessed quickly in case of fire.

5.6. Compressors. There are two basic types of compressors: centrifugal and reciprocating machines. The centrifugal compressor is usually used for higher volume low head applications. It can be either motor-driven or steam-turbine-driven. In some cases, it may even be gas-turbine-driven. The other type of compressor is the reciprocating machine. It is generally used for lower volumetric flow rates or when higher differential pressures are required. Most reciprocating compressors are multistaged units and equipped with intercooling and knockout drums between compression stages. Because of the nature of the operation, reciprocating compressor piping is often subject to vibrations. If slugs of liquid get into the suction piping, disastrous effects and severe damage to the compressor valves and pistons can occur. Therefore, some type of separation drum is usually located upstream of the compressor unit. The pipe run from the knockout drum to the compressor suction is kept as short as possible, with no low point pockets, and the suction line is often heat-traced to prevent any condensation. Because compressors are expensive equipment items, they should be protected from the elements. Some type of building or housing is usually provided, particularly for reciprocating units. The compressor and its auxiliaries are usually separated from the rest of the process facilities. This isolates them from fire and also moves the noise zone away from the process facility.

Space needs to be provided for the auxiliaries, including the lube oil and seal systems, lube oil cooler, intercoolers, and pulsation dampeners. A control panel or console is usually provided as part of the local console. This panel contains instruments that provide the necessary information for start-up and shutdown, and should also include warning and trouble lights. Access must be provided for motor repair and ultimate replacement needs to be considered. If a steam turbine is used, a surface condenser is probably required with a vacuum system to increase the efficiency. All these additional systems need to be considered in the layout and spacing. In addition, room for pulsation dampeners required between stages has to be included. Aftercoolers may also be required with knockout drums. Reference 8 describes the requirements of compressor layouts and provides many useful piping hints.

5.7. Pumps. Pumps (qv) are usually located along two pump rows that are used up underneath the piperack. Pumps are oriented with the motor accessible from the aisle way under the piperack. Each pump is located as close to the suction source as possible. Both the main pump and the spare pump are frequently located on the same support foundation. Small in-line pumps may be supported off the process piping.

However, most in-house pumps require a pedestal for support. Space has to be provided around the pump for the piping and isolation valves as well as the electric supply. If steam turbines are used, then steam supply and exhaust steam piping are required. Some pumps also require flushing oil piping and cooling water supply to the gland coolers.

Most centrifugal pumps have end-suction and top-discharge nozzles, but both top-suction and top-discharge designs are not uncommon. Multistage pumps require much more space than conventional pumps. The casing is usually vertically split for single-stage pumps and horizontally split for multistage pumps. Many high pressure pumps are designed with a barrel casing.

The layout specialist should be aware of any special space requirements for a pump. Otherwise, pumps are usually fitted into a small area normally considered adequate for a general pump service. Sump pumps and other special types of applications need to be called out.

5.8. Storage Tankage. Most tankages are located away from the main process area. Occasionally, the process unit includes a day tank. However, it is safer to provide feed surge in a pressure vessel such as a feed surge drum, rather than in a tank. On plot process, tankage is usually used only for nonflammable substances and the storage volumes are kept small to minimize the plot space taken up (day tanks are typical of storage volume required). Reference 2 provides some useful information about the required spacing for various types of storage tanks as well as guidance on the minimum required spacing between tanks and between the tank and the facility fence line (property line). It also provides useful information on locating tanks relative to each other, the use of tank dikes, grouping tanks in a common diked area, drainage requirements, and other safety-related information. Each site location must comply with local regulations in addition to general guidelines.

Tank storage of liquids at atmospheric conditions is generally classified into three classes: flammable liquids having a flash point below 100°F (38°C), flammable liquids having a flash point $> 100°F$, but $< 140°F$ (60°C), and combustible liquid having a flash point $> 140°F$ and $< 200°F$ (93°C). The National Fire Protection Association (NFPA) has developed criteria based on these classifications and the type of tankage used for storage (fixed roof, floating roof, and no roof). These guidelines must be followed in the early layout. It can be costly to move a tank after it has been constructed. Once a tank is located on the plot plan, it tends to be forgotten until construction time. On one project, for instance, local spacing requirements were more conservative than the space provided for tanks already under construction. As a result, it was expedient to provide the community with a dedicated fire truck than to pour a new tank support ring and air-float the half-constructed tank shell to another location to meet the local tank space requirements.

The following are some general minimum spacing requirements. (*1*) Use 1-m minimum space between..any two flammable liquid storage tanks. (*2*) The minimum distance between any two adjacent tanks should be at least one-sixth of the sum of their diameters. If one tank is less than one-half the diameter of the other, the tank spacing should be at least one-half the diameter of the smallest tank. (*3*) Crude oil storage tanks in production areas should be spaced a minimum of one meter if < 3000 barrels and at a space of at least one-tank diameter (smallest tank) if > 3000 barrels. (*4*) Unstable, flammable, or combustible liquid tankage should be spaced at one-half the sum of the tank diameters. (*5*) Local regulations, including fire protection, insurance codes, and common practices, may require even greater spacing for grouped tankage of three or more rows of irregularly spaced tanks. Tank pattern and spacing must provide adequate space so firefighting equipment can gain access. (*6*) Liquefied petroleum gas (LPG) requires a minimum vessel spacing of 6 m and LPG containers must have dikes that are a minimum of 3 m from the side and the center line of the dike.

5.9. Cooling Towers.

The cooling tower location relative to the prevailing wind direction should be such that the wind hits the short side or the side perpendicular to the inlet louvers. This helps balance the air flow to the two inlet sides.

The direction of the outlet plume relative to local roads should be considered. In foggy weather, the plume can cause the roadway to become a visual problem and a driving safety hazard. Also, the spray carryover from the top of the tower can, in some climates, cause ice to form downwind. The parking areas should never be located downwind of the cooling tower because the chemicals contained in most cooling water can cause severe paint problems. This can cost a plant a large amount of money to repaint the parked cars if a parking area is opened adjacent to the cooling tower.

Air to the cooling tower should be as cool as possible. Equipment that gives off heat should not be located upwind of the tower. The cooling-water pump pit should be located on the side of the tower that minimizes piping. Note that the slope of the bottom of the pit should be such that suction to any of the pumps does not become starved. In addition, water-treating chemical injection equipment and the delivery of these chemicals need to be considered. Also, the water blowdown, which on many towers is regulated by an overflow weir, flows by gravity to the appropriate sewer system, usually the high salts (nonoily) sewer.

Vented risers should be provided on most cooling towers to release only light hydrocarbon leakage from the cooling water before the spray header. No ignition or source of spark should be within 30 m of the vented riser.

5.10. Control Room.

The control room location can be critical to the efficient operation of a facility. One prime concern is to locate it the maximum distance from the most hazardous units. These units are usually the units where LPG or other flammables, eg, hydrocarbons that are heavier than air, can be released and accumulate at grade level. Deadly explosions can occur if a pump seal on a light-ends system fails and the heavier- than-air hydrocarbons collect and are ignited by a flammable source. Also, the sulfur recovery unit area should be kept at a healthy distance away as an upset can cause deadly fumes to accumulate.

A central location where instrument leads are short is preferred. In modern facilities with distributed control systems, all units are controlled from a central control room with few operators. Only a few roving operators are available to spot trouble. It is desirable to keep process equipment a minimum of 8 m away from the control room. Any equipment and hydrocarbon-containing equipment should be separated by at least 15 m if possible. Most control rooms are designed with blastproof construction' and have emergency backup power and air conditioning. The room is pressurized to prevent infusion of outside air that may have hydrocarbon content in the explosive range.

6. Piperack Considerations

Piperack is considered the arterial system of the process plant (see PIPING SYSTEMS). All of the nonnozzle-to-nozzle pipe runs are made by running pipe to and from the piperack. Utility lines, electric lines, and instrumentation lines are often run on the piperack as well. Figure (11) shows various types of piperack configurations (10). These different types of pipe rack layouts are referred to by the shape of the piperack: straight-through (which is the most common type), L-shaped, T-shaped, U-shaped, and a combination of these. The individual unit piperacks are ties into the interconnecting plant piperack that provides the link between units. Each of these types of piperack layouts fits a particular need. The designer selects the most appropriate ones depending on the space availability and the equipment layout requirements.

Multielevation piperacks are usually needed to handle all the required services for piping, electrical, utilities, and instrumentation. The two-level rack is one of the most common, but three-level ones are also used. The utility lines are usually run in the upper level and the process lines in the lower levels. The larger-diameter lines are located to the outside of the rack to be closest to the column supports. Access platforms are required at the battery limit to provide operators access to the block valves and blinds. If long runs of hot pipe are required, a portion of the pipe rack needs to be dedicated to an expansion loop. A horizontal space in the piperack is provided for a set of lines to be flat-turned into a set of expansion loops with the large pipes located on the outside. All of the pipe turns are in the same horizontal plane, which is an exception to normal piping practice. A flat turn takes up and blocks space for other pipes. Flat turns are generally only made from the outside of the rack to minimize this blockage.

High temperature lines that grow due to thermal expansion are supported by shoes welded or strapped to the bottom of the pipe at the pipe support locations. Insulated lines must have insulation breaks at the support or be supported by shoes. Large-diameter lines are often used to support smaller lines at locations in between the supports by running a support beam attached to two larger-sized lines below the smaller lines.

The location of the pipe in the rack is selected to minimize the congestion and eliminate line crossing. If a process line connects two nozzles that are elevated higher than the piperack, then the upper level of the rack is used. Similarly, if the nozzles are both below the piperack, then the lower level rack is used. Other cases in which one nozzle is below and the other above use the least congested part of the piperack. Lines with valves are more easily accessed from the upper level, but require an access platform.

Pumps are usually located under the piperack. An open slot in the piperack has to be provided at the location of the pump suction and pump discharge lines so that the piping can make a straight run down to the pump suction and then the discharge line can be run directly back up to the piperack. Pumps commonly have an end suction and top discharge; but they can also have a top suction and top discharge. The location of these nozzles on the pump can affect the piping configuration. The pump discharge line usually has some type of flow control valve that requires a piping drop from the piperack down to the control valve. The control loop usually has a control valve, a double-block valve around the control valve, and a hand bypass valve so that the valve can be replaced or repaired while the hand bypass is used for temporary control. Double-block and bypass valves should be located at an elevation where the valve and the controller can be accessed without a ladder.

Whenever a change in piping direction occurs, the elevation of the pipe run should also change. If the main piperack is at an elevation of 4 m, then the lateral piping can either go up to 5 m or drop down to 3 m. The piperack can also provide the support for air coolers and other equipment such as elevated drums.

Figure (12) shows the plan and elevation views of a process unit piping (9). A drum is supported off the piperack. Heat exchangers are located far enough back from the support columns so that they are accessible and their shell covers can be removed. Pumps are located underneath the piperack, but sufficient room is provided for maintenance equipment to access the motors and to remove the pump if necessary. The motor is always oriented away from the process equipment and located on that side of the piperack. Instrument valve drops are shown supported from the columns. The instrument trays themselves run on the outside of the support columns. Flat turns are only made from the outside position of the piperack. Nozzle-to-nozzle pipe runs are made whenever possible. Larger lines are located on the outside of the piperack. Connections to nozzles above the rack are made from the top elevation. Recommended spacing of yard pipes on a piperack have been given (15). Minimum equipment spacing requirements for inside as well as outside battery limit equipments, such as offsites, are given in Fig. 13 and 14. In Fig. 13, where environmental factors control discharge of emissions to the atmosphere, a closed collection header has to be provided in the piperack to flares. Relief valves (above tower) are located above such header and sloped accordingly. Where environmental factors are not of concern, relief valve discharges may discharge as indicated. Steam discharges to the atmosphere at a safe location.

7. CAD Models

Computer-aided design (qv) technology is steadily improving. Output from CAD is readable, and hard-copy drawings are available with consistent line weights, symbols, and dimensions. These models still only show 2D representation of 3D models. However, the integration of all equipment, piping, and structural steel makes it easier to detect and interface between two components occupying the same space through interference detection checks. Formerly, plastic models were the only way that this could be checked with any degree of confidence.

Design Power, Inc. began investigating automated 3D physical design software when it needed to find a quicker, more accurate way to route pipe, which is a critical component in process plant design. Traditionally, experienced designers took pencil to paper to create 2D drawings of pipe routings. Borrowing from software ideas used in the semiconductor industry to connect various components, Design Power, Inc. developed what has become known commercially today as PlantWise to automatically route pipe to equipment throughout a facility and generate 3D plant designs.

The output from PlantWise is an intelligent 3D model. Using the intelligent 3D model, material quantities can be automatically extracted and engineering drawings generated. Color images can also be produced and dropped into an aerial photo of the construction site and allow a virtual "walk" through the plant at a early stage. PlantWise is a rule-based software-engineering program. Creating the rules that govern the program required collaboration with engineers and designers from multiple engineering disciplines. Figures 15 and 16 are 3D models generated by PlantWise. A demonstration of PlantWise can be seen at the Design Power, Inc website.

Now feasibility studies, proposals, and front-end engineering activities can be executed in a fraction of the time that it used to take when all of the drawings had to be created manually. The PlantWise also helps to keep the project on track and serves as a vital source of information.

Traditionally, changes were made to the facility layout late in the design process after intensive design efforts. Because a 3D model of the project can be reviewed at the conceptual stage, suggestions and changes can be made at the earliest possible phase, when very few resources have been committed to the project. With PlantWise, nontechnical personnel are able to understand the scope of a project in a way that they could not when they were looking at 2D engineering design drawings. Because PlantWise helps them visualize the project, they can give feedback at an early stage. In addition, since there is commitment to projects at an earlier stage of development, it is possible to place orders for long-lead-time materials and equipment, thereby reducing construction delays due to late material and equipment delivery.

A multiple of "what-if scenarios" can be created to see how changes in equipment layout change the construction costs. Design engineers can move plant components around on the computer screen, and PlantWise automatically reroutes the pipes. The system instantly measures how many feet of each type of pipe are required.

Three-dimensional CAD model development for detailed engineering still requires some 2D preliminary work, eg, plot plans. Individual pieces of equipment need to be dimensionally defined by creating an equipment model file with the special and geometric configuration generation. To these models the locations of nozzles, ladders, platforms, and other externals are added, depending on the desired complexity of the model. This information is entered into the computer in various layers of data which permits the CAD designer to display any or all of these layers. Geometry of the structural steel, piperacks, and foundations are entered. Ultimately, piping instrumentation and electrical information is entered to the level of detail desired.

The piping file can be extracted and used to generate orthographic and isometric drawings that can include a sized list of materials, eg, pipe and fittings with piping classifications, materials of construction, and type of alloy identified. These 3D models can be viewed from almost any perspective by using the zoom-in display and walking through the model. Views can be enlarged by moving the visualization point in closer to the desired reference. Any of the model input levels can be turned off to provide an unobstructed view, ie, by removing instrument, electrical, and structural steel, to see piping only.

7.1. Scale Models. Replicas of a plant are often prepared as part of the design and can be in several forms: equipment only, equipment and major piping, or complete equipment and piping. Model building is both time- consuming and expensive. Models of whole facilities can easily cost millions of dollars but the money is considered well spent by many operating companies. The model can be used as a design tool, a construction aid, and an operation and training aid. When the facility has complex piping, 3D visualization can be depicted on a model that can make for a much more desirable operational layout. Scale models have been replaced by 3D CAD models.

8. Noise Abatement

One of the prime OSHA requirements is control of the noise level, which can usually be met by using proper specification and noise attention devices. Noise can cause hearing impairment and be hazardous to health. It also interferes with work efficiency by inducing stress, hindering conversation of operators, and preventing them from hearing warning signals.

Plant layout and noise suppression material are two general noise abatement methods. Plant layout does not affect noise levels at any given point; however, noise can be abated by screening off a section of the plant. An example of this is to orient cooling towers with their closed faces toward the critical location. This method must also consider wind direction to balance air draft. Tankage can be located to act as a noise screen.

Most rotating equipment includes electric motors or steam dryers that generate noise at a constant frequency. Air cooler fans are a source of noise that can be reduced by lowering the fan speed and increasing the number of blades. Pump motor noise can be reduced by including a shroud or fan cover that is accurately lined. Centrifugal compressor noise reduction can be achieved by blade design and the use of compressor pulsation noise reduction, silencers, and vibration isolation.

Flare noise (roar of combustion) is the most serious because it is elevated and the sound carries. The flare can be located at a remote distance from the operating unit or surrounding community. Noise of steam injection into the burner can be reduced by using multiple nozzles. Furnace noise from air intake, fuel systems, and combustion blower forced draft/induced draft (FD/ID) fans can be reduced by acoustics. The plot plan should be evaluated for noise generation and to find the means of alleviating or moving noise to a less sensitive area.

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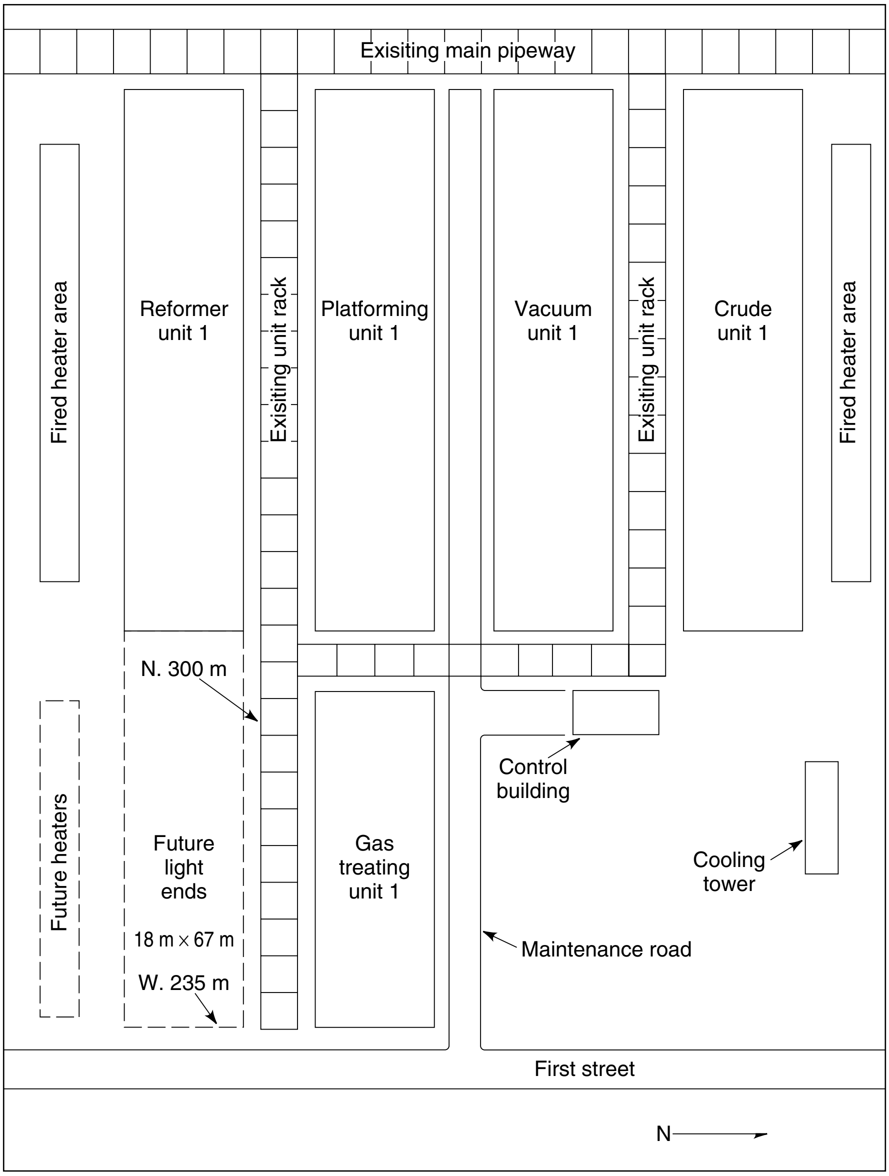


Fig. 1. Overall plot plan (1).

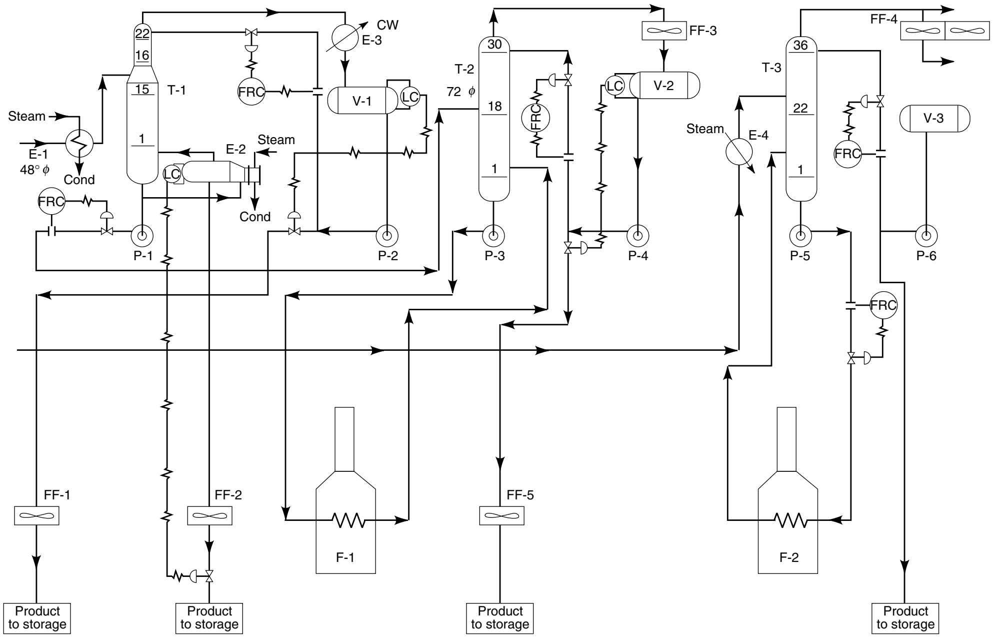


Fig. 2. Process flow sketch where CW = cooling water, FRC = flow recorder controller, and Cond = condensate. (See Fig. 3 for other definitions.)

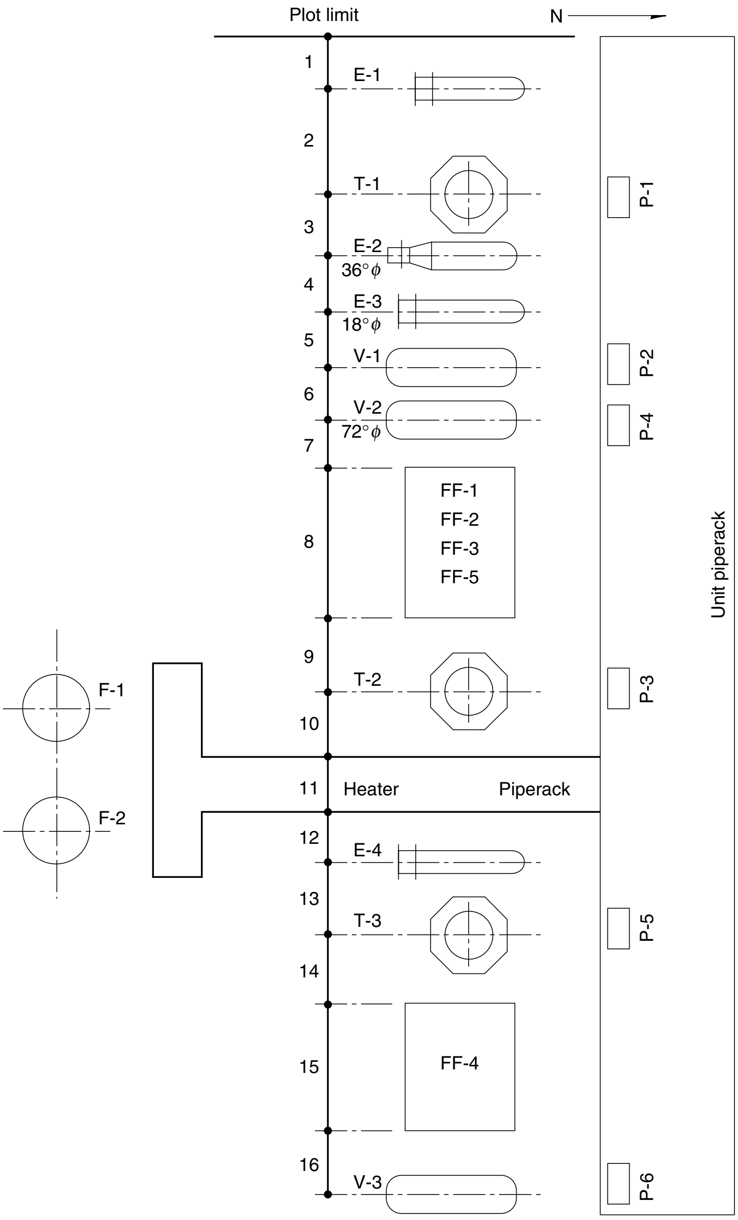


Fig. 3. Rough layout sketch: (*1*) the two fired heaters F-1 and F-2 are located together but are separated from the other equipment with a subpipeway connecting the process area to the heater area; (*2*) the reboiler E-2 is located adjacent to its column, T-1. The preheat exchanger E-4 is located adjacent to tower T-3; (*3*) the elevated overhead condenser E-3 is located next to the overhead accumulator V-1. Also, the air condenser FF-3 is located adjacent to its overhead accumulator V-2; (*4*) the rest of the air coolers (FF-1–3, -5) are grouped together in a common fan structure; (*5*) all equipment and related piping is routed to and from the existing piperack saving the addition of a new piperack; (*6*) all pumps (P-1–P-6) are located in a row under the piperack, and each pump and its spare are located close to the respective upstream suction source (1).

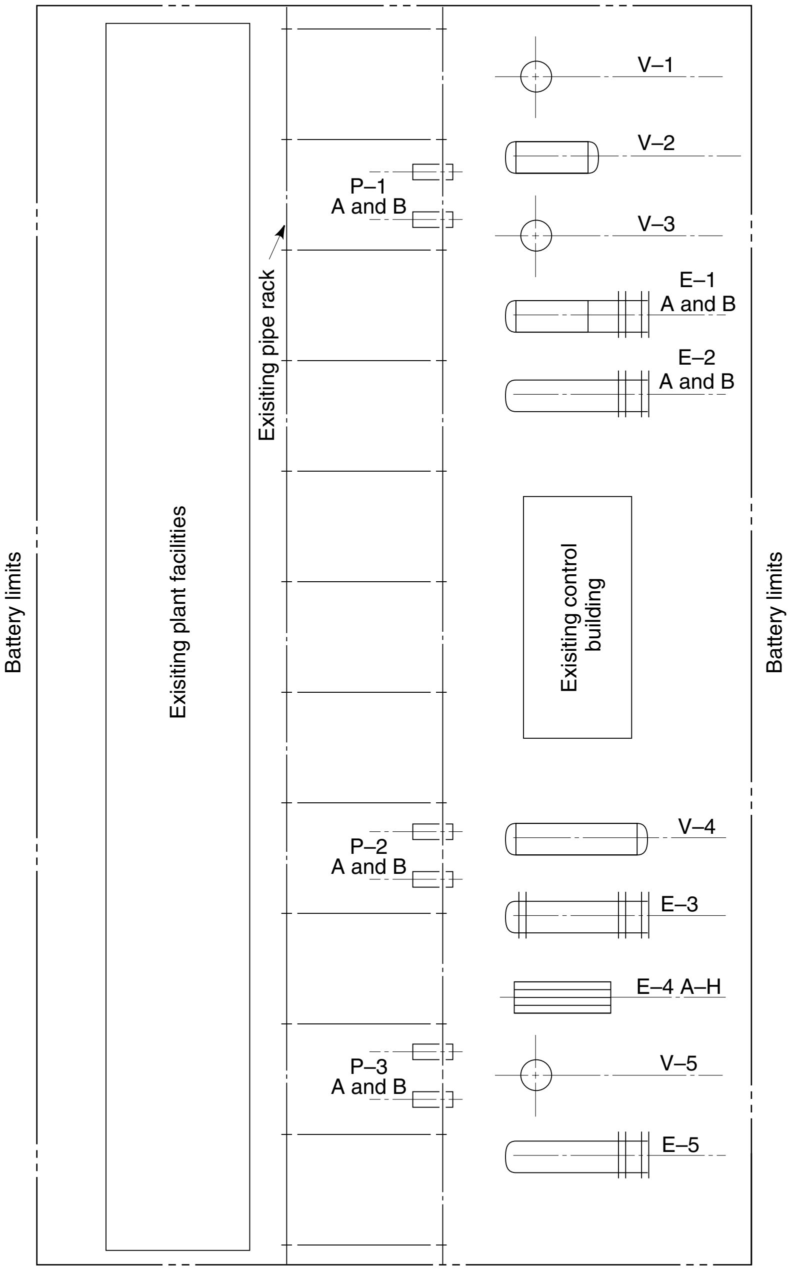
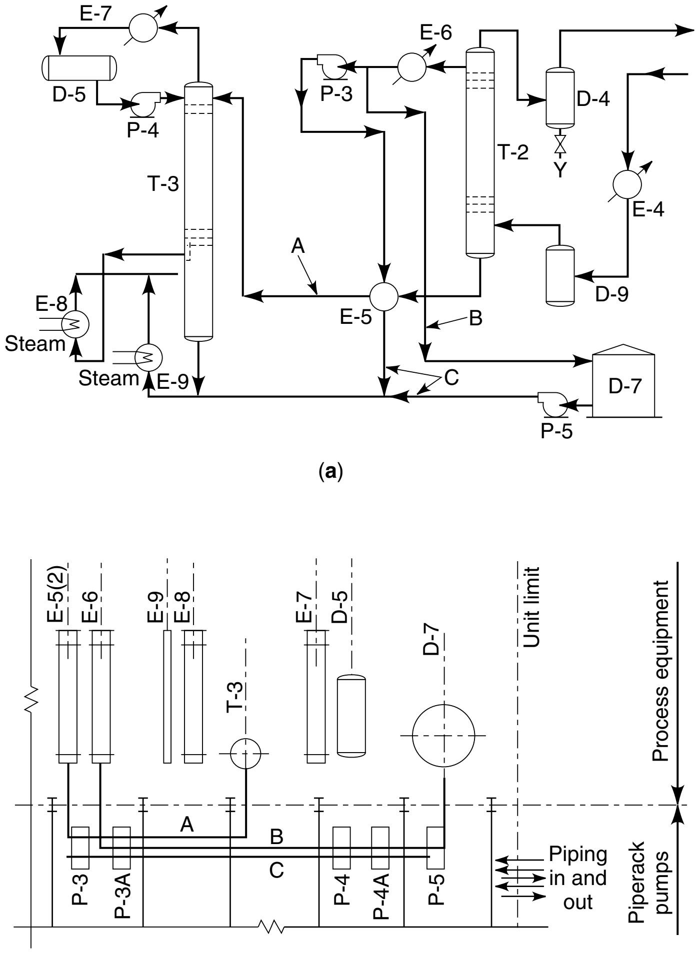


Fig. 4. Preliminary dimensioned plot plan (1).



(**b**)

Fig. 5. Initial piping transposition: (**a**) process flow diagram and (**b**) plot plan (1).

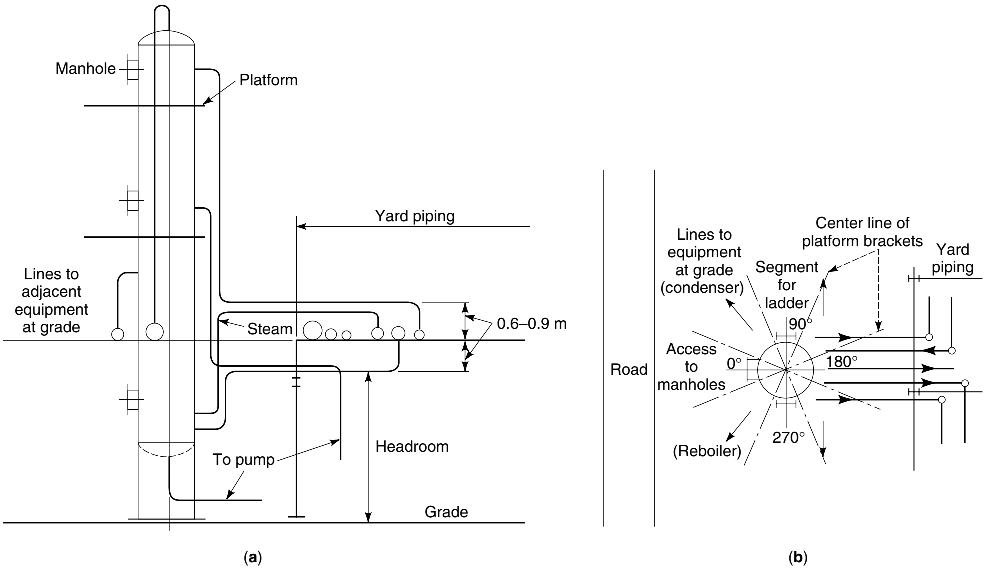


Fig. 6. (**a**) Typical tower elevation and (**b**) plan (6).

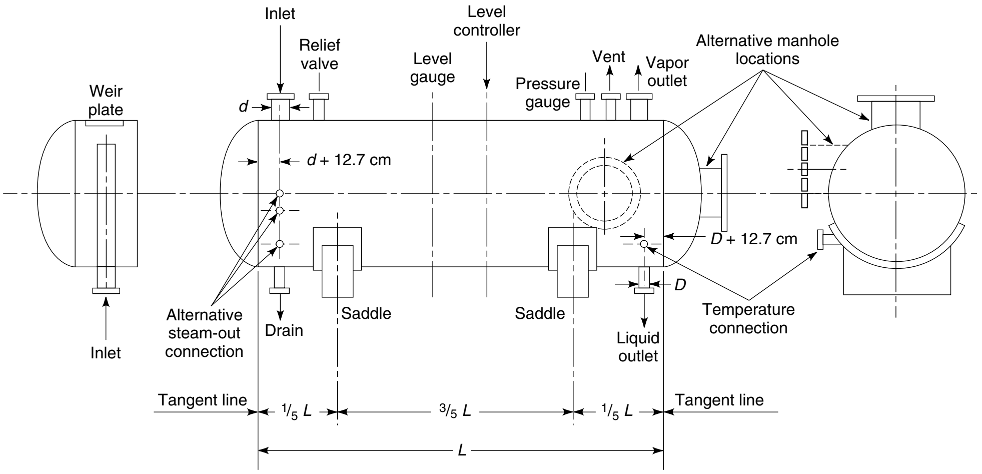


Fig. 7. Vessel support and arrangement where $d =$ nozzle diameter, D = vessel diameter, and L = length. Saddles can be straight or tapered. Single supports can be used for small drums. Combining drums saves the number of necessary supports (7).

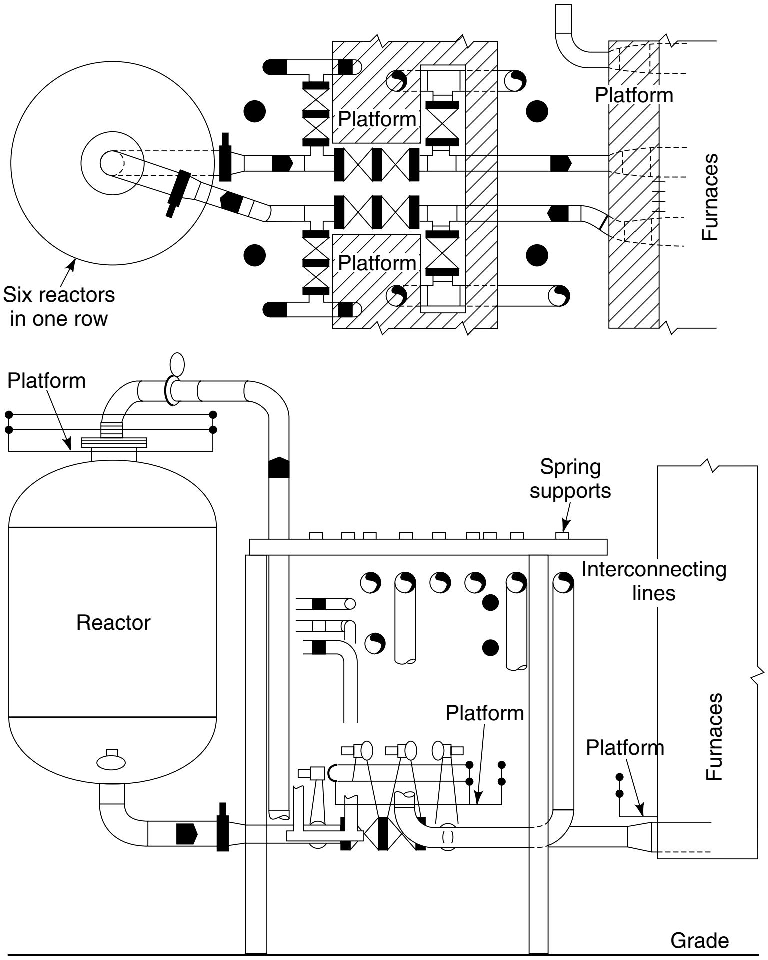


Fig. 8. Reactor vessel drawing (7).

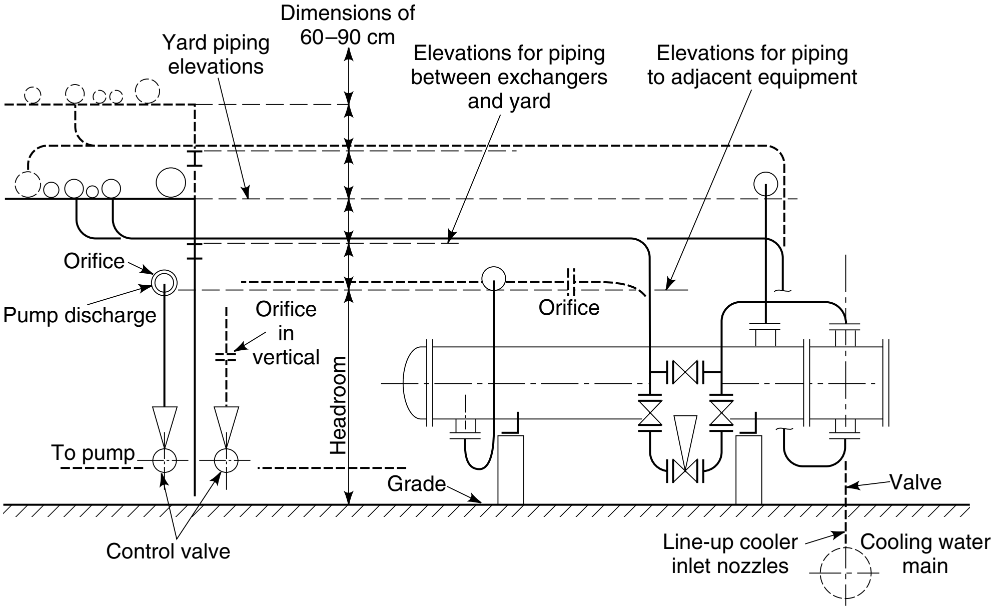


Fig. 9. Exchanger piping elevation.

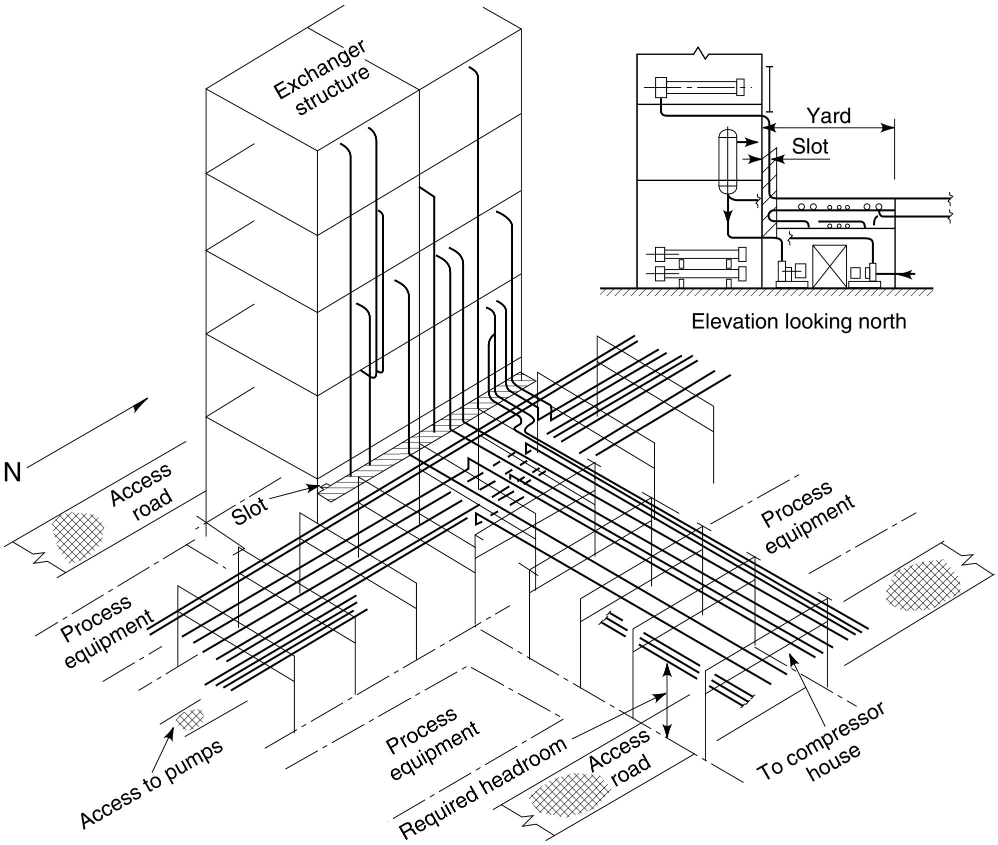


Fig. 10. Exchanger structure piping.

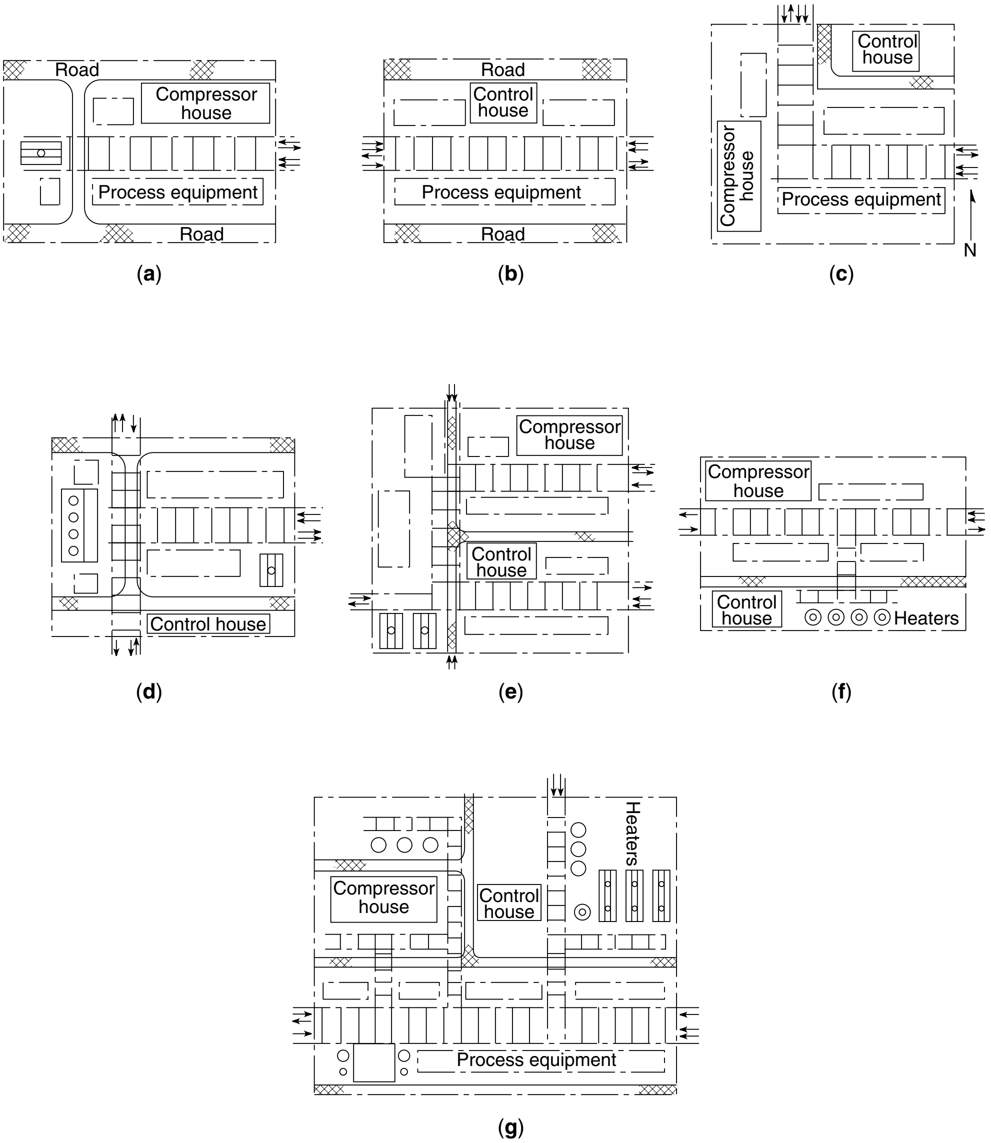


Fig. 11. Types of piperack configurations: (**a**) dead-end yard: lines enter and leave one end of yard; (**b**) straight-through yard: lines can enter and leave both ends of the yard; (**c**) L-shaped yard: lines can enter and leave north and east of the plot; (**d**) T-shaped yard: lines can enter and leave on three sides of the plot; (**e**) U-shaped yard: lines can enter and leave all four sides of the plot; (**f**) combination of I- and T-shaped yard; and (**g**) complex yard piping arrangement for a large chemical plant (9).

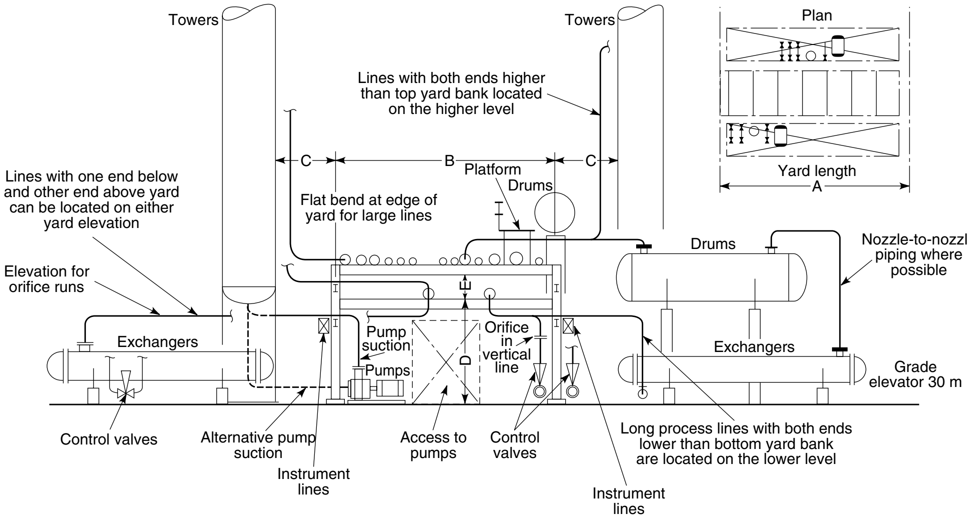


Fig. 12. Piperack, piping, and equipment relationships in a petroleum plant. A–E signify dimensions that affect piping cost.

Row																														
1	Blowdown facilites, eg, pumps, drums, stacks																													
2	Compressors, gas	15	3																											
3	Control houses for one unit	15	30																											
4	Control houses for 2 or more units Ⓐ	30	30																											
5	Coolers, air fin	15	7.5	15	30																									
6	Cooling towers	15	15	22.5	30	15																								
7	Drums	15	7.5	15	30	2.4	15	1.5																						
8	Electrical load centers, main, unit Ⓑ	15	15	1.2	1.2	15	6	15	1.2																					
9	Electrical switch racks, critical	4.5	7.5	0	1.2	4.5	4.5	4.5		0																				
10	Exchangers above autoignition	15	7.5	15	30	7.5	15	6	15	7.5	1																			
11	Exchangers light ends	15	7.5	15	30	2.4	15	2.4	15	4.5	6	Ⓒ 1																		
12	Exchangers, other flammables	15	7.5	15	30	2.4	15	2.4	15	4.5	6	Ⓒ 1	1																	
13	Furnaces	15	22.5	15	30	15	30	15 Ⓓ	15	12	7.5	22.5	15	4.5 Ⓔ																
14	Piperacks, main	6	4.5	4.5	7.5	1	15	1.5	0	0	2.4	1	1	6	0															
15	Pumps above autoignition	15	75	15	30	6	15	6	15	4.5	6	6	6	6	6	2.4														
16	Pumps, light ends	15	7.5	15	30	4.5	15	4.5	15	4.5	6	1.5	1.5	22.5	2.4	6	1													
17	Pumps, other flammables	15	7.5	15	30	4.5	15	4.5	15	4.5	6	1.5	1.5	15	0	6	1	1												
18	Pumps, nontoxic and non-flammable materials	2.4	1	2.4	2.4	2.4	2.4	1	7.5	2.4	2.4	1	1	4.5	0	1	1	1	1											
19	Reactors above autoignition internally insulated	15	7.5	15	30	6	15	6	15	4.5	6	6	6	7.5	6	7.5	7.5	6	2.4	1.5										
20	Reactors above autoignition, externally insulated	15	7.5	15	30	6	15	6	15	4.5	2.4	2.4	2.4	6	6	7.5	7.5	6	2.4	6	1.5									
21	Separators, unit light ends	6	15	15	30	15	15	6	15	4.5	22.5	15	15	22.5	4.5	22.5	15	2.4	1	22.5	22.5	0								
22	Separators, unit other flammables	7.5	7.5	15	30	15	15	6	15	4.5	15	6	6	15	2.4	15	6	2.4	1	15	15	0	0							
23	Snuffing steam manifold for furnaces	15	15	0	0	6	15	6	1.2	1.2	6	6	6	12	0	7.5	6	6	1	15	15	6	6	0						
24	Storage vessels horizontal, under pressure	22.5	22.5	22.5	30	22.5	22.5	22.5	22.5	12	22.5	22.5	22.5	22.5	15	22.5	22.5	22.5	2.4	22.5	22.5	22.5	15	22.5						
25	Structures, main	15	7.5	15	30	2.4	15	00	15	4.5	6	0	0	15	1.5	6	2.4	2.4	0	6	6	15	6	4.5	22.5	0				
26	Towers, light ends	15	7.5	15	30	2.4	15	2.4	15	4.5	6	2.4	2.4	22.5	2.4	6	4.5	4.5	1.5	6	6	15	6	15	22.5	0	3			
27	Towers, light ends	15	7.5	15	30	2.4	15	2.4	15	4.5	6	2.4	2.4	15	2.4	6	4.5	2.4	1.5	6	6	15	6	15	22.5	0	3	3		
28	Water spray deluge valves Ⓕ	15	7.5	0	0	7.5	4.5	7.5	1.2	1.2	7.5	7.5	4.5	7.5	0	7.5	7.5	4.5	1	15	15	6	6	0	22.5	0	6	4.5	0	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	Column

Fig. 13. Inside battery limit equipment spacing (distances are in meters): A, spacing of 22.5 m between control houses and equipment containing flammables is preferred to the 15-m spacing shown; B, drums containing nonflammables require minimum space of 1.5 m to other equipment for operating and maintenance access; C, exchangers in the same service as adjacent ones require only minimum spacing of 0.6 m, regardless of operating temperatures; D, 22.5 m required between furnaces and light-ends drums; E, for furnaces operating above 25 kg^1m^{-2}, spacing to adjacent furnaces is 9 m min; and F, deluge valve is 15 m from equipment being protected.

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Row
Process units: light ends, distillates, other flammables	30	45	60	60	90				90	150	15	6	45	15	90	45	30	60	60	60	30	A
Tanks, Class 2: tanks fixed (flat or cone) and floating roof		NFPA	NFPA	30	30	2.4	7.5	15	90	150	30	2.4	45	30	75	30	30	60	60	30	60	B
Tanks, Class 1: fixed (flat or cone) and floating roof			NFPA	30	60	7.5	7.5	15	90	150	45	6	45	60	75	45	30	60	60	60	60	C
Storage vessels, under pressure					60	7.5	15	30	90	150	60	7.5	30	45	90	60	30	60	60	45	60	D
API separators, main unit					7.5	2.4	30	45	90	150	30	6	60	45	90	90	60	60	60	45	15	E
Pumps, nontoxic and non-flammable materials						1	1	1	90	150	2.4	0	2.4	7.5	2.4	0	2.4	30	60	2.4	2.4	F
Pumps, light ends, and other flammables							1	6	90	150	15	2.4	30	15	7.5	4.5	15	60	60	30	30	G
Pumps above autoignition								2.4	90	150	15	6	60	15	15	15	15	60	60	30	30	H
Flares on ground, shielded									90	150	90	90	90	90	90	90	90	150	90	90	90	I
Flares on ground, open										150	150	150	150	150	150	150	150	300	150	150	150	J
Blowdown facilities: drums, pumps												6	90	15	60	30	22.5	60	60	30	30	K
Piperacks, main													6	4.5	6	4.5	2.4	6	6	6	6	L
Loading racks, light ends, and other flammables														30	90	30	2.4	60	60	60	60	M
Electric substations, main															0	12	6	7.5	30	12	6	N
Fire substations main																30	6	12	12	12	30	O
Boiler houses																	2.4	60	60	30	30	P
Railroad spurs																	3.5	12	6	6	2.4	Q
Public highways and railroads																				6	60	R
Property lines other than roads and railroads																				60	60	S
Service buildings																					30	T
Cooling towers																						U

Fig. 14. Outside battery limit (OSBL) equipment spacing. Minimum spacing for off-site equipment is in meters. Classifications of tankage are Class 1: high hazard, flash point $< 38^\circ$C; Class 2: low hazard, flash point $> 38^\circ$C. NFPA = National Fire Protection Association. Safety standards are calculated by flare stack, height, and sterile-area radius.

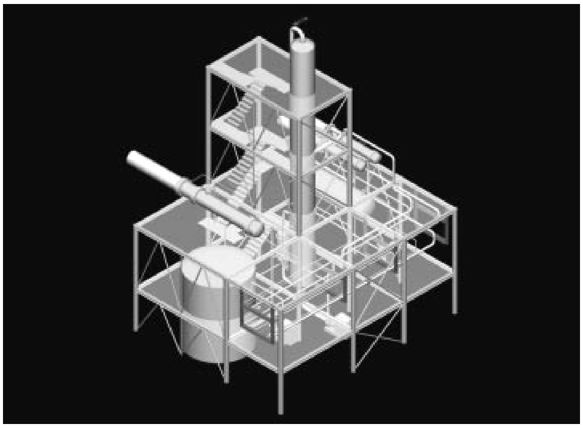


Fig. 15. 3D Models generated by PlantWise.

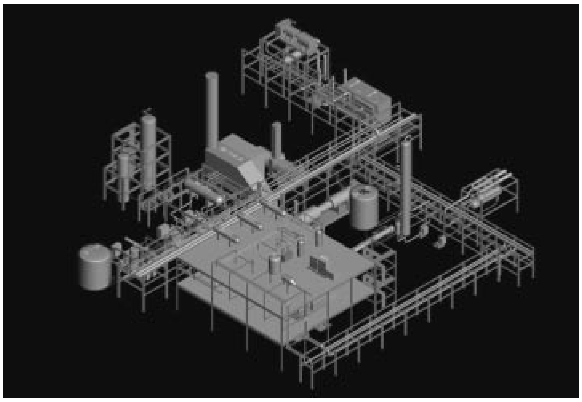


Fig. 16. 3D Models generated by PlantWise.