General Design Considerations

The development of a complete plant design requires consideration of many different factors such as:

a. Plant location	b. Site and plant layout	c. Plant operation and control
d. Utilities	e. Storage	f. Waste disposal
g. Health and safety	h. Materials handling (will be discussed in the next chapters)	

a- Plant Location and Site Selection

The geographical location of the final plant can have strong influence on the success of an industrial venture. Considerable care must be exercised in selecting the plant site, and many different factors must be considered. Primarily, the plant should be located where the minimum cost of production and distribution can be obtained, but other factors, such as room for expansion and safe living conditions for plant operation as well as the surrounding community, are also important.

The major factors in the selection of most plant sites are:

- **Marketing Area**

For materials that are produced in bulk quantities, such as cement, mineral acids, and fertilizers, where the cost of the product per metric ton is relatively low and the cost of transport is a significant fraction of the sales price, the plant should be located close to the primary market. This consideration is much less important for low-volume production and high-priced products, such as pharmaceuticals.

- **Raw Materials**

The availability and price of suitable raw materials will often determine the site location. Plants that produce bulk chemicals are best located close to the source of the major raw material, as long as the costs of shipping product are not greater than the cost of shipping feed. For example, at the time of writing much of the new ethylene capacity that is being added worldwide is being built in the Middle East, close to supplies of cheap ethane from natural gas. Oil refineries, on the other hand, tend to be located close to major population centers, as an oil refinery produces many grades of fuel, which are expensive to ship separately.

- **Transportation Facilities**

The transport of materials and products to and from the plant can be an overriding consideration in site selection. If practicable, a site should be selected that is close to at least two major forms of transport: road, rail, waterway (canal or river), or a sea port. Road transport is increasingly used and is suitable for local distribution from a central warehouse. Rail transport is usually cheaper for the long-distance transport of bulk chemicals. Air transport is convenient and efficient for the movement of personnel and essential equipment and supplies, and the proximity of the site to a major airport should be considered.

- **Availability of Labors**

Labor will be needed for construction of the plant and its operation. Skilled construction workers are usually brought in from outside the site area, but there should be an adequate pool of unskilled labor available locally, and labor suitable for training to operate the plant. Skilled craft workers such as electricians, welders, and pipe fitters will be needed for plant maintenance. Local labor laws, trade union customs, and restrictive practices must be considered when assessing the availability and suitability of the local labor for recruitment and training.

- **Water supply**

Chemical processes invariably require large quantities of water for cooling, washing, steam generation, and as a raw material, and the plant must be located near a source of water of suitable quality. Process water may be drawn from a river, from wells, or purchased from a local authority.

- **Energy Availability (power and fuel)**

Power and steam requirements are high in most industrial plants, and fuel is ordinarily required to supply these utilities. Consequently, power and fuel can be combined as one major factor in the choice of a plant site. If the plant requires large quantities of coal or oil, location near a source of fuel supply may be essential for economic operation. The local cost of power can help determine whether power should be purchased or self-generated.

Electrical power is needed at all sites. Electrochemical processes (for example, chlorine manufacture or aluminum smelting) require large quantities of power and must be located close to a cheap source of power.

A competitively priced fuel must be available on site for steam and power generation.

- **Climate**

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures require the provision of additional insulation and special heating for equipment and pipe runs. Stronger structures are needed at locations subject to high winds (cyclone/ hurricane areas) or earthquakes. Corrosive environments will need strong protection for the plant equipment.

b- <u>Site layout and plant layout</u>

- **Site layout**

The process units and ancillary buildings should be laid out to give the most economical flow of materials and personnel around the site. Hazardous processes must be located at a safe distance from other buildings. Consideration must also be given to the future expansion of the site. The ancillary buildings and services required on a site, in addition to the main processing units (buildings), include

1. Storage for raw materials and products: tank farms and warehouses;
2. Maintenance workshops;
3. Stores, for maintenance and operating supplies;
4. Laboratories for process quality control;
5. Fire stations and other emergency services;
6. Utilities;
7. Effluent disposal plant: waste water treatment, solid and or liquid waste collection;
8. Offices for general administration;
9. Canteens and other amenity buildings, such as medical centers;
10. Parking lots.

When the preliminary site layout is roughed out, the process units are normally sited first and arranged to give a smooth flow of materials through the various processing steps, from raw material to final product storage. Process units are normally spaced at least **30 m** apart; greater spacing may be needed for hazardous processes.

The location of the principal ancillary buildings should then be decided. They should be arranged so as to minimize the time spent by personnel in traveling between buildings. Administration offices and laboratories, in which a relatively large number of people will be working, should be located well away from potentially hazardous processes. Control rooms are normally located adjacent to the processing units, but those with potentially hazardous processes may have to be sited at a safer distance.

The sitting of the main process units determines the layout of the plant roads, pipe alleys, and drains. Access roads to each building are needed for construction and for operation and maintenance.

Some rules (notes) about the site layout

- ✓ Utility buildings should be sited to give the most economical run of pipes to and from the process units.
- ✓ Cooling towers should be sited so that, under the prevailing wind, the plume of condensate spray drifts away from the plant area and adjacent properties.

- ✓ The main storage areas should be placed between the loading and unloading facilities and the process units they serve.
- ✓ Storage tanks containing hazardous materials should be sited at least 70 m (200 ft) from the site boundary.

A typical plot plan is shown in Figures (1) and (2).

- **Plant layout**

The economic construction and efficient operation of a process unit will depend on how well the plant and equipment specified on the process flow sheet is laid out.

The arrangement of the major items of equipment often follows the sequence given on the process flow sheet: with the columns and vessels arranged in rows and the ancillary equipment, such as heat exchangers and pumps, positioned along the outside. A typical preliminary layout is shown in Figure (3).

The principal factors to be considered in making plant layout are:

1. Economic considerations: construction and operating costs;
2. The process requirements;
3. Convenience of operation;
4. Convenience of maintenance;
5. Safety;
6. Future expansion;

1. Economic considerations: construction and operating costs

The cost of construction can be minimized by adopting a layout that gives the shortest run of connecting pipe between equipment and the least amount of structural steel work; however, this will not necessarily be the best arrangement for operation and maintenance.

2. Process Requirements

An example of the need to take into account process considerations is the need to elevate the base of columns to provide the necessary net positive suction head to a pump or the operating head for a thermosiphon reboiler.

3. Operation

Equipment that needs to have frequent operator attention should be located convenient to the control room. Valves, sample points, and instruments should be located at convenient positions and heights. Sufficient working space and headroom must be provided to allow easy access to equipment. If it is anticipated that equipment will need replacement, then sufficient space must be allowed to permit access for lifting equipment.

4. Maintenance

Heat exchangers need to be sited so that the tube bundles can be easily withdrawn for cleaning and tube replacement. Vessels that require frequent replacement of catalyst or packing should be located on the outside of buildings. Equipment that requires dismantling for maintenance, such as compressors and large pumps, should be placed under cover.

5. Safety

Blast walls may be needed to isolate potentially hazardous equipment and confine the effects of an explosion. At least two escape routes for operators must be provided from each level in process buildings.

6. Plant Expansion

Equipment should be located so that it can be conveniently tied in with any future expansion of the process. Space should be left on pipe racks for future needs, and service pipes should be oversized to allow for future requirements.

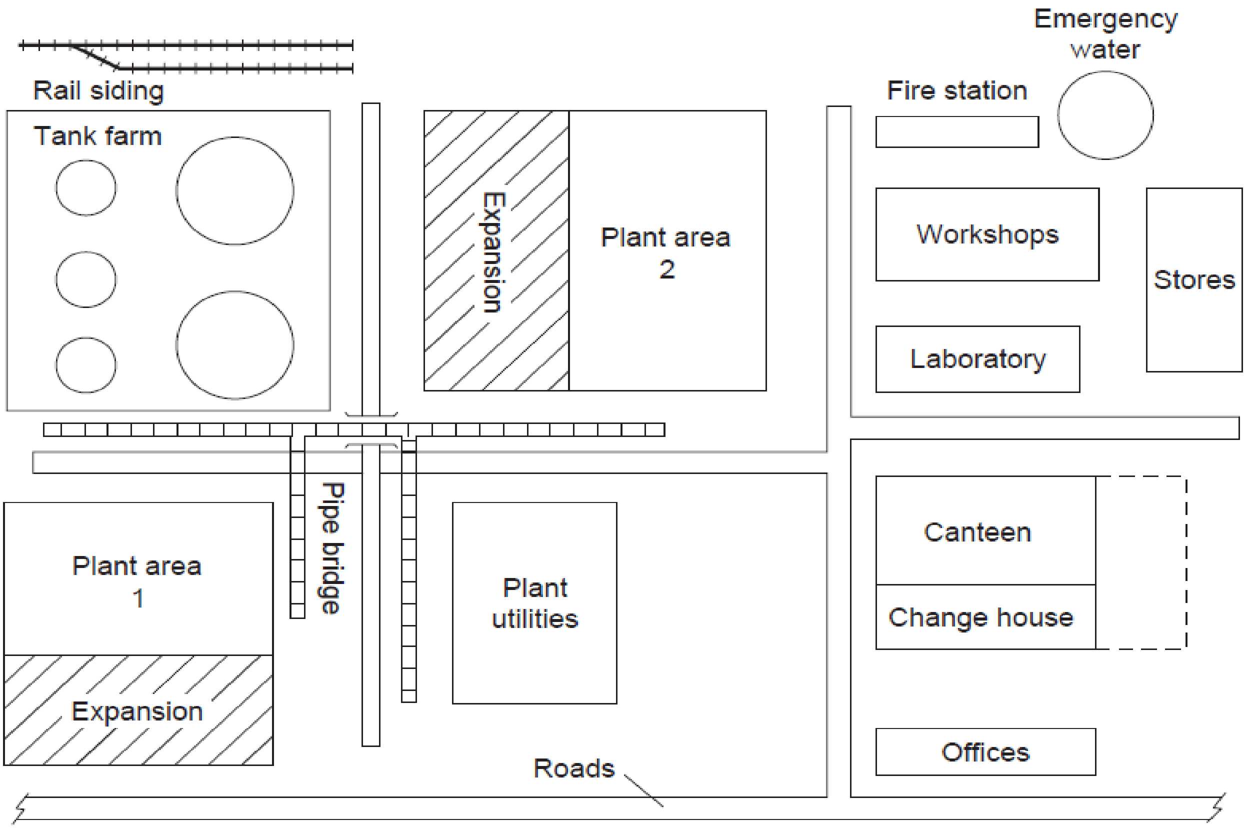

Fig.(1) Typical two dimensional site layout.

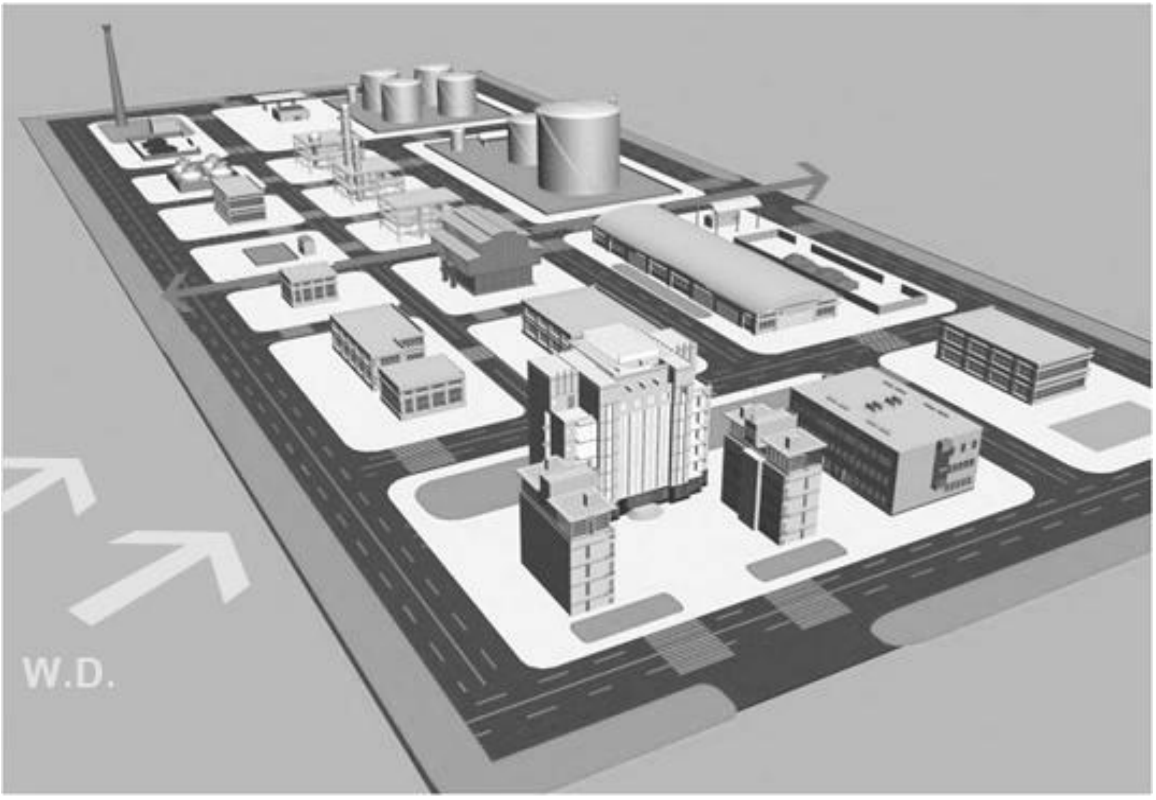

Fig.(2) Typical three dimensional site layout.

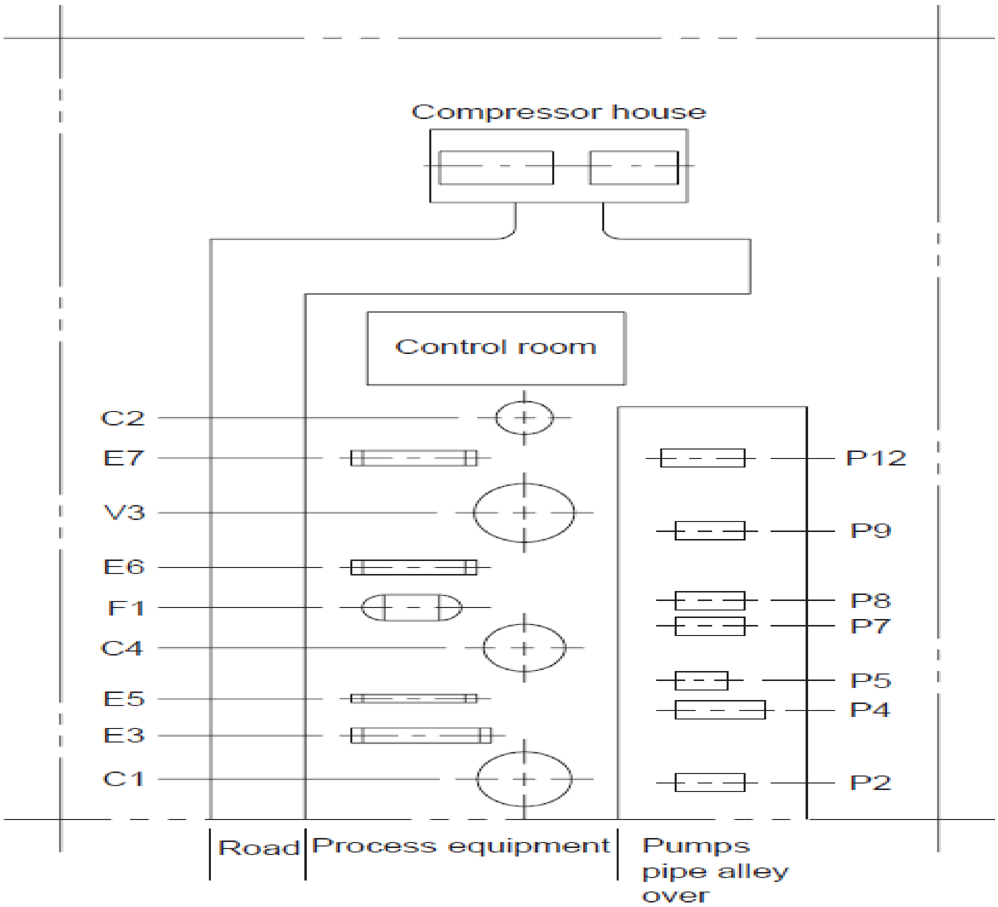

Fig.(3) Typical two dimensional plant layout.

Once the layout of the major pieces of equipment has been decided, the plan and elevation drawings can be made and the design of the structural steelwork and foundations undertaken.

Computer-aided design (CAD) tools are being increasingly used for plant layout studies, and computer models are complementing, if not yet replacing, physical models. Several proprietary programs are available for the generation of three-dimensional models of plant layout and piping. Present systems allow designers to zoom in on a section of a plant and view it from various angles. Developments of computer technology will soon enable engineers to virtually walk through the plant. A typical computer generated model is shown in Figure (4).

Some of the advantages of computer graphics modeling compared with actual scale models are:

1. It is easy to detect interference between pipe runs and pipes and structural steel that occupy the same space.
2. Expert systems and optimization programs can be incorporated in the package to assist the designer to find the best practical layout.

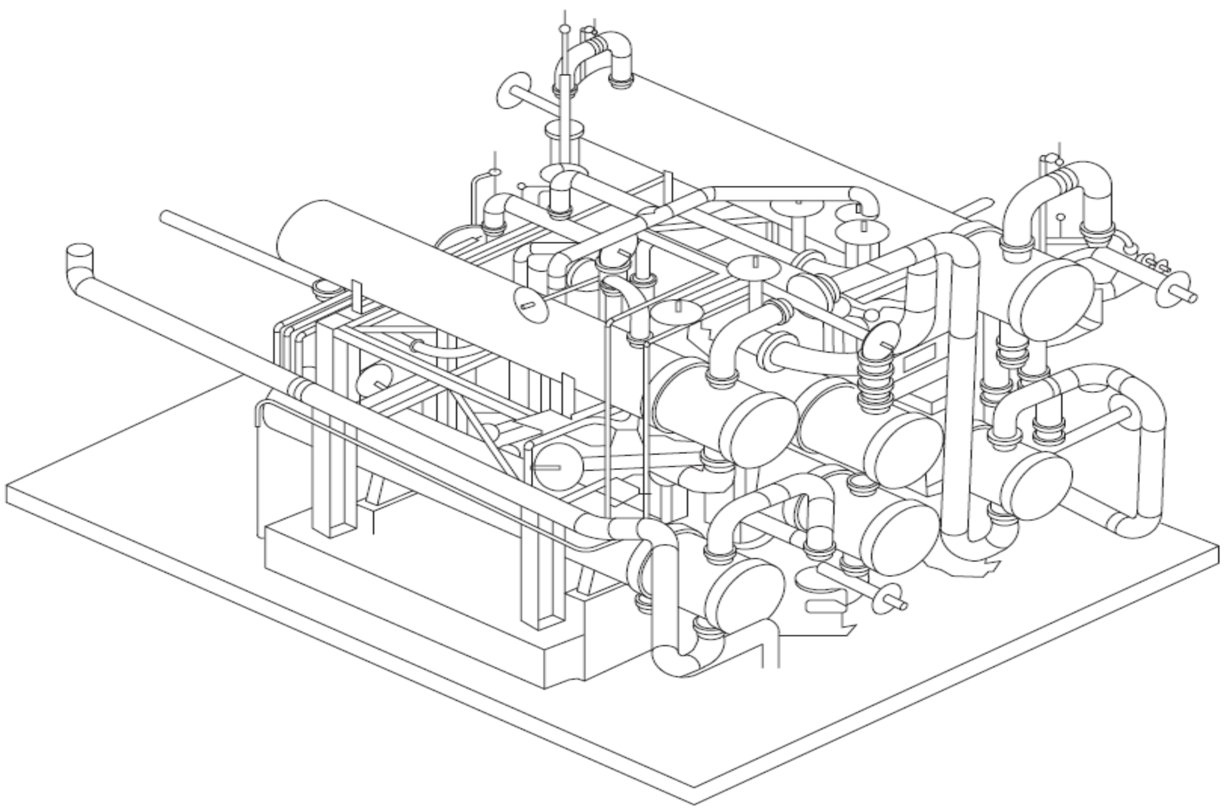

Fig.(4) Computer-generated layout "three dimensional model"

c- Plant operation and control

In the design of an industrial plant, the methods which will be used for plant operation and control help determine many of the design variables. For example, the extent of instrumentation can be a factor in choosing the type of process and setting the labor requirements.

d- Utilities

The word utility is used for the ancillary services needed in the operation of any production process. These services are normally supplied from a central site facility and include:

1. Electricity;
2. Steam, for process heating;
3. Cooling water;
4. Water for general use;
5. Demineralized water;
6. Refrigeration;
7. Compressed air;
8. Inert-gas supplies;

✓ **Electricity**

The power required for electrochemical processes, motor drives, lighting, and general use may be generated on site, but will more usually be purchased from the local supply company.

✓ **Steam**

The steam for process heating is usually generated in **water tube boilers**, using the most economical fuel available.

✓ **Cooling Water**

Natural and forced-draft cooling towers (Cooling towers work by evaporating part of the circulating water to ambient air, causing the remaining water to be chilled) are generally used to provide the cooling water required on a site, unless water can be drawn from a convenient river or lake in sufficient quantity. Sea water, or brackish water, can be used at coastal sites, but if used directly will necessitate the use of more expensive materials of construction for heat exchanger. The minimum temperature that can be reached with cooling water depends on the local climate. If the ambient temperature and humidity are high, then a cooling water system will be less effective and **air coolers** or refrigeration would be used instead.

- ✓ **Demineralized Water**

Demineralized water, from which all the minerals have been removed by ion exchange, is used where pure water is needed for process use and as boiler feed water. Mixed and multiple-bed ion-exchange units are used, one resin converting the cations to hydrogen and the other removing the anions. Water with less than 1 part per million of dissolved solids can be produced.

- ✓ **Refrigeration**

Refrigeration is needed for processes that require temperatures below those that can be economically obtained with cooling water. Vapor compression refrigeration machines are normally used.

- ✓ **Compressed Air (instrument air)**

Compressed air is needed for general use and for the pneumatic controllers that are usually used for chemical plant control. Rotary and reciprocating single-stage or two-stage compressors are used. Instrument air must be dry and clean (free from oil).

- ✓ **Inert Gases**

Where a large quantity of inert gas is required for the inert blanketing of tanks and for purging this will usually be supplied from a central facility. Nitrogen is normally used and can be manufactured on site in an air liquefaction plant (membrane system) or purchased as liquid in tankers.

e- <u>Storage</u>

Storage facilities are required for:

- ✓ Raw materials
- ✓ Intermediate products
- ✓ Final products
- ✓ Recycle materials
- ✓ Off-grade materials
- ✓ Fuels

A **storage tank** is a container, usually for holding liquids, sometimes for compressed gases (gas tank). The word "tank" originally meant "artificial lake" and came from India.

Storage tanks are available in many shapes: vertical and horizontal cylindrical; open top and closed top; flat bottom, cone bottom. Large tanks tend to be vertical cylindrical, or to have rounded corners (transition from vertical side wall to bottom profile, to easier withstand hydraulic hydrostatically induced pressure of contained liquid.

- ✓ **Choice of storage tanks**

Tanks for a particular fluid are chosen according to the flash-point of that substance. Generally in refineries and especially for liquid fuels, there are fixed roof tanks, and floating roof tanks.

A. Fixed roof tanks

Used for liquids with very high flash points, (e.g. fuel oil, water, bitumen etc.) Cone roofs, dome roofs and umbrella roofs are usual. These are insulated to prevent the clogging of certain materials, wherein the heat is provided by steam coils within the tanks. Dome roof tanks are meant for tanks having slightly higher storage pressure than that of atmosphere (eg. slop oil).

Advantages of fixed roof tank:

- ✓ Easy to construct and cheap to build.

Disadvantages:

- ✓ Material losses due to the escape of vapour.

B. Floating roof tanks

The floating roof tanks are developed to store volatile liquids to minimize the loss of valuable vapors, as well as, to minimize the hazard of dangerous vapor formation underneath a fixed roof.

Floating roof tanks are broadly divided into external floating roof tanks (usually called as floating roof tanks: FR Tanks) and internal floating roof types (IFR Tanks).

IFR tanks are used for liquids with low flash-points (eg. ATF, MS. gasoline, ethanol). These tanks are nothing but cone roof tanks with a floating roof (steel disc) inside which travels up and down along with the liquid level. This floating roof traps the vapor from low flash-point fuels. Floating roofs are supported with legs on which they rest.

FR tanks do not have a fixed roof (it is open in the top) and has a floating roof only. Medium flash point liquids such as naphtha, kerosene, diesel, crude oil etc are stored in these tanks.

Advantages of floating roof tanks:

- ✓ Reduce material losses and air pollution.
- ✓ Reduce fire and explosion risk due to very small vapour space.

Disadvantages:

- ✓ High cost.

Materials of construction for storage tanks

While steel remains one of the most popular choices for tanks, there are other materials increasing in popularity such as:

- ✓ GRP
- ✓ Thermoplastic
- ✓ Polyethylene
- ✓ Fiberglass

They offer lower build costs and greater chemical resistance, especially for storage of specialty chemicals.

Tank Wall Thickness

The tank wall must withstand:

- ✓ Hydrostatic pressure of the liquid
- ✓ Wind loading

The minimum wall thickness required to resist the hydrostatic pressure can be calculated from the equation:

$$T_t = \frac{\rho_L H_L g}{2 S_t E} \frac{D_t}{10^3}$$

where

T_t: tank thickness required at depth H_L, mm;

H_L: liquid depth, m;

ρ_L: liquid density, kg/m3;

E: joint efficiency (if applicable);

g: gravitational acceleration, 9.81 m/s^2;

S_t: maximum allowable stress for tank material, N/mm^2;

D_t: tank diameter, m.

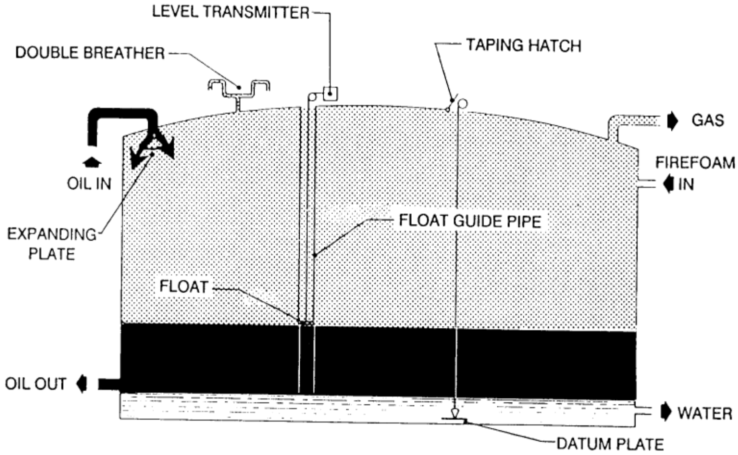

Fig.(5) Fixed roof tank.

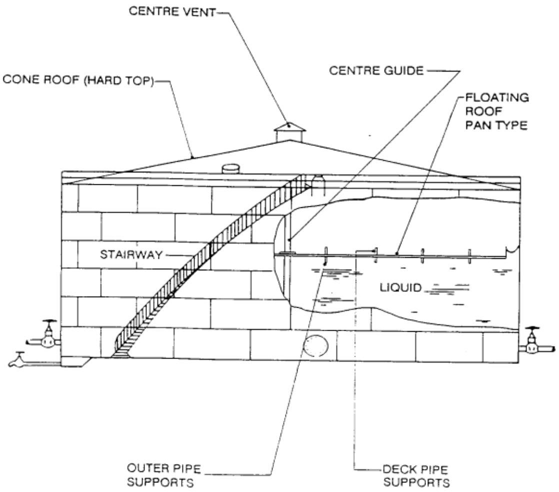

Fig.(6) Internal floating roof tank.

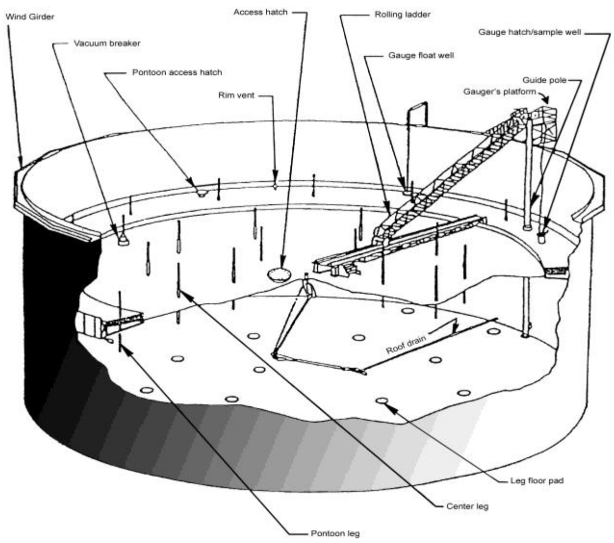

Fig.(7) External floating roof tank.

Important note:

Since most liquids can spill, evaporate, or seep through even the smallest opening, special consideration must be made for their safe and secure handling. This usually involves building a **bunding**, or **containment dike**, around the tank, so that any leakage may be safely contained. In some cases these area is called the tank farm.

Tank failures

There have been numerous catastrophic failures of storage tanks. These failures may be attributed to:

1. Poor design and construction, with a wall too thin to bear repeated loads from the contents.
2. The tank had not been tested before use by filling with water, and was also poorly riveted.
3. Corrosion problem, so storage tanks must be protected against corrosion (e.g cathodic protection)
4. Faulty welding or by sub-standard steel.

However, storage tanks also present another problem, surprisingly, when empty. If they have been used to hold oil or oil products such as gasoline, the atmosphere in the tanks may be highly explosive as the space fills with hydrocarbons. If new welding operations are started, then sparks can easily ignite the contents, with disastrous results for the welders.

Using an inert gas blanket to prevent explosive atmospheres building up from residues may solve this problem.

f- Waste disposal

Waste disposal is a serious problem for many chemical plants. Materials produced by the process that cannot be recycled or sold as byproducts must be disposed of as waste. In some cases additional treatment is required to concentrate the waste stream before sending it to final disposal.