MECHANICAL EQUIPMENT DESIGN Online Course

Part I: Introduction to Mechanical Equipment

STUDY NOTES

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Introduction

This course deals with the fundamentals of mechanical equipment. Mechanical equipment are considered to be fundamental components of process plants such as a Power Plant, Fertilizer Plant, Refineries, Petrochemical Plants, Gas Processing units, pharmaceutical industries etc.

This chapter is meant to be an introduction to the following modules of the course, which will focus more on individual applications and problems. The primary focus of this training session is on piping systems, pressure vessels, heat exchangers and storage tanks.

Piping Systems

Pipes and piping systems are the veins and arteries of chemical process plants used for transporting liquids, vapours, slurries, solids etc. under various conditions, as imposed by the process design of the plant. The network of pipes is subjected to extremes of temperature, pressure, flow and combination of these. In addition, they are subject to corrosion, erosion, toxic condition and radioactivity, all of which calls for proper piping design enabling trouble free operation of the plant over a long period of time.

Pressure Vessels

Pressure Vessels are “containers” which contain various process fluids at a considerably higher pressure than the normal atmospheric pressure. As these equipment are pressurized, they become very critical due to the inherent safety issues. A failure of a pressure vessel may cause damage to the whole process plant where it is installed. Consequently, their design, manufacture, and operation are regulated by engineering authorities backed up by laws.

Pressure Vessels come in various configurations and orientations depending upon their application.

Heat Exchangers

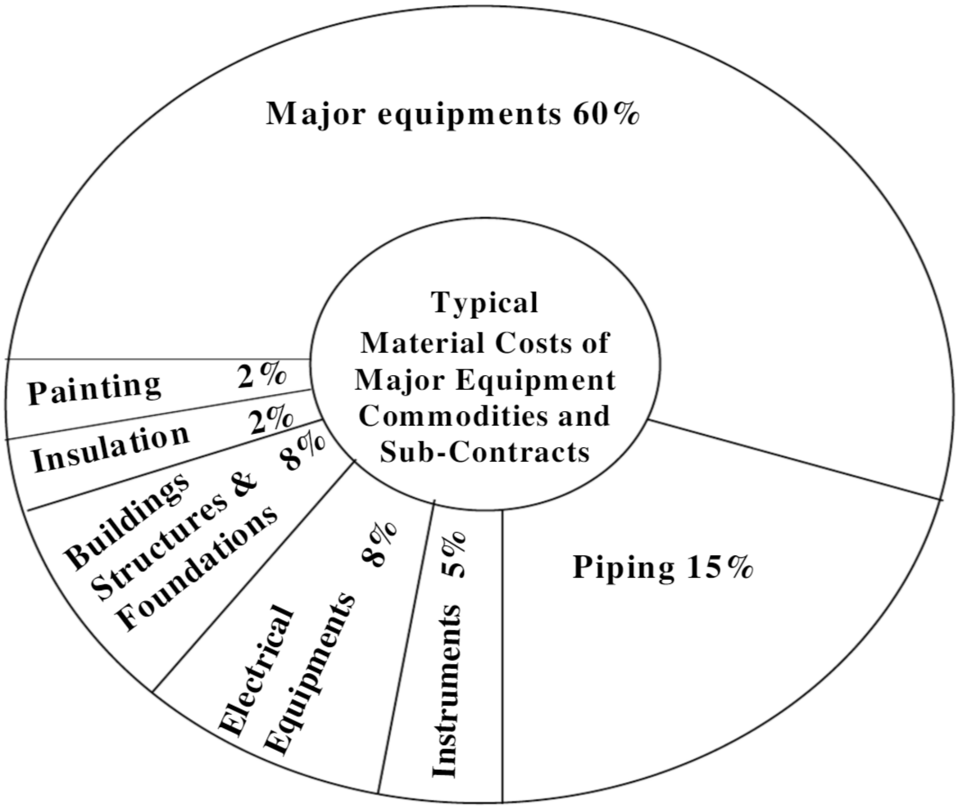
Heat Exchangers are used to change the temperature of a fluid by exchanging heat energy of that fluid with another fluid. This exchange of heat is usually without exchange of mass. In the process industry usually three types of heat exchangers are used: Shell & Tube, Air Coolers, Plate

Storage Tanks

Storage tanks are also containers of process fluid but differ from pressure vessels in various aspects. The purpose of the storage tanks is to store very large amounts of fluid which may be used later in the process (e-g De-mineralized Water Storage tank) or the fluid that is the final product in a processing unit (e-g Oil storage in a refinery). Storage tanks are usually very low pressure containers as compared to pressure vessels. Most of the storage tanks are vertical cylindrical type with very large diameter (some time as large as 100 meters).

1. Piping Systems

Capital cost of piping forms a large portion of the investment in the plant exceeded only by that of major equipment. Pie Chart at the end of this paragraph shows the relative cost of various material components of a plant. As can be seen from the chart, piping accounts for nearly 15% of the overall material cost.



Relative cost of various material components of a plant

Normally, out of the total engineering effort covering project management, detailed engineering, procurement, inspection and expediting, etc., 65% of the hours are required for detailed engineering. Out of this, 25% is required for piping engineering alone, the balance 40% accounting for civil, mechanical, electrical and instrumentation engineering.

Progress in piping engineering being very much dependent upon the feedback of equipment data (static and rotating) as also on control valves and other inline instruments, a close monitoring of the schedule of orders for these equipment and follow up with vendors for data and drawings is required to finalise Piping Plans, generate Isometrics, order bulk Piping Material as well as Piping Speciality Items and release drawings to site for speedy construction and thus facilitate prompt start up.

The trend in recent years has been to develop and employ better techniques in piping design to save time and also to improve accuracy. Computers are being extensively used to obtain speedy solutions to more complex problems of plant design and to solve problems of stresses in piping. Recent past has seen development of software for production of piping detail drawings, piping isometrics, bill of material, estimation and cost control.

Piping Engineer has therefore the added responsibility in understanding and upgrading his / her knowledge on the application of a growing number of techniques of this nature helping speedy work execution.

The most revolutionary advancement in the Piping Design in recent past had been the concept of 3D Modelling of the Plant by using sophisticated Software such as PDMS. This provides an opportunity to build the entire plant on soft media in a 3D environment to the last degree of detailing, to be able to identify and rectify practically every problem related to design and construction prior to actual commencement of erection activities at the Site.

Typical piping Arrangement in a Petroleum Refinery

As a first classification, Piping Engineering is divided into 3 sub-specialties as described below.

1.1) Piping Specification

There are different processes, systems and services in an industrial facility. Each of these systems has specific requirements for pressure, temperature and corrosion among other things.

A Pipe Specification is a document detailing all the features of the elements of a piping system for a specific service. This way, piping, flanges, fittings, valves and any other element necessary shall be specified.

A typical piping specification can be seen below:

SERVICE:	Process	MATERIAL:	Carbon Steel
RATING CLASS:	150, ASME B16.5a-1998	DESIGN CODE:	ASME B31.3-1999
TEMPERATURE LIMIT:	-20F to 800F (Note 09)	STRESS RELIEF:	Per ASME B31.3
NOMINAL CORROSION ALLOWANCE:	0.125 in. (0.10 in. MIN)	EXAMINATION:	Per ASME B31.3

PRESSURE - TEMPERATURE RATINGS

TEMP F	-20 to 100	200	300	400	500	600	700	800
TEMP C	-29 to 38	93	149	204	260	316	371	427
For NPS 1/2 through NPS 26 (Full flange ratings per ASME B16.5 and ASME B16.47, Tables 2-1.1.)								
psig	285	260	230	200	170	140	110	80
kPag	1965	1795	1585	1380	1170	965	760	550
For NPS 28 through 48 (Note 01)								
psig	Calc	Calc	Calc	Calc	Calc	Calc	Calc	Calc
kPag	Calc	Calc	Calc	Calc	Calc	Calc	Calc	Calc

ITEM	NOTES	NPS	SCH/RAT	ENDS	DESCRIPTION
PIPE	01, 19, 137				
		1/2 – 1-1/2	XS		CS, SMLS, ASTM A106-B or A53-B, type S or API 5L-B (E_j=1.00)
		2 – 24	STD		CS, ERW, ASTM A53-B, type E (E_j=0.85)
		26	STD		CS, DSAW, API 5L-B, straight seam (E_j=0.95)
	59	28 – 48	Calc		CS, DSAW, API 5L-B, straight seam (E_j=0.95)
NIPPLES	03, 19				
Branch		1/2 – 1-1/2	XS		CS, SMLS, ASTM A106-B or A53-B, type S or API 5L-B (E_j=1.00)
Swage (CONC)		1/2 – 1-1/2	XS		CS, ASTM A234-WPB-S, MSS SP-95
Swage (ECC)		1/2 – 1-1/2	XS		CS, ASTM A234-WPB-S, MSS SP-95
FITTINGS	02				
Sockolet		1/2 – 1-1/2	Class 3000	Weld	CS, ASTM A105, MSS SP-97
Thredolet	03	1/2 – 2	Class 3000	Weld	CS, ASTM A105, MSS SP-97
SW Latrolet		1/2 – 1-1/2	Class 3000	Weld	CS, ASTM A105
THRD Latrolet	03	1/2 – 2	Class 3000	Weld	CS, ASTM A105
SW Elbolet		1/2 – 1-1/2	Class 3000	Weld	CS, ASTM A105
THRD Elbolet	03	1/2 – 2	Class 3000	Weld	CS, ASTM A105
90 ELL		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
45 ELL		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Tee		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Tee (RED)		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Plug	03	1/2 – 2		THRD	CS, ASTM A105, round head, ASME B16.11
Coupling		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Coupling (RED)		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Coupling	03	1/2 – 2	Class 3000	THRD	CS, ASTM A105, ASME B16.11
Coupling (RED)	03	1/2 – 2	Class 3000	THRD	CS, ASTM A105, ASME B16.11
Cap		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, ASME B16.11
Cap	03	1/2 – 2	Class 3000	THRD	CS, ASTM A105, ASME B16.11
Reducing Insert		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, MSS SP-79
Union (GJ)		1/2 – 1-1/2	Class 3000	SW	CS, ASTM A105, integral seat, MSS SP-83
Reducer (CONC)		2 – 48		Weld	CS, ASTM A234-WPB-W, ASME B16.9
Reducer (ECC)		2 – 48		Weld	CS, ASTM A234-WPB-W, ASME B16.9
Weldolet	05	2 – 42		Weld	CS, ASTM A105, MSS SP-97
90 LR ELL		2 – 48		Weld	CS, ASTM A234-WPB-W, ASME B16.9
45 LR ELL		2 – 48		Weld	CS, ASTM A234-WPB-W, ASME B16.9
Tee		2 – 48		Weld	CS, ASTM A234-WPB-W, ASME B16.9
Cap		2 – 48		Weld	CS, ASTM A234-WPB-S, ASME B16.9

Typical piping class specification

1.2) Plant Layout

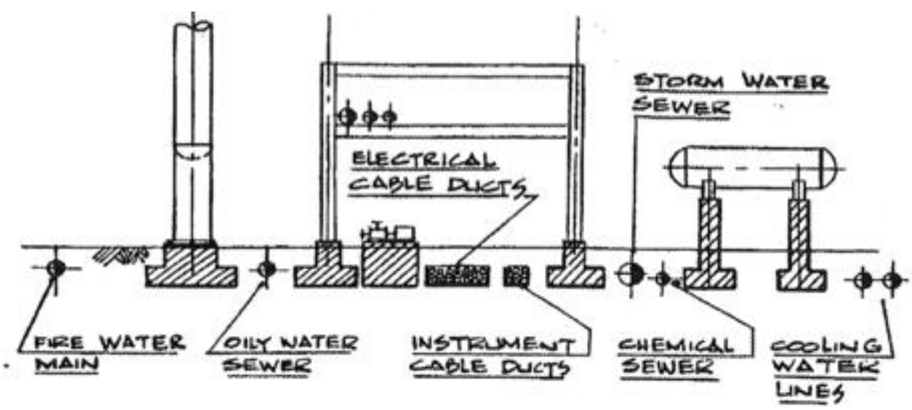
After the diameter and material of the pipe have been selected and that the required thickness of pipe wall and class ("rating") of the flanges has been established, the piping designer will need to develop an economic piping arrangement for the new system.

Equipment should be located and positioned bearing in mind operability and maintainability, while meeting safety requirements. Below is a table that serves as a reference for the provision of equipment:

REF.	ITEM	BASIC SPACING
RA1	TOWERS	1.5
RB1	REACTORS ABOVE AIT EXTERNALLY INSULATED	4.5
RC1	REACTORS ABOVE AIT INTERNALLY INSULATED	7.5
RD1	DRUMS	1.5
RE1	ON-SITE PRESSURE STORAGE VESSEL	22.5
RF1	BLOWDOWN AND DISENGAGING DRUMS	7.5
RG1	EXCHANGERS OPERATING ABOVE AIT	4.5
RH1	EXCHANGERS OPERATING BELOW AIT	1.5
RI1	AIR FIN COOLERS	3
RJ1	FIRED HEATERS	15
RK1	COOLING TOWERS	15/30
RL1	PUMPS ABOVE AIT	4.5
RM1	PUMPS HANDLING FLAMMABLE MATERIALS	3
RN1	GAS COMPRESSORS AND EXPANDERS HANDLING FLAMMABLE MATERIALS	7.5
RO1	COMPRESSOR DRIVERS (OTHER THAN STEAM OR MOTOR)	10.5
RP1	EQUIPMENT HANDLING NON-FLAMMABLES	X
RQ1	CENTRAL CONTROL HOUSE	30
RR1	UNIT CONTROL HOUSE	15
RS1	ELECTRICAL SUBSTATION	15
RT1	MAIN EQUIPMENT STRUCTURES	N.A.
RU1	ON SITE PIPE RACKS	4.5
RV1	EMERGENCY VALVES FOR SHUT-OFF, ISOLATING, SNUFFING ETC	7.5

RA1	RB1	RC1	RD1	RE1	RF1	RG1	RH1	RI1	RJ1	RK1	RL1	RM1	RN1	RO1	RP1	RQ1	RR1	RS1	RT1	RU1	RV1
3																					
4.5	1.5																				
7.5	7.5	1.5																			
1.5	4.5	7.5	1.5																		
22.5	22.5	22.5	22.5	10																	
7.5	15	15	7.5	22.5	X																
4.5	4.5	7.5	4.5	22.5	15	1															
1.5	4.5	7.5	1.5	22.5	7.5	4.5	1														
3	4.5	7.5	3	22.5	7.5	4.5	3	X													
15	4.5	7.5	15	22.5	15	7.5	15	15	Y												
15	15	15	15	22.5	15	15	15	15	30	X											
4.5	4.5	7.5	4.5	22.5	15	4.5	4.5	4.5	7.5	15	1.5										
3	4.5	7.5	3	22.5	7.5	4.5	3	3	15	15	4.5	1									
7.5	7.5	7.5	7.5	22.5	15	7.5	7.5	7.5	22.5	15	7.5	7.5	X								
10.5	4.5	7.5	10.5	22.5	15	4.5	10.5	10.5	7.5	15	4.5	10.5	X	X							
X	4.5	4.5	X	X	X	4.5	X	X	4.5	X	4.5	X	X	X	X						
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	X	X					
15	15	15	15	22.5	15	15	15	15	15	15	15	15	15	15	X	X	X				
15	15	15	15	22.5	15	15	15	15	15	15	15	15	15	X	X	X	X	X			
X	4.5	4.5	X	22.5	X	4.5	X	X	15	15	4.5	3	7.5	X	X	30	15	15	X		
3	4.5	4.5	1.5	4.5	4.5	4.5	1.5	3	6	4.5	3	1.5	4.5	4.5	X	7.5	4.5	4.5	X	X	
7.5	7.5	7.5	7.5	22.5	7.5	7.5	7.5	N.A.	15	N.A.	7.5	7.5	7.5	7.5	X	X	X	N.A.	7.5	X	X

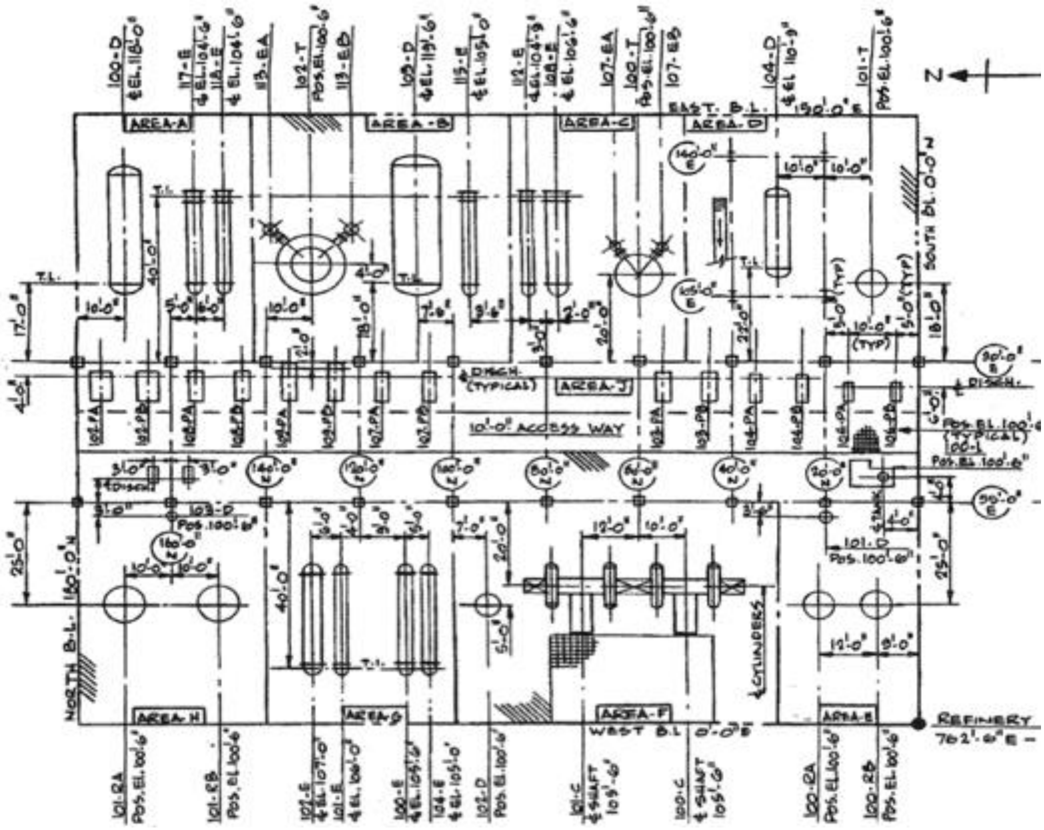
Typical minimum distance of equipment for industrial plants



Cross section of Piperack showing underground elements

The plot plan is one of the key documents in any project of a plant of industrial processes, produced during the engineering stage.

It is mainly used to locate equipment and support infrastructure and to establish the sequence of major construction activities.



Typical plot plant in an industrial plant

The arrangement of a plant must be "fixed" at the beginning of the project, before all equipment requirements have been verified and solved.

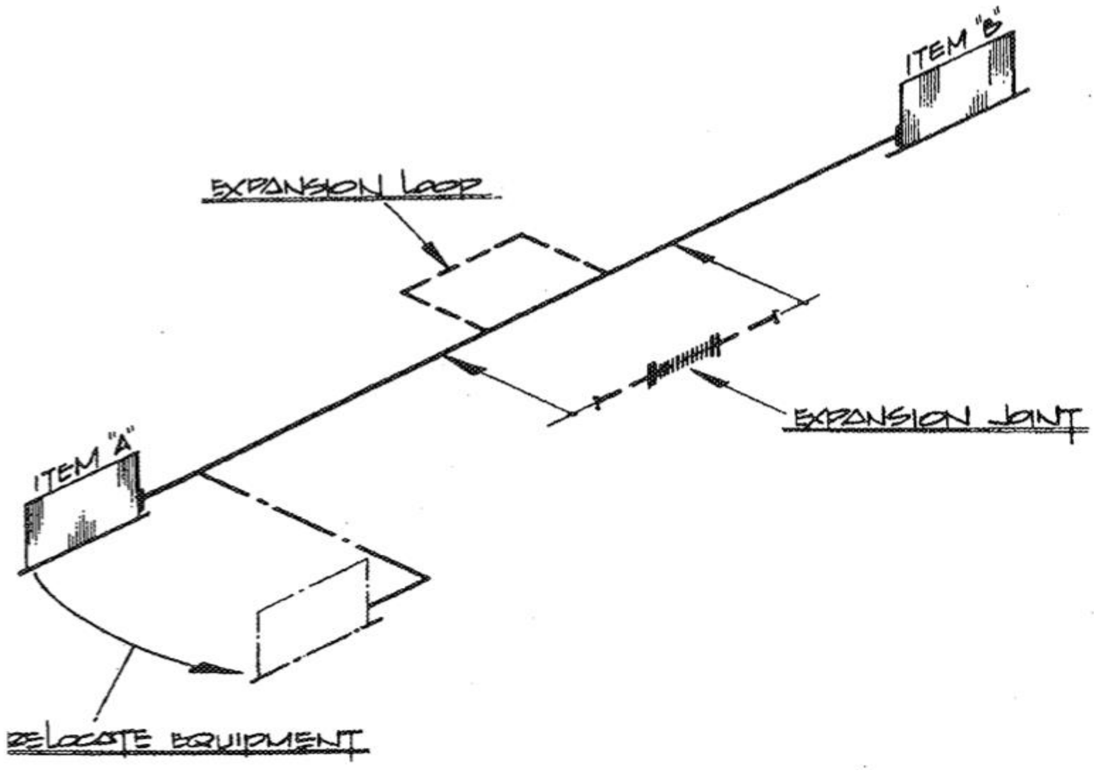
Therefore, this document is a reflection of the designer's ability to anticipate problems concerning the design of mechanical equipment and provide the necessary space to operate and maintain the plant properly and safely.

Once the project contract is obtained, the proposed plot plan has to be updated including the latest information about the positioning of the equipment; it is reviewed and approved by the customer.

This document becomes the basis of all the engineering phase of the project and becomes the "estimated plot plan."

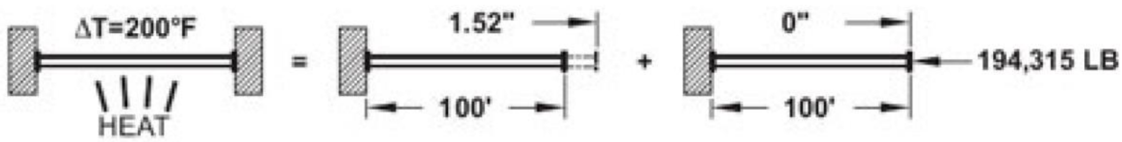
1.3) Piping Stress Analysis

Piping stress analysis consists in determining whether a line has the capacity to absorb the loads that may overstress it, such as the own weight of the pipe, thermal expansion, the forces produced by fluid pressure, vibration, earthquake and other. One factor that may increase or decrease piping flexibility is the pipeline configuration.



Alternatives to obtain a flexible design

A piping system that is free at least in one end, it would be able to expand and contract freely. However, if both ends are anchored, the pipe cannot expand generating an intrinsic load in the system.



Tipical induced force due to temperature change

Piping systems must have sufficient flexibility so that the thermal expansion or contraction, and the movements of supports and equipment don't lead to:

- *Failure of the pipe or the supports by overstress or fatigue*
- *Leaking joints*

- *Failure in nozzles of equipment (pressure vessels, pumps, turbines.), due to overstress.*

Expansion loops in aboveground piping.

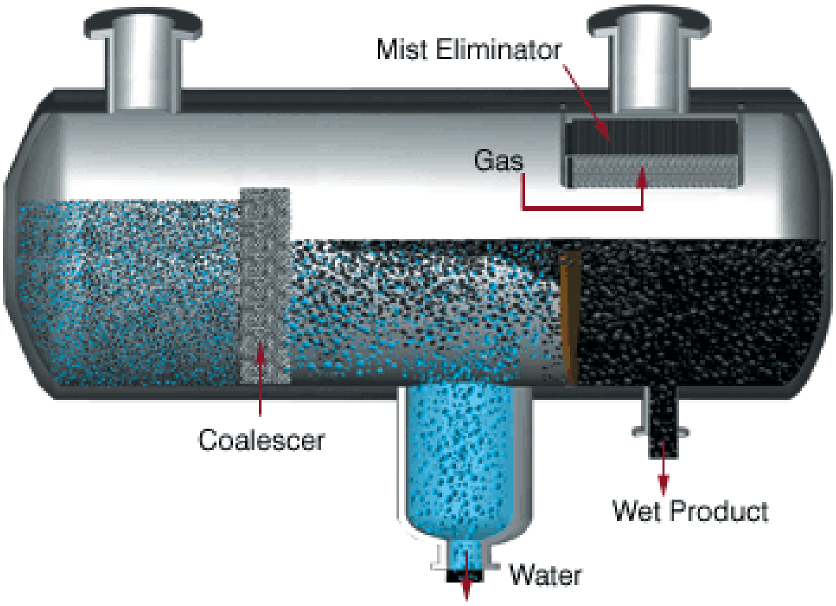
It is recommended that stress analysis calculations are carried out with computer software (CAESAR II for example) which, with a high degree of accuracy, determines the displacement and rotation generated in the system, product of thermal expansions.

2. Pressure Vessels

2.1) Drums

Vessels or drums are provided for the following:

- Vapor - liquid separation
- Liquid - liquid separation (for example oil - water)
- Vapor surge
- Liquid surge (surge ~ rapid change in flow rate)



Coalescer drum

Above is an example of the internals and process in a horizontal vessel. The input is a mixture of fluids and gas, the coalescer makes the fluids and particles easier to separate in the middle. Water will leave at the bottom the black wet product is lighter then water and will overflow in the right compartment. The gas will leave the vessel through a mist eliminator (catches fluid drops) at the right top of the vessel.

Horizontal vessels should be located at grade, with longitudinal axis at right angles to the pipeway if possible. Consider saving plot space by changing vessels from the horizontal and by combining vessels together with an internal head. Size and number of access platforms on horizontal vessels shall be kept to a minimum and are not to be provided on horizontal vessels or drum when the top of the vessel is 2.5 meters or less from grade.

Channel end of vessels provided with internal tubular heaters will face towards open space. Withdrawal area must to be indicated on studies, General Arrangement and Plot Plants.

Horizontal drum ready for transportation

The figure shows at the left a manhole with davit. The davit holds the flat plate (which is heavy) when the manhole is opened. There are small clips at the shell for attachment of the insulation.

Example of a vertical vessel on a skirt

Above is an example of a vertical vessel on a skirt. The manhole with the davit is show at this side and various smaller nozzles.

Vertical vessel on legs

Vertical vessel in structure

Notice the piping at the right is down to grade level for easy access to valves and instruments.

Horizontal drum at elevation on concrete foundation

The drum has a platform at the top for operators and maintenance personnel access to instruments, flanges and valves

Horizontal vessels

The figure shows three similar horizontal vessels with piping, valves, platforms and supports. The amount of steel around the piping is significant.

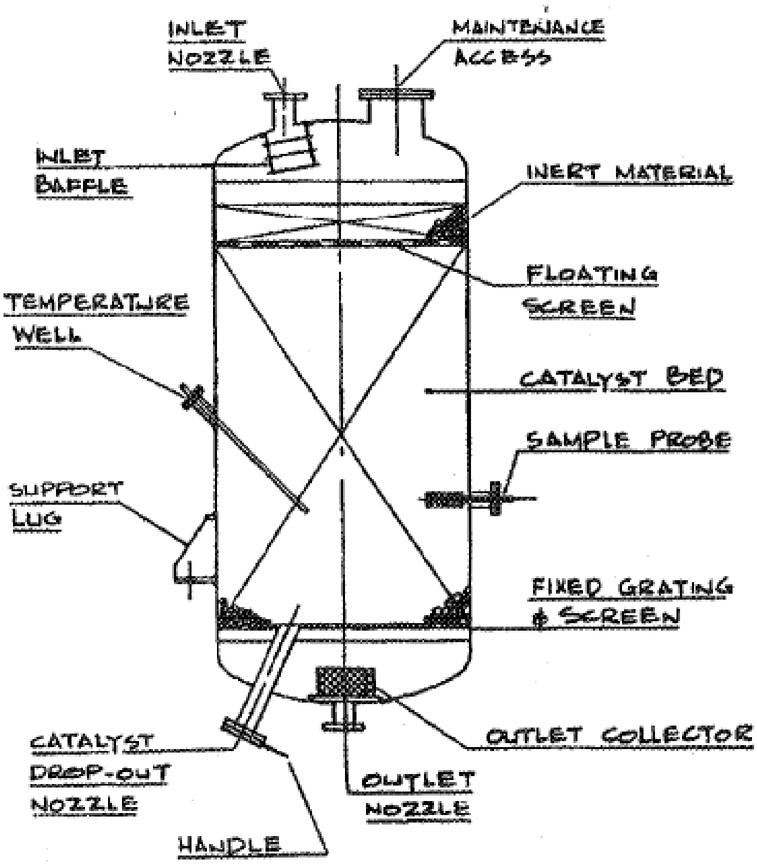
Access to area and instrument

The above figure demonstrates that during the design phase all aspects need to be considered carefully. For example whether platform and ladders could be combined, whether supporting of high pipe lines could not be done more economical by changing the design.

2.2) Reactors

A reactor is a pressure vessel in which the chemical reactions necessary for the production of products takes place. Inside this equipment, there is normally the catalyst and the internal elements, such as: distributor, brackets, racks, etc).

A chemical reaction involves the breaking of certain bonds in the reactant molecules and the formation of new ones that as a result deliver new product molecules.



Typical configuration of Fixed Bed Reactors

The reactor itself is normally a vertical pressure vessel, where the material must be able to withstand elevated operating temperatures and pressure, thus requiring thick cylinders up to 350 mm in some cases.

2.2.1) Design Considerations

Reactors design is a very extensive discipline, these equipment are designed ad-hoc, according to the reaction process, depending on circumstances such as the nature and stage of reactants, catalysts, type of reaction (exothermic or endothermic), flow rate, etc.

The reactor volume is defined by the amount of catalyst necessary for the reaction to occur. This amount is usually defined by the space velocity in the vessel (hourly space velocity).

Sea transportation of Hydrocracking Reactors

2.2.2) Mechanical Design

The optimum cost reactor should be determined based on process requirements, together with mechanical and material considerations. The effect of reactor diameter and height, and the number of reactors in total reactor cost must be balanced against investment and operating costs for the treat gas compressor (when required), pumps, external piping, regeneration facilities, etc. Reactor types (lined, unlined, alloy clad) and shape (cylindrical, spherical) are also factors to be considered.

2.2.3) Catalyzers

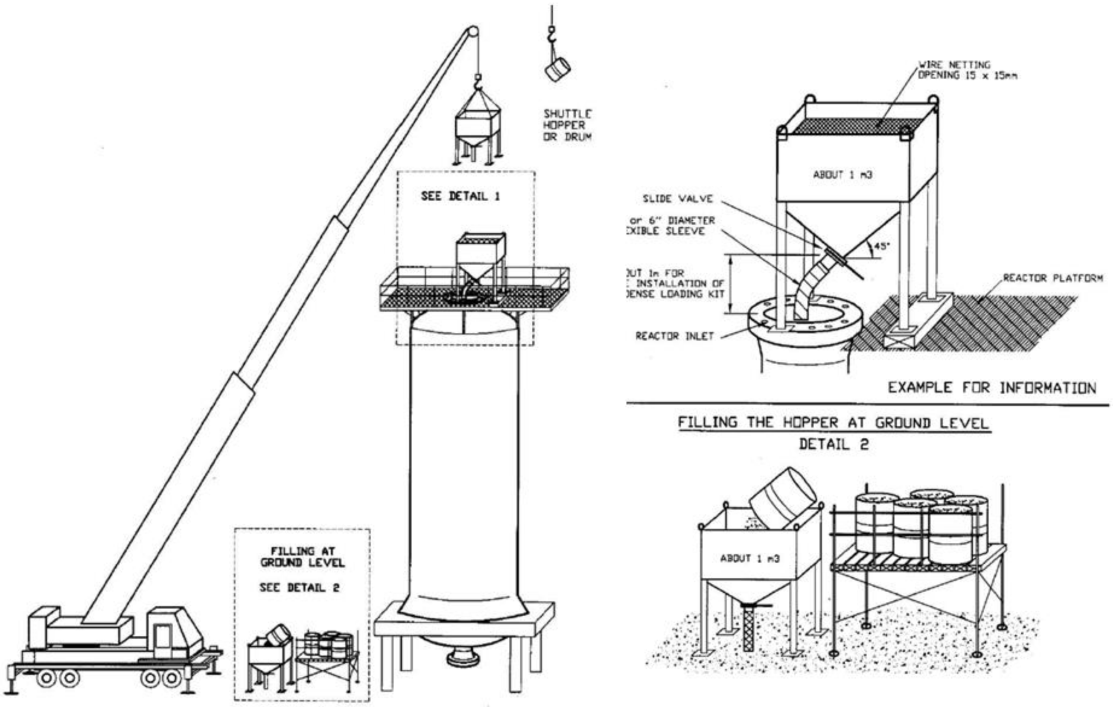
The catalyst is a substance which, even in small quantities, modifies the reaction, decreasing the activation energy.

This phenomenon is called catalysis, which may be homogeneous (single stage reaction) or heterogeneous (two or more phases).

Catalyzers used in reactors depend upon the specific process and specific manufacturer data. They are available in the form of cylindrical pellets, spheres or powder.

When the pieces of catalyst are very small, layers are placed on top and bottom of the bed to minimize catalyst losses.

Catalyzer used in Isomerization Reactors



Catalyzer Loading

2.2.4) <u>Internals</u>

The design of internal parts must follow the licensor's (owner of the patent or technology) specific detailed engineering requirements.

Inlet Distributors

They are used to achieve a uniform distribution of the feed over the catalyst bed.

When two phase inlet distribution is needed, a conical deflector is recommended.

Distribution Baskets

Their aim is to intensify catalyzer efficiency, increasing the surface area in the bed. They are located at the top part of the catalyzer bed and they guarantee the flow even when the bed is obstructed.

Bed supports

They are located on the top and bottom parts of the reactor; the purpose is to support the catalyst bed.

Quench Distributors

Used in multi-bed reactors when the temperature rises above that required for the catalyst bed, therefore cooling between beds is necessary. Overall, the design is similar to feed inlet distributors, although it depends on the type of quench fluid.

Outlet Collectors

They are located at the bottom part of the reactor, they hold the catalyst and allow the outlet of the fluid due to the free space they create.

5. References

This document has been compiled using the following references:

- **Guide to storage tanks and equipment – BOB LONG**
- **Pressure Vessel Design Manual – DENISS MOSS**
- **Gas Processors Suppliers Association - DATA BOOK**
- **Process Equipment Design Brownell, LLOYD. E.**
- **Handbook For Process Plant Engineers - WATERMEYER**