Pressure Vessel Newsletter

Volume 2018, January Issue

Serving the Pressure Vessel Community Since 2007

From The Editor’s Desk:

Where is the oil and gas industry in US headed in the year 2018?

The industry was hit particularly hard in 2014, when oversupply of the liquid gold drove prices down globally. Investment bank Goldman Sachs predicts that the industry has shed nearly 170,000 jobs since the end of 2014. But what goes up must come down – or vice versa in this case. In June 2017, the West Texas Intermediate (WTI) fell to nearly $42 a barrel; in less than seven months today, it is trading at nearly $65 a barrel.

Right now, US is sitting on 264 billion barrels of shale oil reserve – which is more than Saudi Arabia, Russia or any other oil producing country on the planet. All of this shale oil is now starting to be tapped as the prices are rising. Goldman is forecasting that the oil industry in US will make a huge comeback to the tune of 100,000 new jobs by the end of 2018.

Is this growth sustainable? The consensus is that going by the improving fundamentals, the current higher oil process are here to stay. There is expectation that OPEC and other major producers will continue to keep 1.8 million barrels a day off the market in their attempt to clear the supply glut. Supply from these countries – that account for nearly 40% of world’s crude – is expected to remain weak for some time. At the same time, the anticipated surge in demand in 2018 is set to push the global consumption of crude oil above 100 million barrels per day threshold for the first time. This will pave the way for crude oil exports from US to move upward of 2 million barrels a day.

It is expected that oil prices will continue to head higher.

[*Compiled from forecasts by Goldman Sachs and Zacks.*]

Ramesh K Tiwari

ramesh.tiwari@codesignengg.com

In this issue…

OIL REFINERY

REFINERIES MAY APPEAR COMPLICATED AT FIRST GLANCE. BREAKING THEM DOWN INTO A SERIES OF UNITS MAKES THEM EASIER TO UNDERSTAND. THIS ARTICLE DESCRIBES THE BASIC BUILDING BLOCKS OF A TRANSPORTATION FUELS REFINERY, FROM CRUDE OIL INLET TO FUELS DISTRIBUTION.

INTRODUCTION

Refineries - with their multitude of tanks and vessels, numerous pipes of varying sizes, fired heaters, pumps and compressors, instrumentation and control systems, and more – can be overwhelming to the outside observer. The primary purpose of a refinery is to economically convert raw crude oil into more-useful fuels and petrochemicals. The simple flow diagram in Figure 1 shows how crude oil is converted into higher-value fuel products.

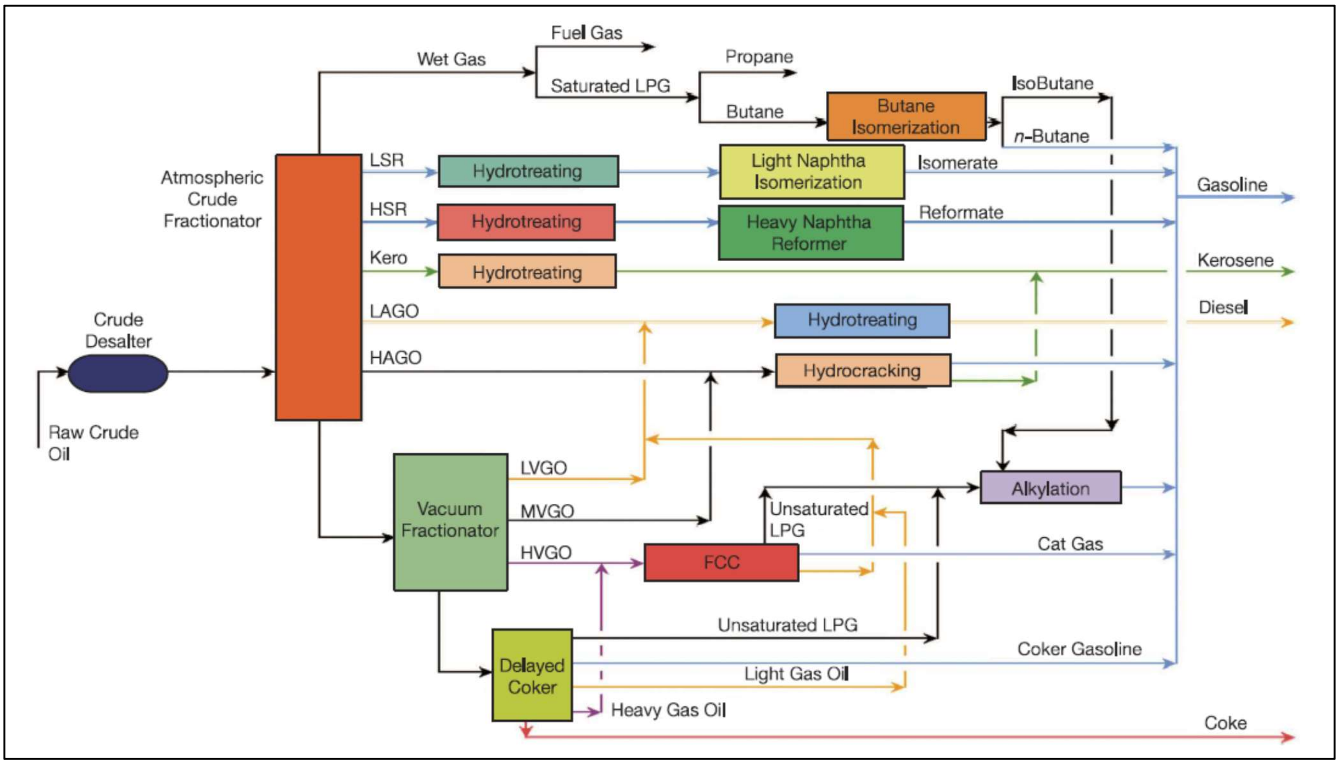


Figure 1: Refinery Flow Diagram

First, the raw crude is washed in a desalter and heated. Next, it enters the atmospheric crude fractionator, followed by the vacuum fractionator. These first units in a refinery involve no chemical reactions or catalysts; rather, based on each component's boiling point, they separate and distribute the range of components for further downstream processing and conversion. Downstream units include such equipment as pumps and compressors, heat exchangers, reactors, and distillation columns. Some of these downstream units contain a specific catalyst to convert one product to a different product with a more desirable qualities. Streams are then separated into intermediate products and off-gases. Finally, certain intermediate products from these units are blended into final products as per required specifications.

Each refinery is designed to process crude oil of a particular composition, whether that is the composition of a single crude oil or the composition of a blend of crude oils. If an individual crude oil with the desired feed properties for a refinery is not available for processing, multiple crude can be blended to obtain a feedstock that better matched the refinery's capabilities. As the crude oil is separated and distributed to downstream processing units, more scrutiny is given to four main types of components – paraffins, olefins, napthlenes, and aromatics (PONA). The crude's PONA content is important in setting the objectives of the catalysts used in downstream units in terms of functionality and desired reaction conversion.

In the U.S., crude oil is measured on a volumetric at a standard temperature of 60°F, typically in units of barrels (1 bbl = 42 gal) per day (bpd). Outside the U.S., crude oil tends to be measured on a mass basis in units of metric tons per day. In general, a small refinery produces 100,000 bpd or less, a mid-size refinery is in the range of 100,000 – 250,000 bpd, and large refineries (typically integrated with a petrochemical processing facility) produce 250,000 bpd or more.

CRUDE DESALTER

After it is received at the refinery, crude oil is stored in large tanks in a tank farm. The first step of the refining process is mixing the crude oil with water in the line upstream of the desalter vessel to dissolve the salts contained in the crude oil. The salts and sediments are captured in the water phase (now referred to as brine), which is then separated from the oil. The desalter typically contains electric grids that assist with the oil-water separation. This allows for a smaller vessel design; without the grids, the required residence time in the vessel would be much higher and a larger vessel would be required. Salts need to be removed from crude oil to mitigate vessel and piping fouling and corrosion, as well as poisoning of downstream catalysts.

Before the desalted oil enters the atmospheric fractionator, it is preheated by several heat exchangers and a fired heater. Up to 50% of the required heat may come from the heat exchange with the side-cut and product draws exiting the atmospheric crude fractionator; the remaining heat comes from the fired heater. The preheating raises the crude oil's temperature to 650-700°F. Above this temperature, thermal cracking would more readily occur, producing carbon or coke deposits on the piping and equipment that would require a shutdown for cleaning.

ATMOSPHERIC CRUDE FRACTIONATOR

The primary objective of the atmospheric crude fractionator (Figure 2) is to separate the desalted, 650-700°F crude oil into fractions, or cuts, based on boiling point ranges of the components (known as cut points).

Components that are still liquid at entry into the atmospheric fractionator become the tower's bottom product. Components that are in vapor form, the "lighter fractions", rise up the tower through a series of distillation stages. The temperature decreases as the vapors rise through the tower and the components condense. Lighter fractions come off the top of the column and progressively heavier components with higher boiling points are pulled off as side draws further down the tower. Each side-cut draw has a target initial boiling point (IBP) and end boiling point (EBP) to match the capabilities and specifications of downstream units. Typical cut points for the atmospheric fractionator and the vacuum fractionator that follows it are:

- light straight-run (LSR) naptha, 90-190°F
- heavy straight-run (HSR) naptha, 190-330°F
- kerosene, i.e., jet fuel, 330-480°F
- light atmospheric gas oil (LAGO), 480-610°F
- heavy atmospheric gas oil (HAGO), 610-800°F
- vacuum gas oil (VGO), 800-1,050°F
- vacuum reduced crude (VRC), above 1,050°F

The target cut-point ranges typically do not change, but flow rates must change if different feedstock crude oil is used.

Each side-draw feeds a stripping column, which uses steam to establish (or control) the IBP of the material leaving the bottom of the side-cut stripper. Steam enters the bottom of the stripper and reduces the hydrocarbon partial pressure. The process fluid partially vaporizes to reestablish vapor-liquid equilibrium. [The heat of vaporization comes from the process fluid itself, not from the stripping steam.] As mentioned earlier, these side draws are used to preheat the incoming crude oil. Typical side-draw cuts include light and heavy naptha, kerosene or jet fuel, diesel, and light and heavy gas oil. The bottom draw, referred to as atmospheric residuum, is a heavy, high-boiling-point oil, which is sent to the vacuum column for further separation.

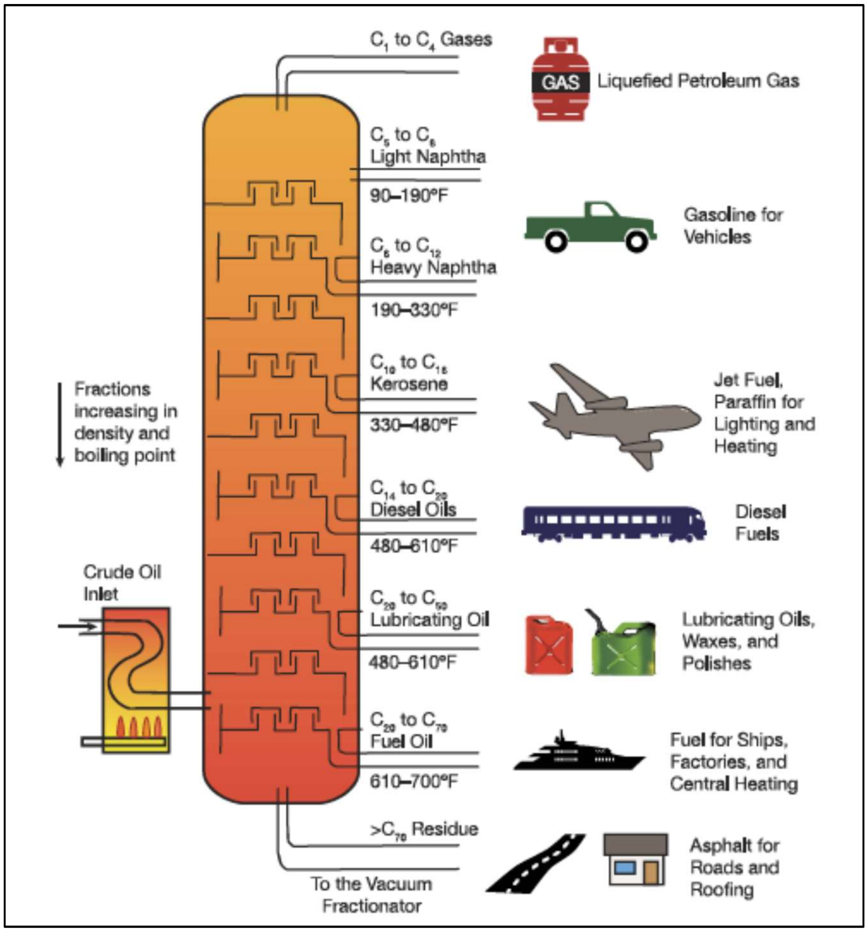


Figure 2: Atmospheric Crude Fractionator

Fractionation separated the crude oil into unfinished products. However, the products do not naturally exist in the crude in the same proportions as the product mix that consumers demand. The biggest difference is that there is too little gasoline and too much heavy oil naturally occurring in crude oil. Heavy oil refers to those fractions that have relatively longer carbon and hydrogen chain. These heavy oils must be broken down “lighter” fractions to convert them to high value gasoline. At times, we may want to change the form of the chain, or even put chains together – collectively these processes are called “conversion” processes.

VACUUM FRACTIONATOR

Downstream of the atmospheric crude fractionator (which operates at temperatures up to 650-700°F), the vacuum fractionator further separates the heavy, higher-boiling-point components under a vacuum to prevent thermal cracking. Because boiling points decrease with lower pressure, these separations can be achieved without initiating thermal cracking. Steam is added to the vacuum column’s inlet to prevent fouling and to the vacuum fractionator bottoms to improve vaporizations of these heavy components. The vacuum fractionator tends to be much larger in diameter than the atmospheric crude fractionator (a good way to tell the two apart from a distance) because under a vacuum the crude oil occupies a larger volume.

GAS CONCENTRATION UNIT

The light hydrocarbon gases that come off the top of the atmospheric crude unit are concentrated, separated, and distributed to where they are needed in what is often referred to as the saturated-gas concentration unit (not shown on Figure 1). Gases are typically separated into wet gases (propane and butane, or liquefied petroleum gas [LPG]) and dry gases (ethane and methane) through a series of distillation columns. The dry gases are primarily used as fuel throughout the refinery for the fired heaters and boilers. Purchased natural gas is used to supplement this fuel gas based on refinery fuel demands.

FLUIDIZED CATALYTIC CRACKER

The fluidized catalytic cracker (FCC), illustrated in Figure 3, was developed collaboratively by refiners during World War II to help meet gasoline demands for the war. Its function is to break – or crack – long chain hydrocarbons such as heavy gas oil into lighter, shorter, naptha-boiling-range hydrocarbons. It is the key conversion unit, and its unique process dynamics can make the FCC unit one of the most challenging refinery units to operate.

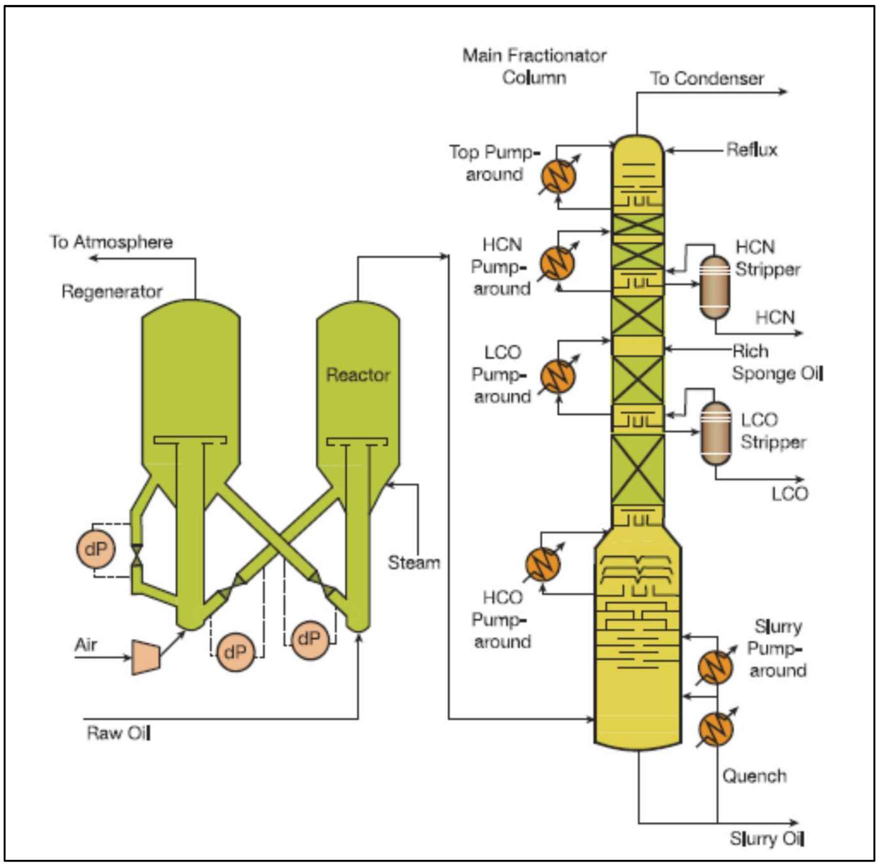


Figure 3: Fluidized Catalytic Cracking (FCC) Unit

The FCC gets its name because the catalyst is so fine that it flows like a liquid. It uses a catalyst (a material that helps a chemical reaction go faster, occur at lower temperature, or control which reactions occur) to convert gas oil into a mix of liquid petroleum gas (LPG), gasoline and diesel. However, even with the fluidized catalyst, the feed mixture requires a lot of heat; therefore the FCC reactor operates at high temperatures (900-1,000°F). The cracking reaction is endothermic, and is fueled by the exothermic catalyst-regeneration reaction. Because about 5 wt% of the feed ends up as coke on the catalyst, the catalyst must be regenerated by introducing air into the regenerator to burn off the coke. The catalyst flowrate is about 1 ton per thousand barrels of oil feed.

The reactor and generator typically sit side by side in a common steel structure, which makes it easy to identify the FCC unit. The catalyst regenerator exit temperatures can range from 1,200°F to 1,500°F.

Downstream of the FCC reactor is the FCC main fractionator column which is the first step in the separation and recovery of the cracked hydrocarbon vapors from the reactor. It is similar to an atmospheric fractionator, but with two key differences: the vapors must be cooled before any fractionation can begin, and significant quantities of light gases pass overhead with the gasoline. The reaction products enter the main FCC fractionation column at high temperatures, 900-1,000°F. The products that are withdrawn from the fractionator include heavy cat naptha (HCN), light cycle oil (LCO), heavy cycle oil (HCO), and slurry oil from the column bottoms.

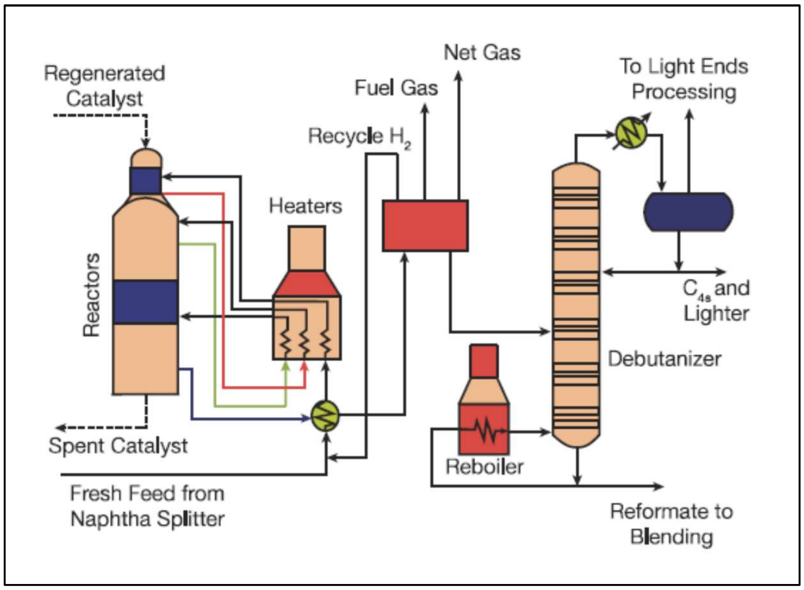


Figure 4: Naptha Reformer

Large quantities of heavy oil are circulated over a series of bottom fractionator trays to cool the vapor and wash down entrained catalyst. The heat removed by the main column bottoms and the heavy oil is used for feed preheating, steam generation, and reboiler heating in the unsaturated gas concentration unit, or some combination of the three. Gas compression and cooling are used to separate the light hydrocarbons from the net gas as a liquid. The remaining vapor phase is passed through two absorbers to further recover light hydrocarbons into the liquid phases leaving the absorbers. A series of distillation columns processes the liquids from the overhead receiver of the main fractionator to remove light gases (e.g. butane) from the gasoline cut, and then the remaining gases are separated into alkylation feed (e.g. olefin LPGs), ethane and fuel gas. This gasoline product is known as FCC gasoline or sometimes “cat gas”.

BUTANE ISOMERIZATION UNIT AND ALKYLATION UNIT

The alkylation unit combines an isobutene feed with olefins (e.g. propylene or butylene) produced in the FCC unit to form larger molecules known as alkylate, which is used in gasoline blending to raise the fuel’s octane. The alkylate component of gasoline has the highest quality of all refinery products. It has high octane (both research octane number [RON] and motor octane number [MON]), low selectivity (i.e. the difference between RON and MON), low RVP, no aromatics, and no sulfur. These qualities make alkylate a valuable gasoline blending component. Alkylate is a main component added to raise the octane of gasoline and produce a premium grade (e.g. 93-octane, compared to 87- or 89-octane for regular grades).

Because isobutane gives the alkylate a much better octane rating than n-butane, butane isomerization is required. The butane isomerization unit converts n-butane into isobutane with excess hydrogen and catalyst. The hydrogen is added to avoid carbon deposition on the catalyst and to shift the reaction to generate more of the desired components. Next, a large distillation column known as a de-isobutanizer (DIB) separates n-butane from isobutane. DIB is often the tallest column in the refinery – the large size is a reflection of how difficult it is to separate these butane isomers because of their close boiling points.

The isobutane from the butane isomerization unit, the olefins from the FCC, and sometimes olefins from the coker (discussed later) are the feeds to the alkylation unit. Alkylation units require an acid catalyst, either sulfuric acid or hydrofluoric acid. Both catalysts operate at low temperatures and high isobutane-to-olefin ratios to reduce side reactions and acid (catalyst) consumption. Without this high ratio, the olefins could easily react with each other to combine into much larger (unwanted) molecules such as C12s, C16s, C20s etc.

When butane isomerization and olefin alkylation take place in a single unit, the bottom of the column serves as a product separator to capture the alkylate for gasoline blending, n-butane is taken as a side draw, and the overhead is isobutane.

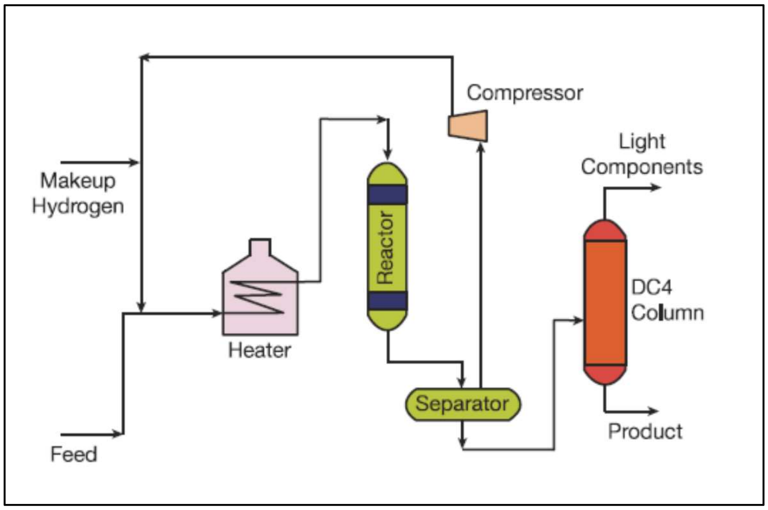


Figure 5: Naptha Hydrotreater

LIGHT NAPTHA ISOMERIZATION UNIT

The light naptha isomerization unit saturates benzene and isomerizes light naptha normal paraffins (pentanes and hexanes) into branched molecules that are higher-octane gasoline components for blending.

Like the butane isomerization unit, it converts n-pentane and n-hexane into isopentane and isohexane in the presence of excess hydrogen and catalyst. The light naptha can be pretreated in a de-isopentanizer or de-isohexanizer column to separate the isoparaffins from the n-paraffins and shift the equilibrium reaction toward the isoparaffins.

After the isomerization reactors, a distillation column removes butane and lighter gases from the gasoline intermediate product, which is referred to as isomerate.

HEAVY NAPTHA REFORMER AND HYDROTREATER

The heavy naptha reformer (Figure 4 – see previous page) contributes to increasing gasoline octane rating by converting napthenes into aromatics and generating a reformate gasoline component. The reforming process is unusual in that the reaction is endothermic. It is carried out in a series of three of four reactors, each of which is preceded by a fired heater.

The catalyst needs to be regenerated. Two main process designs exist: semi-regeneration, which requires a shutdown to regenerate the catalyst in situ in the reactor; and continuous catalyst regeneration (CCR), in which flowing catalyst spheres circulate from the reactor to the regenerator and back. The CCR design is depicted in Figure 4.

The reforming process also generates the hydrogen needed by the refinery's hydrocracking and hydrotreating units, as well as benzene, toluene, and xylene (BTX) feedstocks for downstream petrochemical processing. Hydrotreaters (Figure 5 – see previous page) are located throughout the refinery. Their main purpose is to remove impurities such as sulfur, nitrogen, oxygen, metallic salts, olefins, and to a lesser extent aromatics. They also serve as hydrodesulfurization units to remove sulfur from the FCC naptha in order to meet regulatory requirements. The hydrotreating reaction is not intended to change the boiling range of the feed (unlike hydrocracking).

HYDROCRACKING

Older hydrocracking units in the U.S. were designed primarily to maximize the production of gasoline and jet fuel. Newer hydrocracking units are more focused on maximizing ultra-low-sulfur diesel and jet fuel production, with less focus on gasoline (Figure 6).

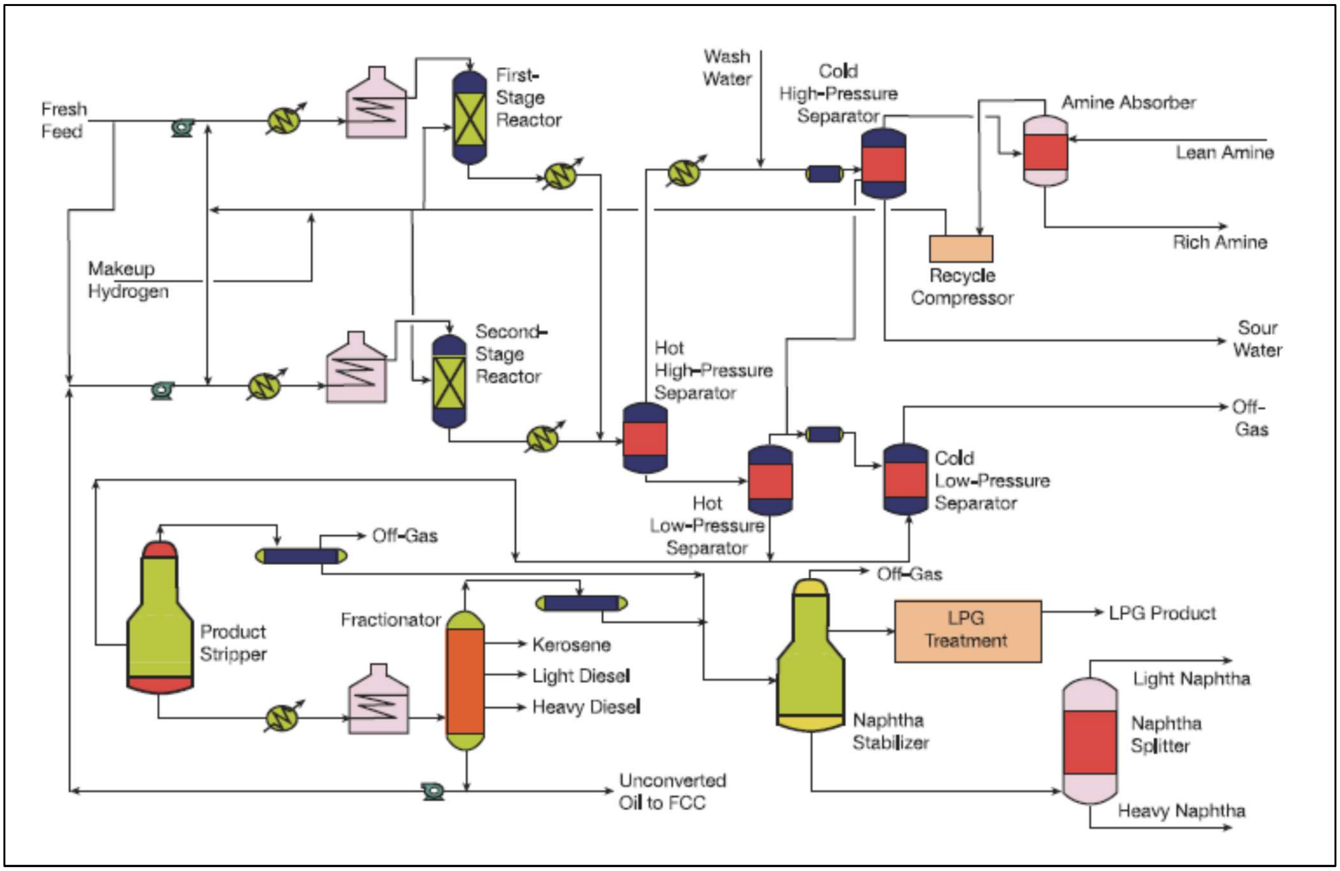


Figure 6: Hydrocracking Unit

Not all refiners have a hydrocracker, mainly because of the high capital costs associated with its construction and its high hydrogen consumption. Operating pressures can reach 3,000 psig, and piping, vessels, pumps, compressors, and instruments that can handle this high pressure are expensive. Additionally, refiner would need to build a hydrogen generation plant or buy hydrogen for hydrocracker use.

Although cracking reactions are endothermic, the overall process is highly exothermic due to the concurrent hydrotreating reactions, with reactor temperatures that can range from 550-850^{o}F. Cool hydrogen is added to the inlet of each catalyst bed in the reactor to control the reactor's internal temperature. The addition of hydrogen increases the production of isoparaffins (which are desired over normal paraffins because they are higher-quality gasoline-blending components) and limits the production of olefin.

The hydrocracking unit includes a product fractionator to separate light gases, gasoline, and diesel. The bottoms product from that column is typically recycled for a second chance at reacting.

DELAYED COKING AND ASPHALT PRODUCTION

The delayed coker (Figure 7) thermally cracks heavy feedstocks to produce solid coke and lighter components that are blended into gasoline or fed to other processing units.

Delayed cokers are easy to identify from a distance – they look like a pair of oil derricks on top of a pair of vertical drums. Delayed cokers are always installed in pairs and their operation is cycled every 24 hours – one is online (as indicated by solid lines in Figure 7) while the other is offline (dashed lines) so that the coke can be cut out of it.

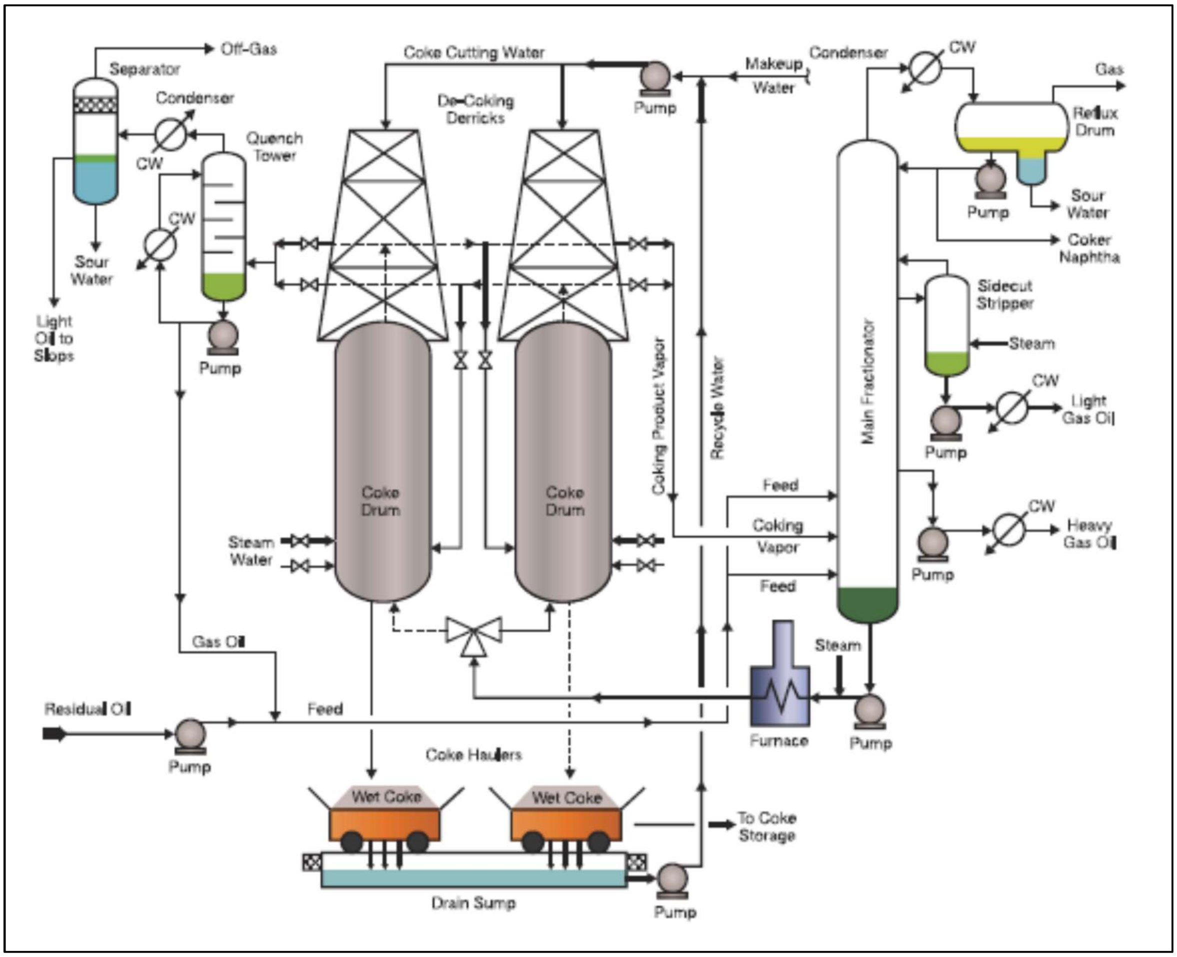


Figure 7: Delayed Coker

The vacuum fractionator bottoms are sent with steam to a fired heater and then to online coke drum, where the entrained liquid is thermally cracked to coke and other vapor products. As the coke drum fills, the cracked vapors leave the top of the drum and are returned to the bottom of the fractionator, where the light intermediate products like gasoline separate as they travel up the column.

Refineries without thermal cracking units have the option of producing asphalt or selling the vacuum residuum to other refineries that can process it.

AMINE TREATING AND SULFUR RECOVERY

An amine treating unit (not shown in Figure 1) captures the hydrogen sulfide from the refinery gas streams and concentrates it through absorption into an amine solution. These rich amine streams are routed to an amine regenerator column; the overhead vapor from this column contains the released hydrogen sulfide, which is converted into elemental sulfur in a sulfur recovery unit (also not shown in Figure 1). The bottoms from the amine regenerator is the lean amine, which is circulated back to the various amine absorbers in the refinery.

As regulations over the past few decades have placed stricter limits on sulfur emissions and reduced the amount of sulfur that fuel products may contain, the sulfur recovery units have required revamps for higher capacity and greater onstream availability.

BLENDING

Various fuel components are blended into final commercial products that meet particular specifications based on the consumers' location. In the U.S., there are many different location-dependent gasoline specifications. For example, large urban areas typically have more restrictive fuel specifications.

Intermediate products include alkylate, isomerate, reformate, cat gas, hydrocracker gas, and coker gas. Normal butane is also added as needed to meet RVP specifications, which are different in summer and winter, and in winter vary by location.

Diesel is also blended from each of the various units that produce intermediate products, such as the crude unit, FCC, hydrocracker, and delayed coker.

TANK FARM AND DISTRIBUTION

Finally, transportation fuel products need to be distribute to the customer. These products are typically transported by pipelines to terminals. At the terminals, ethanol and other biofuels, as well as various additives, are added, and then the gasoline or diesel is trucked to the commercial distribution stations. The additives account for the differences among various brands of fuel.

The refinery's tank farm has various sizes of tanks to store crude oil coming into the refinery, intermediate products (e.g. petrochemical feedstocks), liquefied petroleum gases, and fuel products.

The next time you fill up your vehicle, you will have a greater understanding of the path the crude oil had to travel to become a fuel.

References:

An Oil Refinery Walk-Through by Tim Olsen

A Simple Guide to Oil Refining - ExxonMobil

Deaerators in Industrial Steam Systems – US Department of Energy

Pressure Vessel & Piping Training

Offered by CoDesign Engineering LLC

PRESSURE VESSEL DESIGN: ASME BOILER AND PRESSURE VESSEL CODE

3 DAYS TRAINING COURSE: FEBRUARY 26-28, 2018

Based on the rules for pressure vessel design & construction, this 3-day training course covers the fundamentals of pressure vessel design, requirements of ASME Section VIII, Div. 1 and Part 4 of Div. 2, cyclic service requirements, design for wind and seismic loads, design of vessel supports (both vertical and horizontal), and NDE requirements. The training will highlight the requirements in the new 2017 Code edition.

Course Description:

Training Contents:

Stresses in pressure vessels
Codes and standards
Material of construction
Welding Requirements
Design of shells
Formed heads
Conical heads and sections
Flat heads
Openings and reinforcement
Fabrication requirements
Fatigue
Bolted flange joints
Non-destructive examination
Wind and seismic loads
Supports for vertical vessels
ASME Section VIII, Div.2 – Part 4

Instructor Profile

Ramesh holds Bachelor's and Master's degrees in Mechanical Engineering, and is a registered Professional Engineer in the states of Texas and Maryland in the United States. Ramesh has over 27 years of experience with design of pressure vessels, heat exchangers and storage tanks used in oil & gas, chemical, petrochemical, fertilizer and power industries. He has worked with engineering organizations and pressure vessel manufacturers, and has provided trainings and in-house workshops in US, Canada, Middle East and India. Ramesh is also an approved pressure vessel instructor at several organizations and educational institutions.

REGISTRATION: US$ 1750

Who Should Attend:

The training is well suited for those just entering the field of pressure vessels, as well as for those that are experienced and would like a comprehensive refresher to pressure vessel design and fabrication.

Training Details:

Training will be held every day from 8:00 am to 4:30 pm with breaks for drinks and for lunch. Breakfast will be served on all days. It is not required to have a copy of the ASME Code book during the training; however, participants may bring one with them for reference. A comprehensive author notes covering all the training topics will be provided to all participants, and will serve as a good reference resource for pressure vessels. The venue for training will be Texas Training and Conference Center located at 11490 Westheimer Road, Suite 600, Houston, TX 77077. The venue has free parking for training participants.

Please contact Ramesh at ramesh.tiwari@codesignengg.com, or call at +1 713-562-0368 to register for the training

About CoDesign Engineering:

CoDesign Engineering specializes in the core business of providing training and consultancy services for the design and fabrication of pressure vessels, heat exchangers, storage tanks, and the ecosystem that includes piping, welding, valves, process improvement, and engineering management.

EXTERNAL PRESSURE CONSIDERATIONS FOR CYLINDERS

[*The reference material where the article below is compiled from also discusses the spheres, and formed head. This article is restricted to cylinders only. The readers are encouraged to read the reference provided at the end of this article for an expanded discussion of external pressure considerations.*]

With the exception of local knuckle and discontinuity regions, pressure vessels that are subject to internal pressure develop primary stresses that are tensile. The failure of pressure vessel due to internal pressure is generally preceded by gross general distortions at stresses above the yield strength. However, when these pressure vessels are subject to external pressure, the primary stresses become compressive, and failure is mainly due to buckling instability that can occur at stresses well below the elastic limit or yield strength of the material. There is very little warning of the impending collapse.

When the compressive force in a pressure vessel approaches a critical value, radical deflections begin and increase rapidly with increase in the compressive force. A load equal to this critical value is usually sufficient to produce a complete failure. Therefore, the problem is that of obtaining an expression for the critical collapse or buckling load.

A thin-walled cylinder buckles in a definite pattern, depending on its relative dimensions and the restraint conditions at the ends. Figure 1 show the more common patterns taken by cylinders as they collapse. They are described by the number of lobes (2, 3, 4 etc.) with the smallest number giving the lowest collapsing pressure. The number of lobes for a given cylinder is largely dependent upon the type of restraint at the circumference or edge of the ends of the cylinder and the distance between these restraints. Restraints can take the form of structural rings or bends in the cylinder itself.

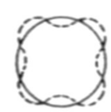
Buckling Mode / Characteristics				
k = Number of lobes (k is the number of full sine waves around the periphery)	1	2	3	4
p_c = Critical pressure the elastic buckling or collapse	0 (No elastic buckling occurs, only sidewise displacement of undistorted circle)	$\frac{3EI}{r^3}$	$\frac{8EI}{r^3}$	$\frac{15EI}{r^3}$

Figure 1: Buckling of Cylindrical Ring under External Pressure Showing Various Modes

ELASTIC BUCKLING OF CYLINDERS UNDER EXTERNAL PRESSURE

A thin-walled cylinder whose length is large in comparison to its diameter will buckle elastically in the form of two lobes when subject to uniform external pressure. The critical load does not depend upon the strength of the material but only on the stiffness as measured by its modulus of elasticity, and on the geometric dimensions as measured by the slenderness ratio of perimeter length to cross sectional moment of inertia. Hence, identical size and thickness vessels made of low and high strength steel will collapse at the same external pressure because the modulus of elasticity of all steels is approximately the same.

The following equation 1 gives the critical value of the pressure, provided the corresponding compressive stress does not exceed the proportional limit of the material.

$$p_c = \frac{2E}{(1-\mu^2)}\left(\frac{h}{d}\right)^3 \qquad \text{(Eq. 1)}$$

The critical stress is obtained by substituting the value of p_c to give:

$$\sigma_c = \frac{E}{(1-\mu^2)}\left(\frac{h}{d}\right)^2 \qquad \text{(Eq. 2)}$$

The modulus of elasticity, E, for materials with a definite yield point remains substantially constant until the yield point is closely approached. The failure curve for a cylinder made of this type of material is shown in Figure 2 and consists of two parts:

1. Part AB for thin, high d/h ratio cylinders where elastic buckling is critical (as given by equation above), and
2. Part BC for thick, low d/h ratio cylinders where plastic yield strength is critical.

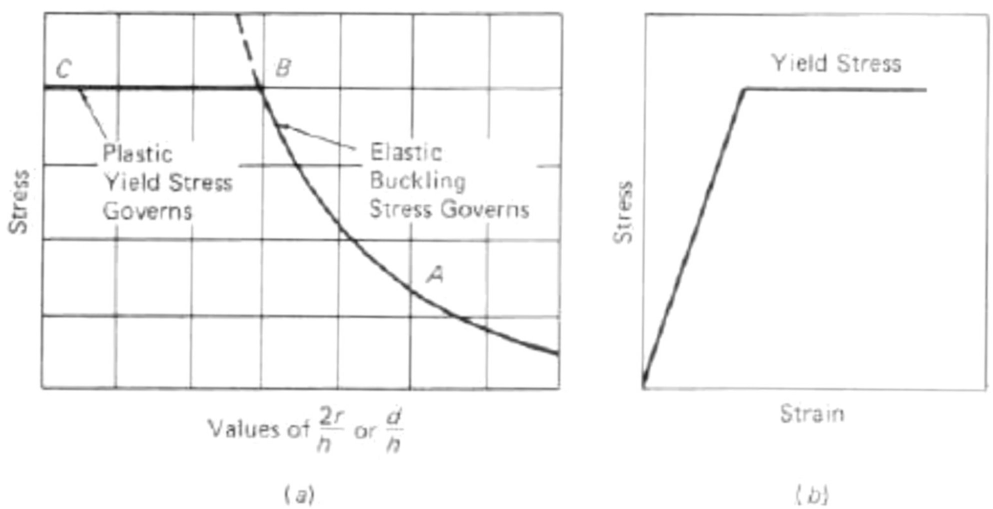


Figure 2: (a) Buckling Failure of Cylinder with (b) Simplified Elastic-Plastic Relationship

The curve shows that for thick or low d/h ratio cylinders, it may be economical to use high yield strength steels, whereas for thin ones with high d/h ratios, such materials offer no advantage because the modulus of elasticity for all steels is approximately the same.

EEFECT OF SUPPORTS ON ELASTIC BUCKLING OF CYLINDERS

The formulas in the previous paragraph also apply to cylinders with end supports if the length is large; consequently, their stiffening effects can be neglected, with the result that collapse will occur in the central portion of the cylinder in the form of two lobes, n = 2, which is the form associated with the minimum critical pressure. Figure 3 shows this condition. Here a long cylinder is supported at the left by a diaphragm, while at the right end, the support that resists buckling is obtained by the double curvature of the bend. If the length of the cylinder is not large relative to its diameter, the end supports must be considered in calculating the buckling collapse pressure because they will prevent the cylinder from collapsing in two lobes and force it into higher modes, thereby increasing the minimum critical pressure before elastic buckling occurs. This can be approximated by the equation 3 on the next page. In this equation, l is the length between supports; i.e. distance between end supports, stiffener rings, or bend tangents where the initial double curvature provides support.

$$p_c = \frac{Eh}{r(1-\mu^2)}\left[\frac{1-\mu^2}{(n^2-1)\left(1+\frac{n^2l^2}{\pi^2r^2}\right)} + \frac{h^2}{12r^2}\left(n^2 - 1 + \frac{2n^2-1-\mu}{1+\frac{n^2l^2}{\pi^2r^2}}\right)\right] \qquad \text{(Eq. 3)}$$

When cylinder is long, l/r is large, and the terms containing the square of this ratio in the denominator the equation above can be neglected to give:

$$p_c = \frac{Eh^3(n^2-1)}{12r^3(1-\mu^2)} \qquad \text{(Eq. 4)}$$

Equation 4 becomes equation 1 for the buckling of a long cylinder when n = 2.

Equation 3 can be written in the form

$$p_c = KE\left(\frac{h}{d}\right)^3 \qquad \text{(Eq. 5)}$$

The effect of the number of lobes and support spacing obtained from Eq. 3 is shown in Figure 3.

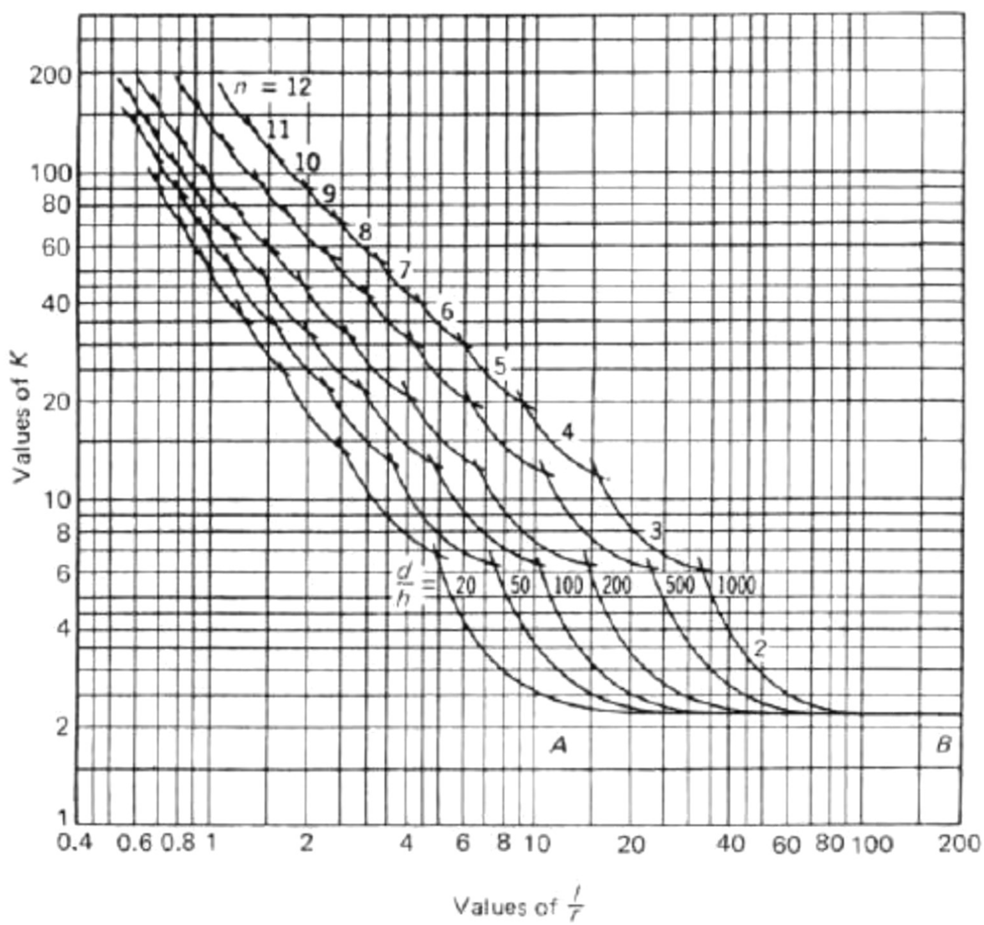


Figure 3: Buckling Coefficients for Cylinders Subject to External Pressure

The value of K corresponding to a given value of l/r (or l/d) and d/h can be found from Figure 3. For instance, the Figure shows that a cylinder with a value of l/r = 5 and d/h = 50 will collapse in three lobes and that the value of K for use in the Eq. 5 is approximately 8.0. As the cylinder becomes long so that its collapse is in the form of two lobes, K becomes constant at $2/(1-\mu^2)$ in the region AB of Figure 3, and Eq. 5 reduces to Eq. 1. The length at which this condition is first reached is called the "critical length", and for $\mu = 0.3$ is given by

$$L_{cr} = 1.11d\sqrt{\frac{d}{h}} \qquad \text{(Eq. 6)}$$

CYLINDERS WITH RING STIFFENERS

When external pressures are high and/or diameters large, plain cylinders become extremely thick and expensive. Savings in weight and material can be made by the use of ring stiffeners attached to these cylinders at intervals along their length. The most commonly used stiffeners are rectangular bars or structural shapes such as tees, channels, and I-beams. Three primary modes of failure may be encountered in the stiffened cylinder as follows:

a. Buckling of the cylinder between rings, manifested by a number of lobes girding the circumference. This type of failure occurs when the ring stiffeners are too widely spaced.

b. Yielding of the cylinder between rings, which is characterized by axisymmetrical accordion-shaped pleats. This occurs when the rings are heavy and closely spaced. The cylinder yields circumferentially in compression and the radius decreases until longitudinal collapse occurs.

c. General instability collapse of the cylinder and rings together. This embodies many rings and occurs over a considerable length of the stiffened cylinder.

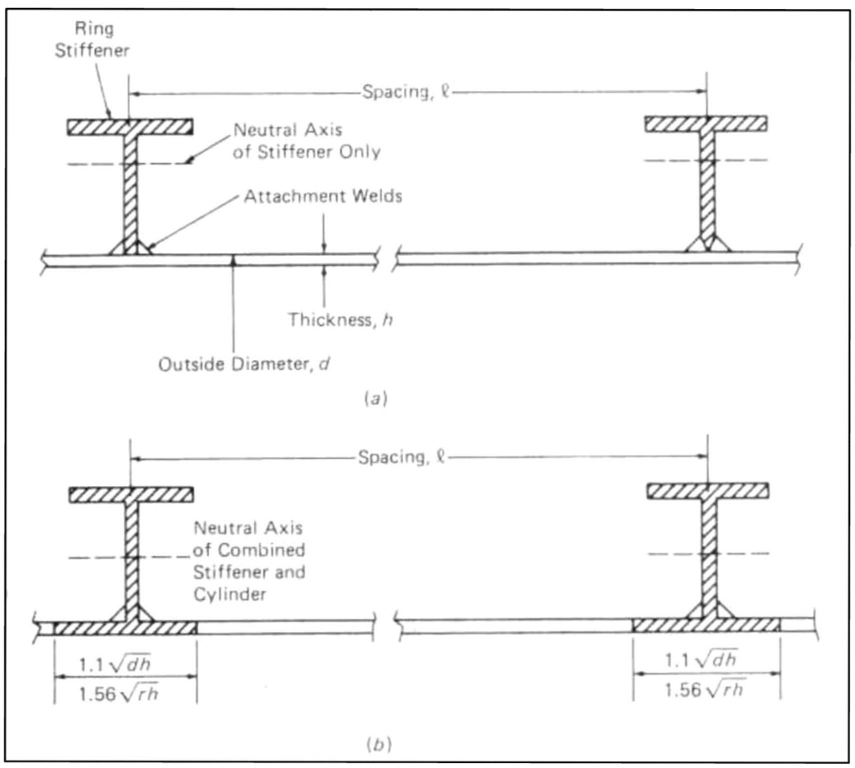


Figure 4: Tee Ring Stiffener Assumed to Act (a) Independent of Cylinder, and (b) in Combination with Portion of Cylinder

Ring stiffeners may be attached to either the inside or outside of the cylinder. They are generally placed on the outside or pressure vessels so they do not obstruct flow and facilitate cleaning. Under external pressure, the web of an external stiffener is in radial tension and circumferential compression, whereas the web of an internal stiffener is in compression in both directions which can cause lateral instability.

If the stiffener is attached to the cylinder so that continuity prevails, it is reasonable to assume that a portion of the cylinder also acts as an integral part of the stiffener moment of inertia geometry. This may be taken as $1/\beta$ on each side of stiffener, or $2\beta = 1.56\sqrt{rh}$ (See Figure 4).

ASME DESIGN CRITERIA

ASME approach is also to consider cylinders to fall into three categories according to length between supports:

a. Long cylinders: These cylinders are independent of the distance between supports, l. That is, the stiffeners or end supports are located beyond the critical length, which for $\mu = 0.3$ is given by Eq. 6.

b. Short cylinders: In these cylinders, failure is by plastic yielding at the yield strength of the material. This type of failure is characteristic of thick walled cylinders in which the influence of l is negligible.

c. Intermediate length cylinders: The theoretical elastic equations for the collapse pressure at which intermediate length cylinders, $l < l_c$, under uniform external radial pressure, or uniform external radial and axial pressure, depend on n, the number of lobes at collapse, Eq. 3. These are cumbersome for design purposes and it is desirable to eliminate n from them. This equation, for $\mu = 0.3$ is, is given by Eq. 7.

$$p_c = \frac{2.6E(h/d)^{2.5}}{l/d} \qquad \text{(Eq. 7)}$$

Assuming the stress-strain diagram of the material is an elastic-plastic one described by Figure 2(b), a series of curves representing constant values of h/d can be plotted on a log-log scale against values of failure or collapse as ordinates and l/d as abscissas. Such an h/d curve consists of three straight line segments, each of which is determined by a different equation dependent upon the cylinder length to diameter ratio, as shown in Figure 5. This basic curve permits modifiers to be applied to each segment as experiment and experience dictates.

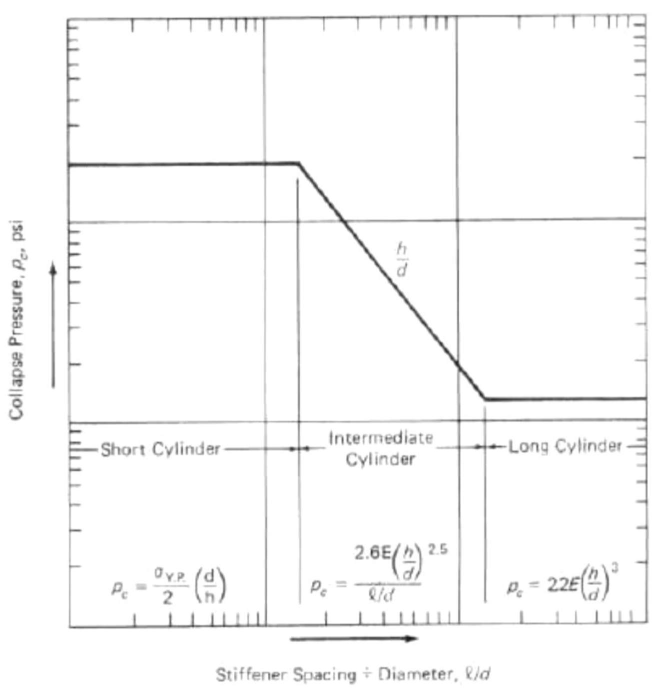


Figure 5: Failure Curve for a Cylinder under External Pressure

For instance, the effect of noncirculatory tolerances on long cylinders as compared to short ones, etc. can be accounted for. When a stress-strain curve more representative of the actual material is employed and the tangent modulus is used for buckling beyond the proportional limit a transition between the segment results. Further, when the instability equations Eq. 3 and Eq. 7 are written so that the material mechanical properties are on one side of the equation and the geometry dimensional variables are on the other, they form a basis for the ASME charts for external pressure design (See Figures 6 and 7).

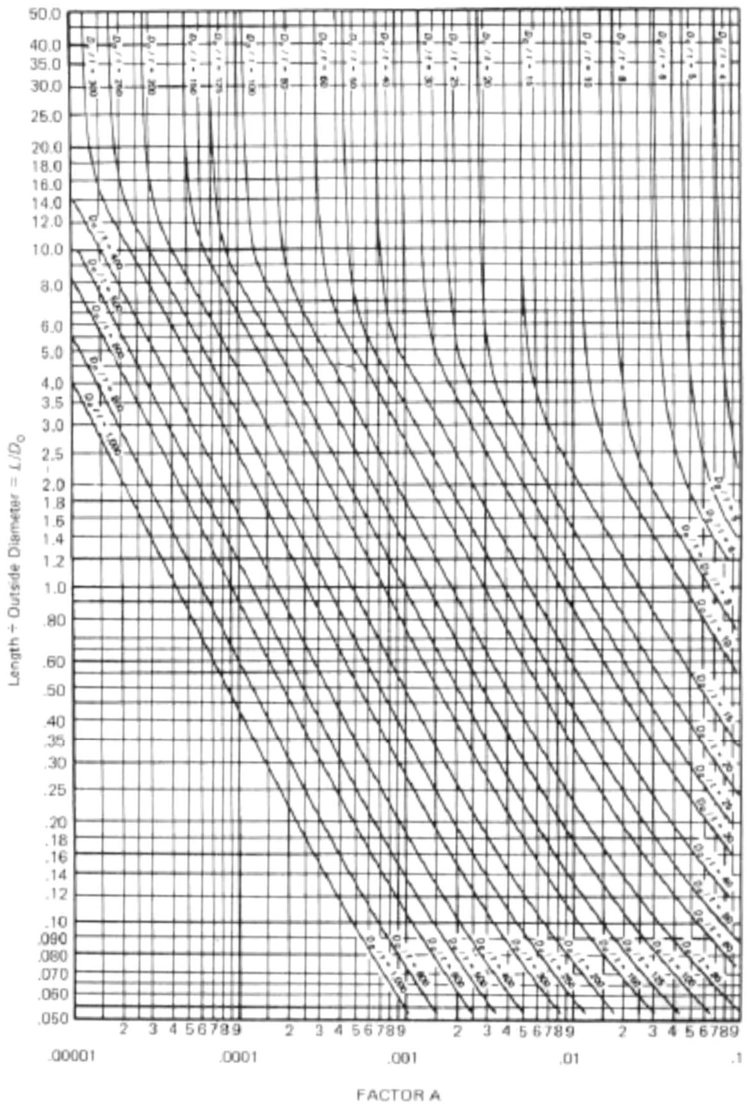


Figure 6: Geometric Chart for Cylindrical Vessels under External Pressure

In Figure 6 (taken from ASME VIII-1), the vertical lines represent long cylinder ($l > l_c$) and the slanting lines represent intermediate length cylinders ($l < l_c$). Since σ_c/E = Factor A is treated as a variable, it is applicable to all materials. Therefore, to introduce the mechanical properties of a particular material, an additional curve is required relating σ_c/E to the collapse pressure P_c. This curve, Figure 7, is a stress-strain curve e ($= \sigma_c/E$) vs. σ_c ($= P_cD_o/2t$) for the material at the design temperature. The allowable working pressure P_a is based on a selected factor of safety. For instance, for a factor of safety of four, $P_a = P_c/4$. The curves in Figures 6 and 7 have a common abscissa, Factor A. Factor B in Figure 7 is defined as $\frac{\sigma_c}{2}$.

In the ASME code, the required moment of inertia of a stiffener-ring can be written as:

$$I_{reqd} = \frac{D_o^2 L}{10.9}\left(t + \frac{A_s}{L}\right) A \qquad \text{(Eq. 8)}$$

Factor B is defined as one-half the average circumferential stress within the stiffening ring spacing. The ASME equation for B is written as:

$$B = \frac{3}{4}\frac{P_a D_o}{\left(t+\frac{A_s}{L}\right)} \qquad \text{(Eq. 9)}$$

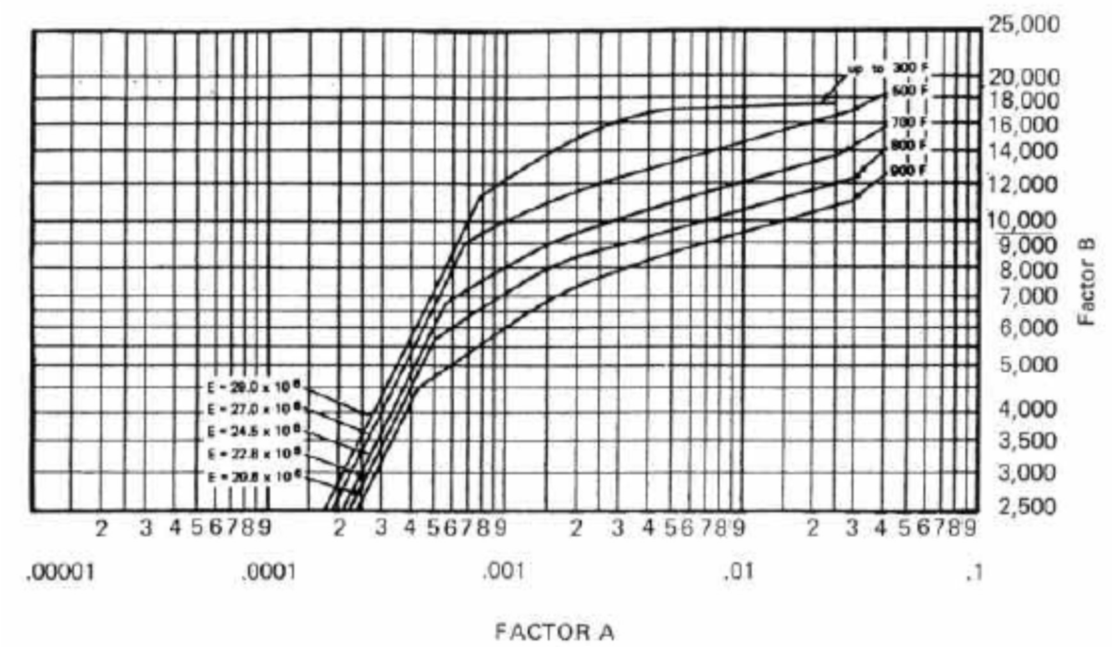


Figure 7: Chart for Determining Thickness of Cylindrical Vessels under External Pressure

---

Example

A cylindrical vessel 14 ft ID x 3/8 in. thick has ring stiffeners located on 40 in. spacing, and is subject to an external pressure of 15 psi at a temperature of 700°F. The material of both the vessel and stiffener rings is carbon steel with a yield strength of 30,000-38,000 psi.

(a) Is the 3/8 in. thickness adequate for a design factor of safety of 4?

$$\frac{L}{D_o} = \frac{40}{168+2 \text{ X } 0.375} = 0.237$$

$$\frac{D_o}{t} = \frac{168.75}{0.375} = 450$$

Enter Figure 6 at a value of L/D_o = 0.237 and D_o/t = 450 to read a value of Factor A = 0.0007. With this value of Factor A, enter Figure 7 and for a temperature of 700°F read a value of Factor B = 7200.

$$B = \frac{\sigma_c}{2} = \frac{P_c D_o}{4t}$$

$$P_c = \frac{B \text{ x } 4 \text{ x } t}{D_o} = \frac{7200 \text{ x } 4 \text{ x } 0.375}{168.75} = 64$$

For a factor of safety of four, the allowable working pressure, $P_a = P_c/4$ = 16 psi.

Accordingly, the 3/8 in. thickness is satisfactory for a factor of safety of 4.

(b) What is the allowable external pressure for a factor of safety of 3?

For a factor of safety of three, the allowable working pressure, $P_a = P_c/3$ = 21.3 psi.

(c) What is the required thickness for the same ID vessel for a factor of safety of 3?

This must be done on a trial-and-error basis. Assume thickness of 5/16 in.

$$\frac{L}{D_o} = \frac{40}{168 + 2 \text{ x } 0.3125} = 0.237$$

$$\frac{D_o}{t} = \frac{168.625}{0.3125} = 540$$

Enter Figure 6 at a value of L/D_o = 0.237 and D_o/t = 540 to read a value of Factor A = 0.0005. With this value of Factor A, enter Figure 7 and for a temperature of 700°F, read a value of Factor B = 6100.

$$B = \frac{\sigma_c}{2} = \frac{P_c D_o}{4t}$$

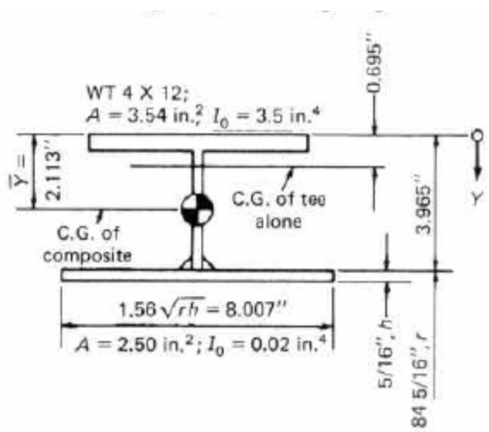
$$P_c = \frac{B \text{ x } 4 \text{ x } t}{D_o} = \frac{6100 \text{ x } 4 \text{ x } 0.3125}{168.75} = 45.2$$

For a factor of safety of three, the allowable working pressure, $P_a = P_c/3$ = 15.1 psi.

Therefore, the required thickness of 5/16 in. is satisfactory.

(d) Determine the stiffening requirements for the vessel in (c) above (D_o = 168.625 in., L = 40 in., t = 0.3125 in., P_a = 15 psi, T = 700°F, factor of safety = 3) if this stiffening ring is to be made from a structural tee shape.

As a first trial, select a 4 in. wide flange tee at 12 lb per ft, A_s = 3.53 in^2 and I = 3.52 in^4. The combined ring-cylinder moment of inertia (see Figure 8) is approximately 20.6 in^4.



Item	A	Y	AY	AY^2	I_0
Tee ℄	3.54 2.50	0.695 4.121	2.46 10.30	1.71 42.46	3.53 0.02
Σ	6.04	~	12.76	44.17	3.55

$\bar{Y} = \Sigma(AY)/\Sigma(A)$ = 2.113 in.
$I = \Sigma(I_0) + \Sigma(AY^2) - (\Sigma AY)\bar{Y}$ = 20.6 ^{4}in.

Figure 8: Data for Structural Tee used in Example

Factor B is calculated from Eq. 9:

$$B = \frac{3}{4}\left(\frac{15 \text{ x } 168.625}{0.3125 \quad \frac{3.53}{40}}\right) = 4{,}733 \text{ psi},$$ and from Figure 7, for this value of B, we get Factor A = 0.0004.

Substituting the respective values in Eq.8, we get:

$$I_{\text{reqd}} = \frac{168.625^2 \text{ x } 40}{10.9}\left(0.3125 + \frac{3.53}{40}\right) 0.0004 = 16.7 \text{ in}^4$$

The required moment of inertia of 16.7 in^4 is less than that provided by the combined ring-cylinder moment of inertia of 20.6 in^4; therefore the chosen size tee is satisfactory. Normally, several trials are required to select a satisfactory stiffener-ring size, and one giving the most economical weight.

A few words on where external pressures are encountered and recommended practices on use of stiffening ring:

External pressure can be caused in pressure vessels by a variety of conditions and circumstances. The design pressure may be less than the atmospheric pressure due to condensing gas or steam. Often refineries and chemical plants design all of their vessels for some amount of external pressure, regardless of intended service, to allow for steam cleaning and the effects of condensing steam. Other vessels are in vacuum service by nature of their venture devices or connection to a vacuum pump. Vacuums can be pulled inadvertently by failure to vent a vessel during draining, or from improperly sized vents.

External pressures can also be created when vessels are jacketed or when components are within multi-chambered vessels. Often these conditions can be many times greater than atmospheric pressure.

When vessels are designed for both internal and external pressure, it is common practice to first determine the shell thickness for the internal pressure condition, then check that thickness for the maximum allowable external pressure. If the design is not adequate, then a decision is made to either bump up the shell thickness to the next thickness of plate available, or add stiffening rings to reduce the “L” dimension. If the option of adding stiffening rings is selected, then spacing can be determined to suit the vessel configuration.

Sometimes the optimum solution lies somewhere between the two extremes of increasing the shell thickness with no stiffening rings, and using thinnest shell with maximum number of stiffening rings. Typically, the utilization of rings with a spacing of 2D for vessel diameters of up to eight feet and a ring spacing of approximately “D” for diameters greater than eight feet provides an economical solution.

Stiffeners should never be located over circumferential weld seams. If properly spaced, they may also serve as insulation support rings. Vacuum stiffeners, if combined with other stiffening rings, such as cone reinforcement rings or saddle stiffeners for horizontal vessels, must be designed for the combined condition, not each independently. If at all possible, stiffeners should always clear shell nozzles. If unavoidable, special attention should be given to the design of a boxed stiffener or connection to the nozzle neck.

References:

Theory and Design of Modern Pressure Vessels *by* John F. Harvey

Pressure Vessel External Pressure Calculations *by* Engineers Edge LLC

NOMINAL PIPE SIZE

Nominal Pipe Size (NPS) is a set of standard pipe sizes used for pressure piping in North America. The same pipe dimensions are used with different names in other countries. It is often incorrectly called National Pipe Size, due to confusion with National Pipe Thread. The European and international designation equivalent to NPS is DN (diametre nominal/ nominal diameter/ Durchmesser nach Norm), in which sizes are measured in millimeters.

Pipe size is specified with two non-dimensional numbers: a Nominal Pipe Size (NPS) and a schedule (SCH). The relationship between these numbers and the actual pipe dimensions is a bit strange. The NPS is very loosely related to the inside diameter in inches, but only for NPS 1/8 through NPS 12. For NPS 14 and larger, the NPS is equal to the outside diameter in inches. For a given NPS, the OD stays constant, and the wall thickness increases with larger SCH. For a given SCH, as the OD increases with increasing NPS, the wall thickness increases or stays constant.

In March 1927, the American Standards Association authorized a committee to standardize the dimensions of wrought steel and wrought iron pipe and tubing. At that time, only a small selection of wall thicknesses were in use: standard weight (STD), extra-strong (XS), and double extra-strong (XXS), based on the Iron Pipe Size (IPS) system of the day. However, these three sizes did not fit all applications. Also, in 1939, it was hoped that the designations of STD, XS and XXS would be phased out by schedule numbers; however, these original terms are still in common use today (although sometimes referred to as *standards*, *extra-heavy*, and *double extra* or *extra extra-heavy*, respectively).

Stainless steel pipes, which were coming into more common use in the mid-20th century, permitted the use of thinner pipe walls with much less risk of failure due to corrosion. By 1949, thinner schedules 5S and 10S, which were based on pressure requirements modified to the nearest BWG number, had been created, and other “S” sizes followed later. Due to their thin walls, the smaller “S” sizes cannot be threaded together according to ASME code, but must be fusion-welded.

The most commonly used schedules today are 40, 80 and 160. There is a commonly held belief that the schedule number is an indicator of the service pressure that the pipe can take. For example, some books say that the schedule number can be converted to pressure by dividing the schedule by 1000 and multiplying by the allowable stress of the material. However, this is not true. Pressure rating actually goes down with the increasing NPS and constant schedule.

NPS TABLES FOR SELECTED SIZES

NPS 1/8 to NPS 3½:

NPS	DN	OD [in (mm)]	Wall thickness [in (mm)]							
			SCH 5S	SCH 10S/20	SCH 30	SCH 40S/40/STD	SCH 80S/80/XS	SCH 120	SCH 160	SCH XXS
1/8	6	0.405 (10.29)	0.035 (0.889)	0.049 (1.245)	0.057 (1.448)	0.068 (1.727)	0.095 (2.413)	---	---	---
1/4	8	0.540 (13.72)	0.049 (1.245)	0.065 (1.651)	0.073 (1.854)	0.088 (2.235)	0.119 (3.023)	---	---	---
3/8	10	0.675 (17.15)	0.049 (1.245)	0.065 (1.651)	0.073 (1.854)	0.091 (2.311)	0.126 (3.200)	---	---	---
1/2	15	0.840 (21.34)	0.065 (1.651)	0.083 (2.108)	0.095 (2.413)	0.109 (2.769)	0.147 (3.734)	---	0.188 (4.775)	0.294 (7.468)
3/4	20	1.050 (26.67)	0.065 (1.651)	0.083 (2.108)	0.095 (2.413)	0.113 (2.870)	0.154 (3.912)	---	0.219 (5.563)	0.308 (7.823)
1	25	1.315 (33.40)	0.065 (1.651)	0.109 (2.769)	0.114 (2.869)	0.133 (3.378)	0.179 (4.547)	---	0.250 (6.350)	0.358 (9.093)

NPS	DN	OD [in (mm)]	Wall thickness [in (mm)]							
			SCH 5S	SCH 10S/20	SCH 30	SCH 40S/40/STD	SCH 80S/80/XS	SCH 120	SCH 160	SCH XXS
1 1/4	32	1.660 (42.16)	0.065 (1.651)	0.109 (2.769)	0.117 (2.972)	0.140 (3.556)	0.191 (4.851)	---	0.250 (6.350)	0.382 (9.703)
1 1/2	40	1.900 (48.26)	0.065 (1.651)	0.109 (2.769)	0.125 (3.175)	0.145 (3.683)	0.200 (5.080)	---	0.281 (7.137)	0.400 (10.160)
2	50	2.375 (60.33)	0.065 (1.651)	0.109 (2.769)	0.125 (3.175)	0.154 (3.912)	0.218 (5.537)	0.250 (6.350)	0.344 (8.738)	0.436 (11.074)
2 1/2	65	2.875 (73.03)	0.083 (2.108)	0.120 (2.108)	0.188 (4.775)	0.203 (5.156)	0.276 (7.010)	0.300 (7.620)	0.375 (9.525)	0.552 (14.021)
3	80	3.500 (88.90)	0.083 (2.108)	0.120 (2.108)	0.188 (4.775)	0.216 (5.486)	0.300 (7.620)	0.350 (8.890)	0.438 (11.125)	0.600 (15.240)
3 1/2	90	4.000 (101.60)	0.083 (2.108)	0.120 (2.108)	0.188 (4.775)	0.226 (5.740)	0.318 (8.077)	---	---	0.636 (16.154)

NPS 4 to NPS 8:

NPS	DN	OD [in (mm)]	Wall thickness [in (mm)]											
			SCH 5	SCH 10S/10	SCH 20	SCH 30	SCH 40S/40/ STD	SCH 60	SCH 80S/80/ XS	SCH 100	SCH 120	SCH 140	SCH 160	SCH XXS
4	100	4.500 (114.30)	0.083 (2.108)	0.120 (2.108)	---	0.188 (4.775)	0.237 (6.020)	---	0.337 (8.560)	---	0.437 (11.100)	---	0.531 (13.487)	0.674 (17.120)
5	115	5.563 (141.30)	0.109 (2.769)	0.134 (3.404)	---	---	0.258 (6.553)	---	0.375 (9.525)	---	0.500 (12.700)	---	0.625 (15.875)	0.750 (19.050)
6	150	6.625 (168.28)	0.109 (2.769)	0.134 (3.404)	---	---	0.280 (7.112)	---	0.432 (10.973)	---	0.562 (14.275)	---	0.719 (18.263)	0.864 (21.946)
8	200	8.625 (219.08)	0.109 (2.769)	0.148 (3.759)	0.250 (6.350)	0.277 (7.036)	0.322 (8.179)	0.406 (10.312)	0.500 (12.700)	0.593 (15.062)	0.719 (18.263)	0.812 (20.625)	0.906 (23.012)	0.875 (22.225)

NPS 10 to NPS 24:

NPS	DN	OD [in (mm)]	Wall thickness [in (mm)]						
			SCH 5S	SCH 5	SCH 10S	SCH 10	SCH 20	SCH 30	SCH STD/40S
10	250	10.75 (273.05)	0.134 (3.404)	0.134 (3.404)	0.165 (4.191)	0.165 (4.191)	0.250 (6.350)	0.307 (7.798)	0.365 (9.271)
12	300	12.75 (323.85)	0.156 (3.962)	0.156 (3.962)	0.180 (4.572)	0.180 (4.572)	0.250 (6.350)	0.330 (8.382)	0.375 (9.525)
14	350	14.00 (355.60)	0.156 (3.962)	0.156 (3.962)	0.188 (4.775)	0.250 (6.350)	0.312 (7.925)	0.375 (9.525)	0.375 (9.525)
16	400	16.00 (406.40)	0.165 (4.191)	0.165 (4.191)	0.188 (4.775)	0.250 (6.350)	0.312 (7.925)	0.375 (9.525)	0.375 (9.525)
18	450	18.00 (457.20)	0.165 (4.191)	0.165 (4.191)	0.188 (4.775)	0.250 (6.350)	0.312 (7.925)	0.437 (11.100)	0.375 (9.525)
20	500	20.00 (508.00)	0.188 (4.775)	0.188 (4.775)	0.218 (5.537)	0.250 (6.350)	0.375 (9.525)	0.500 (12.700)	0.375 (9.525)
22	550	22.00 (558.80)	0.188 (4.775)	0.188 (4.775)	0.218 (5.537)	0.250 (6.350)	0.375 (9.525)	0.500 (12.700)	0.375 (9.525)
24	600	24.00 (609.60)	0.218 (5.537)	0.218 (5.537)	0.250 (6.350)	0.250 (6.350)	0.375 (9.525)	0.562 (14.275)	0.375 (9.525)

NPS	DN	Wall thickness [in (mm)]							
		SCH 40	SCH 60	SCH 80S/XS	SCH 80	SCH 100	SCH 120	SCH 140	SCH 160
10	250	0.365 (9.271)	0.500 (12.700)	0.500 (12.700)	0.593 (15.062)	0.718 (18.237)	0.843 (21.412)	1.000 (25.400)	1.125 (28.575)
12	300	0.406 (10.312)	0.562 (14.275)	0.500 (12.700)	0.687 (17.450)	0.843 (21.412)	1.000 (25.400)	1.125 (28.575)	1.312 (33.325)
14	350	0.437 (11.100)	0.593 (15.062)	0.500 (12.700)	0.750 (19.050)	0.937 (23.800)	1.093 (27.762)	1.250 (31.750)	1.406 (35.712)
16	400	0.500 (12.700)	0.656 (16.662)	0.500 (12.700)	0.843 (21.412)	1.031 (26.187)	1.218 (30.937)	1.437 (36.500)	1.594 (40.488)
18	450	0.562 (14.275)	0.750 (19.050)	0.500 (12.700)	0.937 (23.800)	1.156 (29.362)	1.375 (34.925)	1.562 (39.675)	1.781 (45.237)
20	500	0.593 (15.062)	0.812 (20.625)	0.500 (12.700)	1.031 (26.187)	1.280 (32.512)	1.500 (38.100)	1.750 (44.450)	1.968 (49.987)
22	550	---	0.875 (22.225)	0.500 (12.700)	1.125 (28.575)	1.375 (34.925)	1.625 (41.275)	1.875 (47.625)	2.125 (53.975)
24	600	0.687 (17.450)	0.968 (24.587)	0.500 (12.700)	1.218 (30.937)	1.531 (38.887)	1.812 (46.025)	2.062 (52.375)	2.343 (59.512)

NPS 26 to NPS 36:

NPS	DN	OD [in (mm)]	Wall thickness [in (mm)]						
			SCH 5S	SCH 10S	SCH 10	SCH 20	SCH 30	SCH STD/40S	SCH 40
26	650	26.000 (660.400)	---	---	0.312 (7.925)	0.500 (12.700)	----	0.375 (9.525)	---
28	700	28.000 (711.200)	---	---	0.312 (7.925)	0.500 (12.700)	0.625 (15.875)	0.375 (9.525)	---
30	750	30.000 (762.000)	0.250 (6.350)	0.312 (7.925)	0.312 (7.925)	0.500 (12.700)	0.625 (15.875)	0.375 (9.525)	---
32	800	32.000 (812.800)	---	---	0.312 (7.925)	0.500 (12.700)	0.625 (15.875)	0.375 (9.525)	0.688 (17.475)
34	850	34.000 (863.600)	---	---	0.312 (7.925)	0.500 (12.700)	0.625 (15.875)	0.375 (9.525)	0.688 (17.475)
36	900	36.000 (914.000)	---	---	0.312 (7.925)	0.500 (12.700)	---	0.375 (9.525)	---

References:

Nominal Pipe Size - Wikipedia

EASY TO KEEP NEW YEAR RESOLUTIONS

In today’s interconnected electronic world, we are constantly bombarded with social media messages and “forwarded wisdoms” from well-meaning family and friends. The following article is one such forward from a good friend that is perhaps apt for the first issue of the newsletter in year 2018.

A new year brings with it a sense of renewal and a desire to undergo various experiences and to keep old promises; we get a great opportunity to refresh our lives, our body, and our home, and can take advantage of this significant symbolic moment to move things forward and commit to certain processes.

For this to really work, we've captured the 10 most common resolutions people make and added ways and ideas to help you realize each one. The most important thing to keep in mind is that change is more than possible and that you’ll be happy to return to this article in a year's time and see how much you’ve progressed. Good luck!

EAT HEALTHIER

This first resolution is one that we try to maintain throughout the year, but are usually not very successful. We want to lose weight, start a diet and change our habits. So how can we do this? The key to the answer lies in the insinuation of "more" that appears in the promise - trying to be perfect and eating only vegetables starting today is a sure recipe for disappointment. The solution lies not in self-discipline and in a regime that we won’t be able to tolerate, but in moderation.

If you promise yourself that you’ll cut down eating sweets to once or twice a week - you are already taking a big step in the right direction. The most important thing for you to understand is that the body considers everything you eat and accumulates, so you should develop attention to the things you put into your mouth and always strive to be on the healthier side of your nutritional balance.

START WORKING OUT

We've already touched on proper nutrition, but the part we all know that needs to accompany it is physical activity. We sign up for a gym or a class, come for a short period and often give up and quit too soon. Here too it is important to maintain balanced expectations and not expect to become marathon champions overnight. The desire to see results is indeed an important motivational factor, but if you exercise regularly and don’t see immediate results, you don’t have to give up.

In our age, the Internet is loaded with information that can guide you as effectively as a private trainer. It is very important that you look for an exercise routine that won’t bore you so that you won’t feel it is a burden you’d rather avoid, and try to have a regular training routine even when at home - there are a variety of ways to do it.

TRAVEL

It's a resolution we all want to keep because it's just so enjoyable. The problem in realizing it is usually due to economic considerations, lack of time or just from addiction to idleness. Luckily, you can choose a variety of recreation and hiking options that’ll suit every pocket, and setting up a tent in the open air under the stars in any part of the country is always an inexpensive and exciting option. If you still prefer to stay in hotels or travel abroad, reorganize your priorities so that you can realize your ambition and break from routine.

INVEST IN RELATIONSHIPS AND FAMILY

There is something a little shameful about the promise that we will invest more in our family and spouse in the coming year - when they are the most important thing in our lives and should be the ones that get our best at all times. But the reality is sometimes complex and we are of course not perfect, but at least we’re willing to improve. The good news is that with awareness, mutual desire and a little guidance, it is possible to improve a lot in our relationships with our children, parents, siblings and the rest of the family, and this investment will reward us throughout life.

Always try to learn something new and effective about the role of parenthood, which is the most important in the world, but don't neglect your partner at the same times, because at the end of the day your spouse is your best friend. Adopt the best tips, look for ways to surprise and invigorate, and if you have free time - lift your head from the screens and focus your gaze on your favorite people.

LEARN SOMETHING NEW

The brain is an organ that needs to be trained, the mind always aspires to open up and the soul wants to be invigorated. No, you don't have to go back to school now and complete another degree, just be curious enough and give yourself the opportunity to explore the world a bit.

Try a new hobby, adopt a craftsmanship, express yourself creatively, learn a new language or volunteer in an organization that needs you. The main thing is that you feel that you are developing satisfaction and meaning from your life and nurturing the mind as well as the body.

SAVE MONEY

If you think it's impossible to save, and that small change won't accumulate to a large sum – you're wrong. The moment you want to take a vacation, host a party or you're met with a surprise expense, the amount you have on the side is what will allow you to pay for these things without getting into an economic mess. As for how and what you can cut back or save on, there is your own experience and if that is not enough, family and friends you can consult. If you only take situations where we spend too much on things we could buy for much less, then already we can have a few hundred dollars put aside.

IMPROVE YOUR EXTERNAL APPEARANCE

Let's face it, we aren't always looking our best. To avoid these situations, the most exhilarating thing we can say about improving our appearance is that a small change can make you feel so much better, especially when others notice and compliment it.

When you come across an idea, a product or service that could make you feel better, thoughts like "It's not for my age," "I don't have time to do it," or "It won't make me look good" should be thrown aside. In addition, you do not have to pay large amounts to look and feel giddy and attractive, and the best products for nourishing your skin and hair usually come from natural sources at a very reasonable cost. All you really need is just a desire to start and adopt some good ideas.

REDESIGN YOUR HOUSE AND GARDEN

Just as we need to change our look from time to time, our home need such a change to improve our mood when in our safe zone. We tend to invest in its design when we first move in or when we decide on a serious and expensive renovation, but smaller changes that require much less effort can occur more frequently.

With a little paint, a number of accessories and a light sense of design you can renew your home and garden and make both bloom. Start with some order and organization, throw out unused objects, grow plants and try to refurbish and recycle some of your stuff - there is no more appropriate time than the present to do all this.

LEARN TO COOK AND BAKE

Perhaps you're not exactly a chef and cooking and baking are not a talent of yours, and that's fine. Not all of us were born with a ladle in our hand, and working in the kitchen isn't the most natural or even loved thing by many of us. But if you have the desire and the need to learn and improve, if your family sometimes asks for food that's a little different and if the abundance of cooking shows on TV make you want to try it yourself, it's time to walk confidently towards the stovetop.

We promise that it can be quite simple, that there are recipes that won't take much of your time and will still be tasty and very healthy, and that all the information you need exists - you just have to follow it and start feeling the ingredients. Imagine the delightful and satisfied look of your dinner guests, and start forming your winning dish today.

LAUGH MORE

If things go awry in the way of fulfilling the other resolutions you made (which will probably happen, because nobody is perfect) you'll need a lot of humor to laugh at the little failures and get up more determined. Laughter is a matter of attitude, and the sooner you realize that life is short and that it is better to put some lightness, playfulness, and humor into it, the better your situation will be. Not only will you be happier, but also healthier, as laughter strengthens your immune system, increases longevity and is the best way to deal with difficulties, so don't keep it for rare moments.

BUILDING A BETTER TOMMORROW

It is becoming less practical for many companies to maintain in-house engineering staff. That is where we come in – whenever you need us, either for one-time projects, or for recurring engineering services. We understand the codes and standards, and can offer a range of services related to pressure vessels, tanks and heat exchangers.

Training & Development
Engineering and Design Services

CoDesign Engineering

Pressure Vessels ● Heat Exchangers ● Tanks ● Piping

Petroleum ● Petrochemical ● Chemical ● Power ● Fertilizer