ENGINEERING PRACTICE

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Key Process Considerations for Pipeline Design Basis

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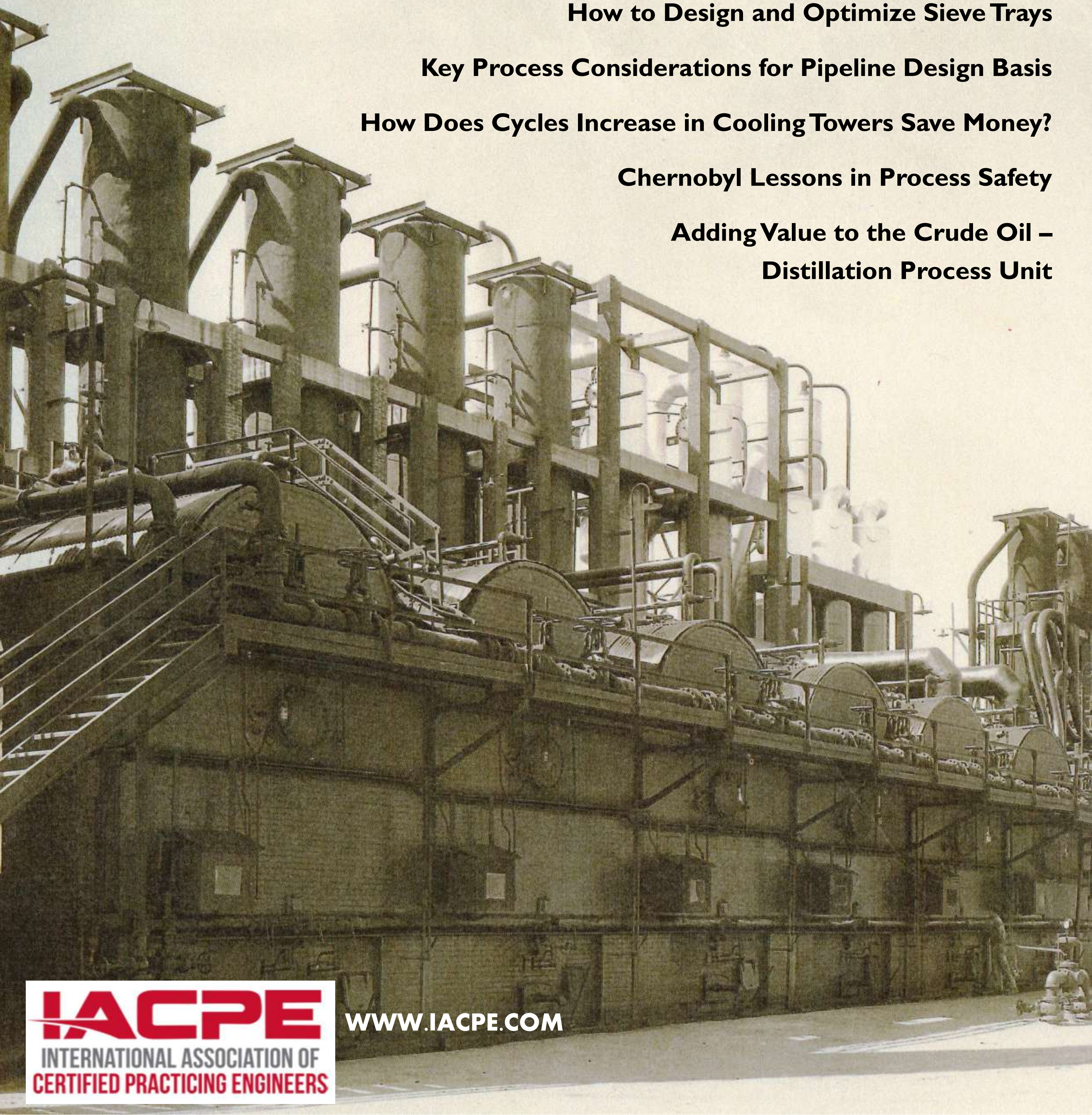
Chernobyl Lessons in Process Safety

Adding Value to the Crude Oil – Distillation Process Unit



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ABOUT

International Association of Certified Practicing Engineers provides a standard of professional competence and ethics. Identifies and recognizes those individuals that have meet the standard. And requires our members to participate in continuing education programs for personal and professional development.

In additional to insuring a professional level of competency and ethics the IACPE focuses on three major areas of development for our members: Personal, Professional, and Networking.

HISTORY

The International Association of Certified Practicing Engineers concept was formulated by the many young professionals and students we meet during our careers working in the field, running training courses, and lecturing at universities.

During question and answer sessions we found the single most common question was: What else can I do to further my career?

We found, depending on the persons avail able time and finances, and very often dependent on the country in which the person was from, the options to further ones career were not equal.

Many times we found the options available to our students in developing countries were too costly and or provided too little of value in an expanding global business environment.

The reality is that most of our founders come from countries that require rigorous academic standards at four year universities in order to achieve an engineering degree. Then, after obtaining this degree, they complete even stricter government and state examinations to obtain their professional licenses in order to join professional organizations. They have been afforded the opportunity to continue their personal and professional development with many affordable schools, programs, and professional organizations. The IACPE did not see those same opportunities for everyone in every country.

So we set out to design and build an association dedicated to supporting those engineers in developing in emerging economies.

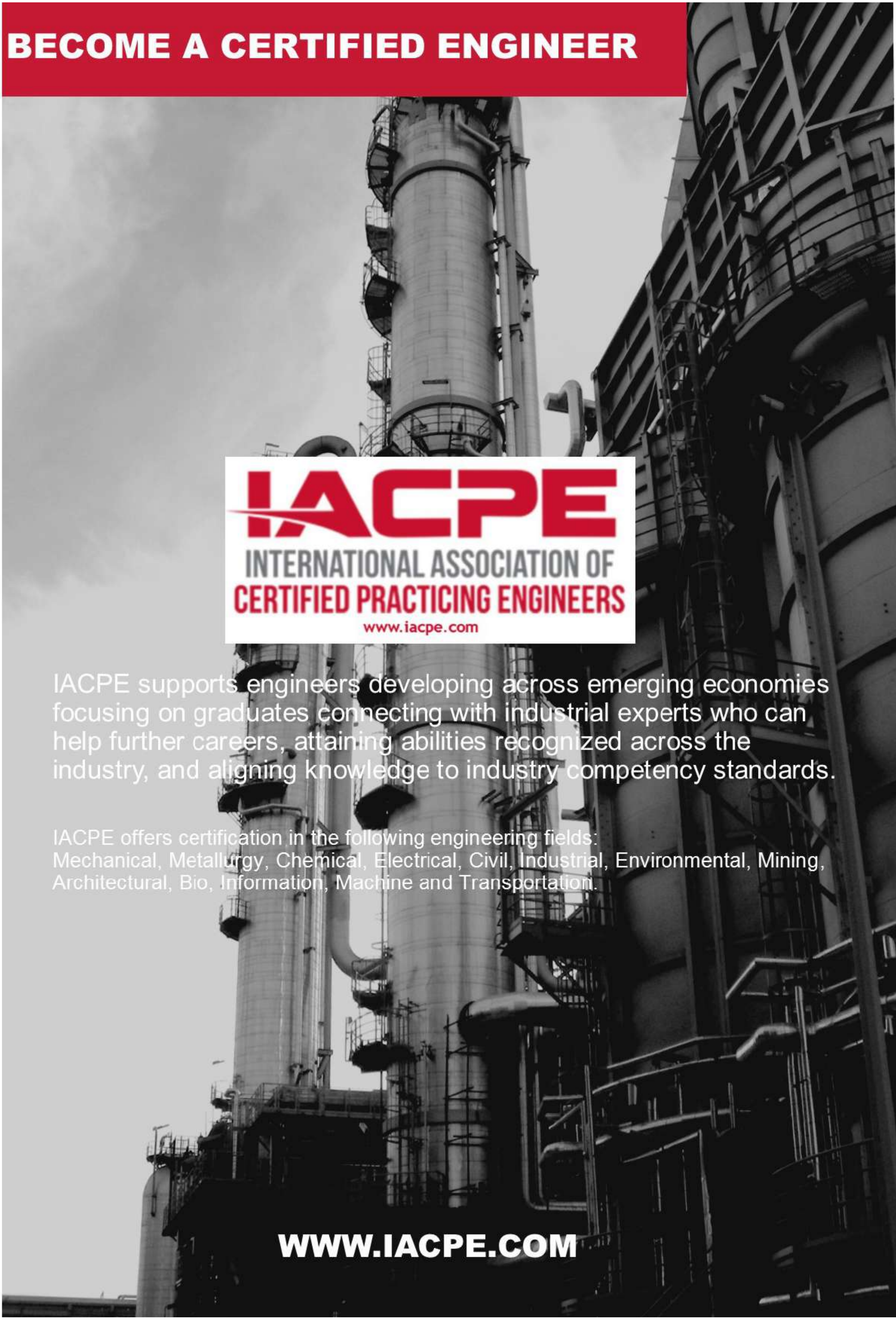
The IACPE took input from industry leaders, academic professors, and students from Indonesia, Malaysia, and the Philippines. The goal was to build an organization that would validate a candidates engineering fundamentals, prove their individuals skills, and enhance their networking ability. We wanted to do this in a way that was cost effective, time conscience, and utilized the latest technologies.

MISSION

Based on engineering first principles and practical real world applications our curriculum has been vetted by academic and industry professionals. Through rigorous study and examination, candidates are able to prove their knowledge and experience. This body of certified professionals engineers will become a network of industry professionals leading continuous improvement and education with improved ethics.

VISION

To become a globally recognized association for certification of professional engineers.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How to... SIEVE TRAY

How to design and optimize Sieve Trays

Part 1

Dr.-Ing. Volker Engel

Tower trays and internals are the heart of all distillation columns. Their design is an essential part of a process engineer's task and determines the process reliability and economy.

This article is the start of a series on different kinds of trays and internals.

On a distillation tray vapor enters liquid and forms a two phase regime (bubbling, froth, spray). The tray types differ mainly in the way the vapor gets into the liquid. For *Sieve Trays* (also called *Perforated Trays*) the vapor enters through horizontal round holes in the tray deck panels.

Sieve trays have been used for about a hundred years and are therefore one of the best studied tray type. They can be easily adapted to different design scenarios (flow rates) using different perforations, they do not require any special tool in production and thus are inexpensive to manufacture.

On the downside they are quite susceptible to bumps and non-level installation. As the gas flow passes vertically through sieve holes and froth layer, the sieve tray tends more to jet flooding compared to other tray types at the same load.

The perforation hole diameters of common sieve

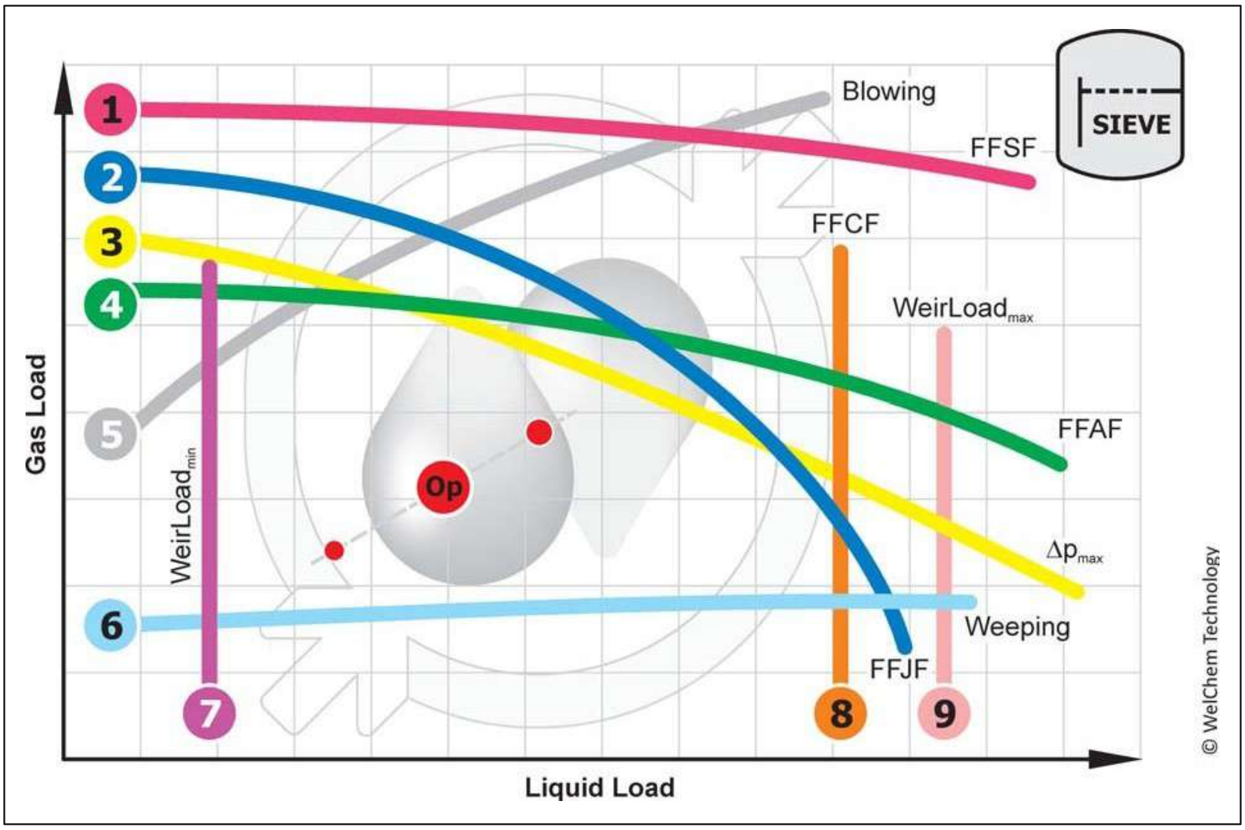

Fig. 1: Qualitative Operation Diagram for Sieve Trays

trays (for atmospheric applications and standard physical properties) usually reaches from 5 to 12.7mm, the relative free area (hole area per active area) is about 5 to 15% and the resulting total pressure drop per tray is advantageously low, about 5 to 8mbar. The tray spacing is usually not less than 400mm. Please note, that small holes are preferable due to hydraulic reasons, but higher in fabrication costs. Do not use hole diameters less than the material thickness, as they are difficult to punch.

As always, there are exceptions to these rules of thumb. There are cryogenic applications with hole diameters less than 1mm, cartridge towers with tray spacings of 300mm and wash trays with a relative open area of about 3%.

The turndown of sieve trays is significant less than that of valve trays.

The *Operating Area* of a sieve tray is defined by different limits. In Fig. 1 a qualitative operation diagram is shown. Please note, that the position and shape of all curves depend on the physical data, the tray geometry and the gas/liquid load. Each curve can be limiting!

The *Operation Point* (**Op** in Fig. 1) of the understanding, Jet Flood describes any liquid design case (as well as the minimum and maximum load) has to stay inside all limiting curves. For stable operation and good efficiency there is a useful operation area with narrower limits (e.g. 80%-FFCF and 85%-FFJF curves).

The first step for analyzing a design is – of course – calculating all relevant parameters. For a sieve tray design there are nine main parameters shown as curves in Fig. 1. These parameters are discussed in this article. There are some additional effects you will have to look at: entrainment, head loss at downcomer exit (clearance), flow regime, throw width over weir (anti-jump baffles), hydraulic gradients, downcomer residence time, efficiency, sealing, construction issues, statics, …

Please note, that all free suppliers' software only show a limited number of these parameters and therefore are not save to use for design, rating and troubleshooting of trays. For save design you should be able to calculate all parameters! (ref. to TRAYHEART OF WELCHEM)

In the following sections, all nine parameter curves of Fig. 1 are described. Each suggested action for preventing a certain effect may result in fertilizing another. The main task for designing trays is to balance these different and contradicting effects.

1 System Flood FFSF

There is a system limit set by the superficial vapor velocity in the tower. When the vapor velocity exceeds the settling velocity of liquid droplets („Stokes Law Criterion"), vapor lifts and takes much of the liquid with it. A well known model was published by STUPIN AND KISTER 2003.

This flooding effect cannot be reduced by use of other tray types or by increasing tray spacing.

The only way is to enlarge the vapor cross section area (e.g. enlarging tower diameter or reduce downcomer area).

Jet Flood FFJF 2

There are several definitions in literature for the so called *Jet Flood*. Similar definitions are *Entrainment Flood, Massive Entrainment, Two- Phase Flood or Priming*. For practical understanding, Jet Flood describes any liquid carried to the tray above by the gas stream. This leads to a shortcut recycling of the liquid with loss of tray efficiency, additional pressure drop and additional downcomer load. For good tray performance, the Jet Flood value should be less than 75-80%.

You can reduce Jet Flood by

a. lowering the gas velocity (higher open area, i.e. more holes, larger holes)

b. enlarging the tray spacing

c. lowering the froth height on the tray deck (by reducing weir height or weir crest height)

d. enlarging the active area (i.e. the gas flow area) by sloping the downcomers

e. using push valves (there are special push valves which are used in sieve tray designs)

3 Pressure Drop

In most cases there is specified a maximum allowable pressure drop of a tower (e.g. vacuum applications). You have to ensure that the pressure drop per tray does not exceed a certain value. This leads to a limiting curve within the operation diagram.

To reduce the pressure drop of a design, you can

a. lower the gas velocity by enlarging the hole area (the pressure drop is directly proportional to the square of the gas velocity!)

b. use smaller holes (based on the same absolute hole area, small holes have a lower pressure drop than larger ones)

c. lower the froth height on the tray deck (by reducing weir height or weir crest height)

d. enlarge the active area (for more holes) by reducing the downcomer area or sloping the downcomers

Aerated Downcomer Backup FFAF 4

This limiting curve is also known as Downcomer *Backup Flood*. It describes the (aerated) backup of the downcomer due to pressure drop effects. It is important to not mix this up with the

Choke-Flood-effects (ref. to 8).

The level of the liquid in the downcomer is the result of (i) head loss at the clearance, (ii) the liquid height on the outlet deck, (iii) an inlet weir (if present) and (iv) the pressure drop of the tray itself. All these effects can be expressed by “hot liquid height”. This resulting level in the downcomer has to compensate these effects! Taking into account the aeration of the liquid in the downcomer, the level has to be less than tray spacing plus weir height.

To reduce a high aerated Downcomer Backup value:

a. reduce the pressure drop of the tray (ref. to 3)

b. reduce the head loss of the clearance (use higher clearance height or radius lips or recessed seal pans in case of insufficient sealing)

c. avoid inlet weirs

Please note, that it is no option to enlarge the downcomer area to reduce this flooding effect!

5 Blowing

The effect of running a tray deck dry is called *Blowing*. It occurs at low froth height and/or high gas load. The Blowing effect has to be taken into account particularly at low liquid loads – at high gas load other effects are more limiting.

To visualize this effect one can imagine that the two-phase layer is separated from the panel and carried upwards.

To prevent Blowing, you can

a. enlarge the two-phase layer (by increasing outlet weir height or by using picket fence / blocked weirs)
b. reduce the flow path length
c. enlarge the hole diameter (at same absolute hole area)

Weeping 6

Weeping describes liquid raining through the sieve holes. The weeping rate tells you the ratio of liquid flow lost by weeping. Since the weeping liquid leads to an uneven distribution on the active area (danger of gas break-through, unsealing of downcomer, cross flow channeling), weeping rates should be less than 10% and should not occur on design load.

Liquid raining through the hole changes all other liquid loads on the tray (weir crest height, downcomer backup height, froth height, ...).

To reduce Weeping you have to

reduce the liquid head on the tray deck (by reducing outlet weir height or weir crest height)

reduce the hole diameter (small holes resist better)

enlarge the gas velocity in sieve holes (by reducing sieve hole area)

7 Minimum Weir Load

The uniform thickness of the two-phase layer is essential for the successful operation of a tray. This applies even more to a sieve tray than to other tray types. To achieve this uniform flow, the tray panels have to be in level and the outlet weir has to be installed accurately.

To compensate small tolerances, the weir crest should be higher than 3mm and the weir load more than 9 $m^3/m/h$. In case of low weir loads you will normally have to consider gasketing the tray to avoid any leakage and loss of liquid.

To ensure these minimum values, you can use

a. notched weirs
b. blocked weirs

Choke Flood 8

The maximum liquid throughput of a down- comer is limited by the liquid velocity and the effect of overload (so called *Choke Flood*). The maximum allowable liquid velocity in the down- comer depends on the density ratio of gas to liquid, the tray spacing and the system factor. (The system factor describes the difficulty of phase separation. For common applications it is 1.0.) The most popular downcomer choke flooding calculation was published by GLITSCH 1993.

Another effect of Choke Flood at center and off-center downcomers is initiated by the mutual interference of the two liquid flows into the downcomer.

To prevent downcomer Choke Flood you have to

a. enlarge the downcomer area
b. implement more flow passes (with in sum an-overall higher downcomer area)
c. enlarge the tray spacing (if limiting)
d. install anti-jump baffles for center / off-center downcomers

9 Maximum Weir Load

The maximum liquid flow handled by a downcomer can also be limited by the weir.

If the weir crest exceeds 37mm or the weir load 120 $m^3/m/h$, the liquid will not enter the downcomer properly.

To prevent overload of the weir, you have to extend the weir length by

a. larger downcomers with longer weirs (or multichordal downcomers)
b. more flow passes
c. swept back weirs at the side downcomers

Conclusion

There are multiple limiting effects that have to be considered at the design and operation of sieve trays. Sieve trays can be adjusted very well to a certain design point (the pressure drop is often better than for "modern" solutions), just their operation area is not as flexible as for valve tray designs and the Jet Flood is not as good as that for valve trays.

Sieve trays are rarely suggested by suppliers, because they are no proprietary solutions.

About the Author

Volker Engel studied process engineering at the Technical University of Munich and did his Ph.D. thesis on packed columns with Prof. Johann G. Stichlmair. Since 1998 he has been the managing director of WelChem Process Technology GmbH and head of the TrayHeart software. TrayHeart has developed into a state-of-the-art design tool for trays and internals in process technology.

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WelChem Process Technology: TrayHeart Software. Tower Internals Calculation Software. Internet: www.welchem.com; Info: service@welchem.com

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Key Process Considerations for Pipeline Design Basis

Jayanthi Vijay Sarathy, M.E, CEng, MIChemE, Chartered Chemical Engineer, IChemE, UK

Prior to venturing into an oil & gas pipeline project, the project team would require a design basis, based on which the project is to proceed. Oil & Gas Pipeline design begins with a route survey including engineering & environmental assessments. The following document provides a few key considerations for process engineers to keep in mind, the factors that matter when preparing a pipeline design basis from a process standpoint.

1. Well Production Data/Profile

Well production profiles are required as this determines the size of the pipeline required to transport volume/time of fluid. Gases are highly compressible and cannot be treated the same as liquids such as, crude oils & petroleum distillates. The operating pressures & temperatures are required to be known as they determine the design conditions of the pipeline.

2. Fluid Physical Properties

The physical properties of the materials being transported dictate the design and operating parameters of the pipeline. Specific gravity, compressibility, kinematic & dynamic viscosity, pour point, and vapour pressure of the material are the primary considerations. The pour point of a liquid is the temperature at which it ceases to pour. The pour point for oil can be determined under protocols set forth in the ASTM Standard D-97.

In general, crude oils have high pour points. When transported hydrocarbons operate below their pour point, auxiliary measures such as heating, diluting with lighter hydrocarbons that are miscible & allows lowering the viscosity & pour point temperature, mixing with water to allow the waxes to slide through the pipe walls, or modifying the chemical composition of the hydrocarbon. It is to be noted that, in the case of finished products, (e.g., gas oil or Jet A1 fuel), many of the auxiliary measures like addition of water or mixing with lighter hydrocarbons becomes infeasible, since they affect the product specification.

Vapour Pressure of a liquid is its capacity to vaporize/evaporate into its gaseous phase. In pipeline operations, slack flow is a situation where due to the elevational & pipeline pressure drops, a portion of the hydrocarbon experiences pressure below its vapour pressure. As a result, a portion of the liquid vaporizes & reaches the high points in the pipeline. Upon restarting the pipeline, the vapour pockets experience a compressive rise in pressure due to the upstream & downstream liquid pockets, only to collapse & release energy that can rupture pipelines.

Reid vapour pressures are critical to liquid petroleum pipeline design, since the pipeline must maintain pressures greater than the Reid vapour pressure of the material in order to keep the material in a liquid state. Pipelines that handle finished products are preferred to be operated with single phase flow regime & fully filled pipes. This ensures there is no scope for volatilization that reduces the scope for fire hazards.

3. Pumping Costs

Viscous fluids require more power to deliver required motive force to the hydrocarbons to transport them across the pipeline. Waxy crudes can be pumped below their pour point However if the flow is stopped, for e.g., after a pipeline shutdown, the energy required to restart the pipeline would be much higher than what was required to keep it flowing. Pipelines also suffer from the formation of hydrates & asphaltenes. Waxes can form crystalline structures that tend to agglomerate & is referred to as gelling.

Gelling is also a phenomenon that is found in storage tanks in production facilities where the fluid sits motionless for hours or even days, resulting in operational difficulties. Hence to attend to these limitations, pour point estimation becomes vital to determine if external heating is required. In some cases, if the waxy crude does not gel enough, it can get transported to the pump where shear forces & rise in temperature allow the waxy crudes to stay above the pour point.

4. Thermal Stresses

Petroleum pipelines are normally buried unless local regulation prevents them. To do so, trenches are dug & are laid below grade/frost line level. Such measures also provide the advantage of maintaining relatively constant temperature in line with the ambient/season soil temperature, thereby ensuring the pipeline expansion does not occur to the point of deflection. Expansion joints as well as in some cases, trenches are dug extra wide to accommodate any lateral movement. In case of river crossings, the pipeline is to be laid above ground. In locations that are prone to landslides, buried pipelines option is preferred to avoid direct impact of rock structures. But this does not necessarily mean buried pipelines are free from structural damage, since the weight of the soil/rock structures deposited above the pipeline can also crush the buried pipelines.

5. Pipeline Pressure Drop

Pipelines are designed keeping in mind, the material and construction costs as well operating costs. Material costs are determined by the pipeline weight, whereas operational costs are largely impacted by the pressure drop experienced which is a function of the flow regime. The two key forces dictating the pipeline total pressure losses are – Hydrostatic pressure drop due to the pipeline elevation & frictional pressure drop which depends on the flow rate. In multiphase pipelines across hilly terrains, hydrostatic pressure drop decreases while frictional pressure drop increases with flow. The sum of both these pressure losses gives the total pressure loss. The pipeline size chosen should be preferably, the point at which the total pressure loss is the least.

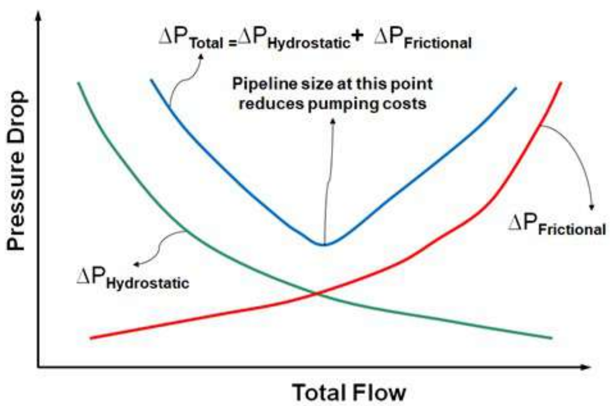

Fig 1. Pipeline Total Pressure Loss – Hilly Terrain

From the above figure it can be seen that operating a multiphase line at a lower flowrate can actually cost more to pump.

6. Max Hydro Test & Leak Pressure Test

The maximum allowable operating pressure [MAOP] is taken as 90% of the design pressure & for an 8 hour minimum test pressure, the hydro test pressure is based on the location class and maximum test pressure becomes the lower value of 8 hour minimum test pressure & test pressure at low point. The leak test pressure is taken as 80% of the design pressure. Liquid Pipelines are quite prone to surge/liquid hammering. For this reason at the design stage itself, a surge analysis is conducted to ensure, the pipeline can withstand surge at 110% of the MAOP/design pressure.

7. Valve Spacing

Pipelines need valves to placed & spaced taking into consideration – Rapid Isolation/Shutdown of pipeline sections to minimize inventory breach, maintain pipeline design integrity, and facilitate maintenance, repairs & hot tapping operations. Pipelines would also be subjected to pigging operations – Cleaning/Intelligent pigging & hence the valve placement must enable recovery of stuck pigs.

8. Hydrocarbon Flares

Pipelines would sometimes have to be blown down of any hydrocarbons (liquid or liquid mixed vapours) during events of over pressure. Burn pit lines serve this purpose. It is important to monitor pilot flames and provide pilot flame failure alarms. Since burn pit lines are a source of open flame, they are to be located at least 150 m away from roadways, process & storage facilities. In cases of pipeline in remote locations requiring maintenance or repair, mobile flare units can be used.

However not all occasions would allow open flaring, as a result of which, enclosed ground flares can be used. These conform to the requirements of flaring & disposal in populated areas or process facilities that are in close proximity to the flare system. The flaring is smokeless with no visible flame & noiseless due to insulation of the combustion chamber. To attend to the flare capacities required, a flare study report is to be made part of the design basis.

9. Pipeline Standards/Codes1

ASME has been a pioneer in developing industry codes & standards for oil & gas pipelines. The scope of the first draft of the ASME Code for Pressure Piping, which was approved by the American Standards Association in 1935, included the design, manufacture, installation, and testing of oil and gas pipelines (ASME B31.4). As the needs of the industry evolved over the years, rules for new construction have been enhanced, and rules for operation, inspection, corrosion control, and maintenance have been added. In addition to ASME, several other organizations, including the API and NACE International, also developed standards used by the pipeline industry. Some of the ASME/API/ANSI standards are,

1. "Gas Transmission and Distribution Piping Systems," ASME B31.8, 1999.
2. "Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids," ASME B31.4, 1998.
3. "Power Piping", ASME B31.1, 1998; Addenda B31.1A, 1999; Addenda B31.1B, 2000
4. "Process Piping" ASME B31.1, 1999; Addenda B31.3A, 1999
5. "Slurry Transportation Piping Systems" ASME B31.11, '89; Addenda B31.11A, 1991
6. "Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids" ASME B31.4, 2002
7. "Gas Transmission and Distribution Systems," ASME 31.8, 2003
8. "Specification for Line Pipe", API 5L, Mar 2004 / Errata 1, Jan 2005
9. "Steel Pipelines Crossing Railroads and Highways" API 1102 (1993)
10. "Specification for Pipeline Valves (Gate, Plug, and Check Valves)", 21st edition, API 6D1, June 1998 Supplement 2
11. Pipeline wall thickness (API B31.G)

Velocity Considerations 3

Gas line velocities should be less than 60 to 80 ft/s to minimize noise & allow for corrosion inhibition. A lower velocity of 50 ft/s should be used in the presence of known corrosives such as CO2. The minimum gas velocity should be between 10 and 15 ft/s, which minimize liquid fallout. The minimum fluid velocity in multiphase systems must be relatively high to keep the liquids moving in order to prevent/minimize slugging. The recommended minimum velocity is 10 to 15 ft/s. The maximum recommended velocity is 60 ft/s to inhibit noise & 50 ft/s for CO2 corrosion inhibition. In two-phase flow, it is possible that the flow stream's liquid droplets can impact the pipe wall causing erosion of the corrosion products. Erosion of the pipe wall itself could occur if solid particles, particularly sand, are entrained in the flow stream.

Pipeline Mechanical Design

As an example to perform Gas Pipeline mechanical design, ASME B31.8 is used. The requirement to be met for pipeline wall stresses as per ASME B31.8 is Design factor [F], Temperature De-rating [T], Longitudinal Joint Factor [E] for the chosen pipeline joining methods. This is shown below as follows,

Table 1. Reference Mechanical Design Parameters

Design Factors [F] - Gas Pipeline Location		
Class	**Description**	**F**
Class 1, Div 1	Deserted	0.80
Class 1, Div 2	Deserted	0.72
Class 2	Village	0.60
Class 3	City	0.50
Class 4	Densely Populated	0.40
Temperature De-rating [T] for Gas Pipelines		
T [^{0}F]	**T [^{0}C]**	**T**
$\leq$ 250	$\leq$ 120	1.00
300	150	0.97
350	175	0.93
400	200	0.91
450	230	0.87
Abbreviation	**Joining Method**	**E**
SMLS	Seamless	1.0
ERW	Electric Resistance Weld	1.0
EFW	Electric Flash Weld	1.0
SAW	Submerged Arc Weld	1.0
BW	Furnace Butt Weld	0.6
EFAW	Electric Fusion Arc Weld	0.8

The pipeline specification requirement as per API 5L plain end line pipe specifications, ranges from 6" ND to 80" ND. The product pipeline specification (PSL) with its respective Specified Minimum Yield Strength (SYMS) to be used as per API 5L are PSL 1 and PSL 2. The pipeline grades are as follows,

Table 2. Product Specification Level (PSL)

Grade	SMYS MPa	Grade	SMYS MPa
PSL 1 Gr A25	172	PSL 2 Gr B	241
PSL 1 Gr A	207	PSL 2 X42	290
PSL 1 Gr B	241	PSL 2 X46	317
PSL 1 X42	290	PSL 2 X52	359
PSL 1 X46	317	PSL 2 X56	386
PSL 1 X52	359	PSL 2 X60	414
PSL 1 X56	386	PSL 2 X65	448
PSL 1 X60	414	PSL 2 X70	483
PSL 1 X65	448	PSL 2 X80	552
PSL 1 X70	483	-	-

Location of the Gas Pipelines

1. **Class 1 location** - A Class 1 location is any 1-mile pipeline section that has 10 or fewer buildings intended for human occupancy including areas such as, wastelands, deserts, rugged mountains, grazing land, farmland, sparse populations.
2. **Class 1, division 1 Location** – A Class 1 location where the design factor, F, of the pipeline is greater than 0.72 but equal to, or less than 0.80 and which has been hydrostatically tested to 1.25 times the maximum operating pressure.
3. **Class 1, division 2 Location** - This is a Class 1 location where the design factor, F, of the pipeline is equal to or less than 0.72, and which has been tested to 1.1 times the maximum operating pressure.
4. **Class 2 Location** - This is any 1-mile section of pipeline that has more than 10 but fewer than 46 buildings intended for human occupancy including fringe areas around cities and towns, industrial areas, and ranch or country estates.
5. **Class 3 Location** - This is any 1-mile section of pipeline that has 46 or more buildings intended for human occupancy except when a Class 4 Location prevails, including suburban housing developments, shopping centres, residential areas, industrial areas & other populated areas not meeting Class 4 Location requirements
6. **Class 4 Location** - This is any 1-mile section of pipeline where multi-storey buildings are prevalent, traffic is heavy or dense, and where there may be numerous other utilities underground. Multi-storey means four or more floors above ground including the first, or ground, floor. The depth of basements or number of basement floors is immaterial.

Line Specification of Gas Pipelines – API 5L

1. PSL1 pipes are available through size 2/5” to 80” whereas the smallest diameter pipe available in PSL2 is 4.5” & the largest diameter is 80”. PSL1 pipelines are available in different types of ends, such as Plain end, Threaded end, Bevelled end, special coupling pipes whereas PSL2 pipelines are available in only Plain End.
2. For PSL2 welded pipes, except continuous welding & laser welding, all other welding methods are acceptable. For electric weld welder frequency for PSL2 pipeline is minimum 100 kHz whereas there is no such limitation on PSL1 pipelines.
3. Heat treatment of electric welds is required for all Grades of PSL2 pipes whereas for PSL1 pipelines, grades above X42 require it. All kinds of welding method are acceptable to manufacture PSL1; however, continuous welding is limited to Grade A25.

Gas Pipeline Wall Thickness Estimation

The B31.8 code is often used as the standard of design for natural gas piping systems in facilities, such as compressor stations, gas treatment facilities, measurement & regulation stations & tank farms. The B31.8 wall-thickness formula is stated as,

$$t = \frac{DP \times OD}{2 \times F \times E \times T \times SMYS} \qquad (1)$$

Where,

t = Minimum design wall thickness [in]

DP = Pipeline Design Pressure [psi]

OD = Pipeline Outer Diameter [in]

SMYS = Specific Minimum Yield Stress [psi]

F = Design Factor [-]

E = Longitudinal Weld Joint Factor [E]

T = Temperature De-rating Factor [-]

References

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"Overview of the Design, Construction, and Operation of Interstate Liquid Petroleum Pipelines", ANL/EVS/TM/08-1, Argonne National Laboratory

https://petrowiki.org

About the Author

Vijay Sarathy holds a Master's Degree in Chemical Engineering from Birla Institute of Technology & Science (BITS), Pilani, India and is a Chartered Engineer from the Institution of Chemical Engineers, UK. His expertise over 12 years of professional experience covers Front End Engineering, Process Dynamic Simulation and Subsea/Onshore pipeline flow assurance in the Oil and Gas industry. Vijay has worked as an Upstream Process Engineer with major conglomerates of General Electric, ENI Saipem and Shell.


TrayHeart
Tower Internals Design
TrayHeart is a professional software that performs hydraulic calculations for all types of tower trays, random and structured packings and liquid distributors. The development of TrayHeart started in 1998 and was continued jointly by universities, companies of the chemical industry and tower internals suppliers. TrayHeart ...
is based on multiple calculation models and large databases of packings, float valves, fixed valves, bubble caps, and liquid distributor templates
is a supplier-independent tool. There are no preferred product placements or promoted designs
considers static dimensions, manways and fastenings
offers an interactive 3D-view for all designs
can be used for single stage, profile and data validation calculations
has a unique, logical and multi-lingual user interface, with multiple input and output options
applies hundreds of online queries to check the feasibility and limits of the calculated designs
is a well introduced software many companies have relied on for more than 20 years
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PROCESS TECHNOLOGY

How does Cycles increase in cooling towers save money?

Shahzeb Hassan, Process Engineer (ME, AIChE Professional Member & Guest Speaker)

As we all know that the water conservation is a big challenge to the Process industries these days. Most of the industries are recycling the waste water from effluent treatment plant & use it to fulfill the purpose that can be used as a makeup for cooling tower after proper treatment & sterilization. Cooling water cycle of concentration (COC) running in every process industry normally in the range from 4 to 6. Most of the plants are receiving water from government at different rates i.e. 64 PKR/m3. If you are running at 4 then u can save money for the company.

What is cycle of concentration, COC?

An important concept related to Cooling Towers is the Cycles of Concentration (also known as Cycles or Concentration Ratio). Cycles of Concentration is monitored with a conductivity meter and it is a measure of the concentration of dissolved solids in the Cooling Tower process water. As water evaporates from a Cooling Tower it leaves behind dissolved solids. These dissolved solids will therefore increase in concentration in the process water, until there is a Blow-down. As the dissolved solids increases, so does the Cycles of Concentration.

Water is typically removed from a Cooling Tower in one of the following ways:

1. Evaporation
2. Drift
3. Blow-down or Bleed-off
4. Basin Leaks and/or Overflows

Make-up Water = Evaporation + Blowdown + Drift + Leaks/Overflows

COC = TDS ppm in Cooling water/TDS ppm in Makeup water.

If we increase the COC from 4 to 6 then we can conserve water to such extent that It can be utilized either in desalter water injection & conservation. However, we need to increase sulfuric acid (98%) dosage to convert the carbonate hardness into sulfate hardness. The pH range will also be changed from 8.2-8.6 to 7.8-8.2. This low pH will help to reduce the alkalinity & calcium hardness. Due to less blowdown & increased cycles, cooling tower chemical consumptions will also be lower which ultimately reduce the chemical cost.

The cooling water PH monitoring need to be increased or install an online PH analyzer at makeup line of cooling tower. Accidentally or unintentionally increase in sulfuric acid dosage at cooling tower will turn the system towards corrosion, low PH. The other option to manage acid dosing is to test sulfates in cooling water and against PH set the maximum limit of sulfates in cooling water. Like RSI or LSI indexes are calculated to check either the system is stable or towards scaling/ Corrosion. Corrosion coupon can also be installed at recirculation line to identify any upset & monitor the system performance during operation. This is all the monitoring techniques to do better optimization of cooling water system.

What is RSI?

The Ryznar stability index (RSI) attempts to correlate an empirical database of scale thickness observed in municipal water systems to the water chemistry. Like the LSI, the RSI has its basis in the concept of saturation level. Ryznar attempted to quantify the relationship between calcium carbonate saturation state and scale formation. The Ryznar index takes the form:

RSI = 2(pHs) - pH

Where:

- pH is the measured water pH
- pHs is the pH at saturation in calcite or calcium carbonate

pHs = (9.3 + A + B) - (C + D)

Where:

- A = (Log10 [TDS] - 1) / 10
- B = -13.12 x Log10 (oC + 273) + 34.55
- C = Log10 [Ca2+ as CaCO3] - 0.4
- D = Log10 [alkalinity as CaCO3]

The empirical correlation of the Ryznar stability index can be summarized as follows:

RSI << 6 the scale tendency increases as the index decreases

RSI >> 7 the calcium carbonate formation probably does not lead to a protective corrosion inhibitor film

RSI >> 8 mild steel corrosion becomes an increasing problem.

What is LSI?

The Langelier saturation index (LSI) is probably the most widely used indicator of cooling water scale potential. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth. It provides no indication of how much scale or calcium carbonate will actually precipitate to bring water to equilibrium.

LSI can be calculated as

LSI = (pHs) - pH

If LSI is negative: No potential to scale, the water will dissolve $CaCO_3$

If LSI is positive: Scale can form and $CaCO_3$ precipitation may occur.

If LSI is close to zero: Borderline scale potential. Water quality or changes in temperature, or evaporation could change the index.

What is Larson-skold index?

The Larson-Skold index describes the corrosivity of water towards mild steel. The index is based upon evaluation of in-situ corrosion of mild steel lines transporting Great Lakes waters. The index is the ratio of equivalents per million (epm) of sulfate (SO_4^{2-}) & chloride (Cl^-) to the epm of alkalinity in the form bicarbonate plus carbonate:

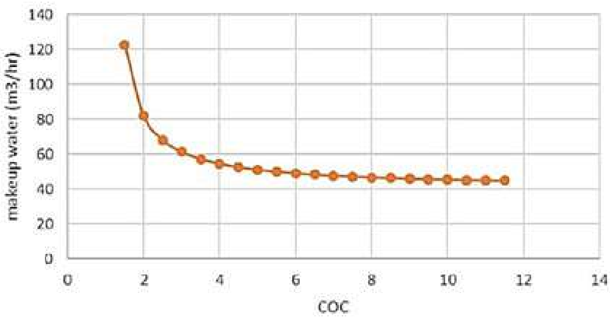
Larson-Skold index = (epm Cl^- + epm SO_4^{2-})/(epm HCO_3^- + epm CO_3^{2-})

Index >> 1.2 the tendency towards high corrosion rates of a local type should be expected as the index increases

The most notable parameter is PH but these indexes should be calculated on weekly basis to monitor the system.

The cooling system will remain scale & corrosion, trouble free. Also, best micro-biological & algae control is achieved at low cooling water pH (7.8 to 8.2), since, the efficiency of chlorine to kill Algae & micro-organism is more/ increased at lower cooling water PH.

This below graph explains the range of COC vs makeup, the most feasible range is 4 to 6 as u see that if we increase the cycle makeup water is decreasing.



Demonstration in detail that how CW cycles can actually save water. Detailed analysis & calculations on each cycle are as follow.

COC AT 4.0

Volume, (m3)	745
Recirculation, (m3/h)	2210
Temperature drop, (°C)	13.00
Hot skin temperature, (°C)	60
m-alkalinity factor	0.90
Ev. factor, (% per 10 °C)	1.4
Drift, (% RR)	0.050
Target Cycle	4.00
Target Increment	0.50
pH correction	Yes
Working days	365

Target pH	8.4
Acid used	H2SO4
Acid strength, (%)	98
Acid density, (kg/L)	1.8
Target alkalinity	189

	Make Up1	Make Up2	Make Up	2.50	3.00	3.50	↓ **4.00**	4.50	5.00	5.50	6.00
Evaporation, (m3/h)				40.2	40.2	40.2	**40.2**	40.2	40.2	40.2	40.2
Blow-down, (m3/h)				26.8	20.1	16.1	**13.4**	11.5	10.1	8.9	8.0
Make-up, (m3/h)				67.0	60.3	56.3	**53.6**	51.7	50.3	49.2	48.3
% Make Up	100.0%	0.0%	100.0%								
pH	8.6		8.0	8.4	8.4	8.4	**8.4**	8.4	8.4	8.4	8.4
m-alk, (mg/L $CaCO_3$)	106		106	189	189	189	**189**	189	189	189	189
Ca, (mg/L $CaCO_3$)	125		125	313	375	438	**500**	563	625	688	750
Mg, (mg/L $CaCO_3$)	65		65	163	195	228	**260**	293	325	358	390
Conductivity, (uS/cm)	828		828	2070	2484	2898	**3312**	3726	4140	4554	4968
SiO_2, (mg/L)	8		8	20	24	28	**32**	36	40	44	48
Cl^-, (mg/L	127		127	318	381	445	**508**	572	635	699	762
SO_4, (mg/L)	80		80	248	334	419	**505**	591	677	762	848
oPO_4, (mg/L)											
Suspended solids, (mg/L)	1		1	3	3	4	**4**	5	5	6	6
Fe^{+2} + Al^{+3}, (mg/L)	0.1		0.1	0.3	0.4	0.4	**0.5**	0.5	0.6	0.7	0.7
LSI	1.37		0.75	1.76	1.84	1.90	**1.95**	2.00	2.04	2.08	2.11
MgSi	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
CaMgSi	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
$CaSO_4$	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
Half-life, (days)				0.8	1.1	1.3	**1.6**	1.9	2.1	2.4	2.7
Larson-Skold Index	2.5		2.5	3.7	4.7	5.6	**6.6**	7.5	8.5	9.4	10.4
Sulfuric acid, (mg/L)				49.9	97.6	145.3	**193.0**	240.7	288.4	336.1	383.8
Sulfuric acid, (kg/day)				32.1	47.1	56.1	**62.1**	66.4	69.6	72.1	74.1
Sulfuric acid, (L/h)				0.7	1.1	1.3	**1.4**	1.5	1.6	1.6	1.7

Analysis:

At cycle 4.0 the makeup water is 53.6 m3/hr and pH to be maintained is 8.4 so that the actual consumption of acid is 62.1 Kg/day. Conductivity to be maintained in cooling tower is 3312 Microsiemens/cm (2100 ppm TDS).

COC AT 6.0

Volume, (m3)	745
Recirculation, (m3/h)	2210
Temperature drop, (°C)	13.00
Hot skin temperature, (°C)	60
m-alkalinity factor	0.90
Ev. factor, (% per 10 °C)	1.4
Drift, (% RR)	0.050
Target Cycle	6.00
Target Increment	0.50
pH correction	Yes
Working days	365

Target pH	8.1
Acid used	H2SO4
Acid strength, (%)	98
Acid density, (kg/L)	1.8
Target alkalinity	125

	Make Up1	Make Up2	Make Up	4.50	5.00	5.50	↓ **6.00**	6.50	7.00	7.50	8.00
Evaporation, (m3/h)				40.2	40.2	40.2	**40.2**	40.2	40.2	40.2	40.2
Blow-down, (m3/h)				11.5	10.1	8.9	**8.0**	7.3	6.7	6.2	5.7
Make-up, (m3/h)				51.7	50.3	49.2	**48.3**	47.5	46.9	46.4	46.0
% Make Up	100.0%	0.0%	100.0%								
pH	8.6		8.0	8.1	8.1	8.1	**8.1**	8.1	8.1	8.1	8.1
m-alk, (mg/L $CaCO_3$)	106		106	125	125	125	**125**	125	125	125	125
Ca, (mg/L $CaCO_3$)	125		125	563	625	688	**750**	813	875	938	1000
Mg, (mg/L $CaCO_3$)	65		65	293	325	358	**390**	423	455	488	520
Conductivity, (uS/cm)	828		828	3726	4140	4554	**4968**	5382	5796	6210	6624
SiO_2, (mg/L)	8		8	36	40	44	**48**	52	56	60	64
Cl, (mg/L	127		127	572	635	699	**762**	826	889	953	1016
SO_4, (mg/L)	80		80	652	738	824	**910**	995	1081	1167	1253
oPO_4, (mg/L)											
Suspended solids, (mg/L)	1		1	5	5	6	**6**	7	7	8	8
Fe^{+2} + Al^{+3}, (mg/L)	0.1		0.1	0.5	0.6	0.7	**0.7**	0.8	0.8	0.9	1.0
LSI	1.37		0.75	1.53	1.57	1.61	**1.64**	1.67	1.70	1.73	1.75
MgSi	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
CaMgSi	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
$CaSO_4$	OK		OK	OK	OK	OK	**OK**	OK	OK	OK	OK
Half-life, (days)				1.9	2.1	2.4	**2.7**	2.9	3.2	3.5	3.7
Larson-Skold Index	2.5		2.5	11.9	13.3	14.8	**16.2**	17.6	19.1	20.5	21.9
Sulfuric acid, (mg/L)				304.6	352.3	400.0	**447.7**	495.4	543.1	590.8	638.5
Sulfuric acid, (kg/day)				84.0	85.0	85.8	**86.4**	87.0	87.4	87.7	88.1
Sulfuric acid, (L/h)				1.9	1.9	1.9	**2.0**	2.0	2.0	2.0	2.0

Analysis:

At cycle 6.0 the makeup water is reduced to 48.3 m3/hr and pH to be maintained at 8.1 so that the actual consumption of acid is increased to 86.4 Kg/day. Conductivity to be maintained in cooling tower is 4968 Microsiemens/cm (3200 ppm TDS). Blowdown is automatically reduced to maintain the required conductivity.

COSTING:

INDUSTRIAL water Supply Cost		**64**	**Rs/m3**
Saving of INDUSTRIAL water when cycles increased to 6.0	(5.3x24x64)	8140.8	Rs/day
Current Sulphuric Acid (98%) dosage 62 Kg/day	(62x22)	1366.2	Rs/day
Sulphuric Acid cost @22 Rs/kg			
Recommended dosage of Sulphuric Acid (98%) 86 kg/day	(86x22)	1892	Rs/day
New Sulfuric Acid cost @22 Rs/kg			
Total Estimated Expenditure in increasing dosage	(1892-1366.2)	525.8	Rs/day
Total Estimated Savings of INDUSTRIAL raw water (saving – expenditure)	(8140.8-525.8)	**7615**	**Rs/day**

CONCLUSION:

By increasing the COC of cooling tower, the Total estimated saving per day is 7615 PKR (2.79 Million per year). This amount can also be increased by optimizing the chemical dosing rates against the cycle increased. This saving cost varies from organization to organization & the cooling water system.

About the Author:

Shahzeb Hassan holds a master degree in chemical engineering From NED Institute of Technology, Karachi, Pakistan. He is AIChE Professional member & speaker. His expertise over 6 years of experience Covers Shell refinery operations and technical services. His Major role is Process simulation support, optimization & Troubleshooting. Currently working as Lead Engineer Process for Reformer & Utilities.


SUMMIT
Technology Management

Chernobyl Lessons in Process Safety

Karl Kolmetz

Executive Summary

- What we learn from a study of history is that the humans do not learn from their history.
- The reactor design was inherently unsafe. The engineers installed safety shutdowns to keep the reactor out of the unstable operating regions.
- The operations group was conducting a transient test that had previously failed.
- The operations group that was trained on the procedure was not conducting the procedure due to the test being delayed 10 hours to 01:24 AM. The shifts changed at 24:00
- Critical Emergency Shutdowns for the unstable operating regions were bypassed.
- The operations group on the following shift did not follow the written procedures.
    - ◊ The minimum number of graphite control rods was 15 to 18 and it was estimated there were only 7 to 8 control rods installed due to low MWt at the time.
    - ◊ The minimum Rate of the Reactor was 700 MWt and the test was conducted at 200 MWt.
- The operations group did not understand the critical purposes of the unit shutdowns that were bypassed.

Chernobyl Time Line

Late at night (1 AM) on 26 April 1986 in the then USSR, a team of nuclear workers prepared to conduct a test on Reactor 4 of the Chernobyl nuclear power plant as part of an otherwise routine shutdown. [1]

The test was a simulation of an electrical power outage, to aid the development of a safety procedure for maintaining cooling water circulation until the back-up generators could provide power. This operating gap was about one minute and had been identified as a potential safety problem that could cause the nuclear reactor core to overheat.

Three such tests had been conducted since 1982, but had failed to provide a solution. This type of test had been run the previous year, but the power delivered from the running down turbine fell off too rapidly, so it was decided to repeat the test using the new voltage regulators that had been developed.

Unfortunately, this test, which was planned to test the non-nuclear part of the power plant, was carried out without a proper exchange of information and coordination between the team in charge of the test and the personnel in charge of the safety of the nuclear reactor.

Therefore, inadequate safety precautions were included in the test program and the operating personnel were not alerted to the nuclear safety implications of the electrical test and its potential danger. On this fourth attempt, the test was delayed by 10 hours, so the operating shift that had been trained and prepared was not present.

As the shutdown proceeded, the reactor was operating at about half power when the electrical load dispatcher refused to allow further shutdown, as the power was needed for the electrical grid. In accordance with the planned test program, about an hour later the ECCS was switched off while the reactor continued to operate at half power. The ECCS is the reactor's emergency core cooling system, which provides water for cooling the core in an emergency.

It was not until about 23:00 on 25 April that the grid controller agreed to a further reduction in power. [4] At 24:00 shifts changed

For this test, the reactor should have been stabilized at about 700-1000 MWt (megawatt thermal) prior to shut down, but due to operational error, the power fell to about 30 MWt at 00:28 on 26 April. The operating procedures stated that operation below 700 MWt was forbidden, but sustained operation of the reactor below this level was continued.

Efforts to increase the power to the level originally planned for the test were frustrated by a combination of xenon poisoning, reduced coolant void and graphite rod cool-down.

Many of the control rods were withdrawn to compensate for these effects, resulting in a violation of the minimum operating reactivity margin. Calculations performed after the accident showed that at 01:22:30 was equal to seven or eight manual control rods. The minimum permissible stipulated in the operating procedures was 15 rods.

At 01:03, the reactor was stabilized at about 200 MWt and it was decided that the test would be carried out at this power level. The test commenced at 01:23:04; the turbine stop valves were closed and the four pumps powered by the slowing turbine started to run down.

The slower flowrate, together with the entry to the core of slightly warmer feed water, may have caused boiling (void formation) at the bottom of the core. This, along with xenon burnout, could have resulted in a runaway increase in power.

An alternative view is that the power excursion was triggered by the insertion of the control rods after the Emergency Shutdown button (AZ-5) was pressed (at 01:23:40).

When the AZ-5 button was pressed, the insertion of control rods into the reactor core began. The control rod insertion mechanism moved the rods at 0.4 meters per second (1.3 ft/s), so that the rods took 18 to 20 seconds to travel the full height of the core, about seven meters (23 ft).

A bigger problem was the design of the RBMK control rods. Each of which had a graphite neutron moderator section attached to its end to boost reactor output by displacing water when the control rod section had been fully withdrawn from the reactor.

Consequently, injecting a control rod downward into the reactor in an emergency initially displaced (neutron-absorbing) water in the lower portion of the reactor with (neutron-moderating) graphite. Thus, an emergency initially increased the reaction rate in the lower part of the core

At 01:23:43, the power excursion rate emergency protection system signals came on and power exceeded 530 MWt and continued to rise. Fuel elements ruptured, leading to increased steam generation, which in turn further increased power.

Damage to even three or four fuel assemblies would have been enough to lead to the destruction of the reactor. The rupture of several fuel channels increased the pressure in the reactor to the extent that the 1000 ton reactor support plate became detached, consequently jamming the control rods, which were only halfway down by that time.

As the channel pipes began to rupture, massive steam generation occurred because of depressurization of the reactor cooling circuit. A note in the operating log of the Chief Reactor Control Engineer reads:

"01:24: Severe shocks; the RCPS rods stopped moving before they reached the lower limit stop switches; power switch of clutch mechanisms is off."

The exposed reactor core continued to burn for approximately 10 days with continued releases of radioactivity into the atmosphere over this period.

Since the accident, the other three Chernobyl reactors, an additional Russian RMBK and both Lithuanian RBMKs have permanently shut down. Chernobyl's Unit 2 was shut down in 1991 after a serious turbine building fire; Unit 1 was closed in November 1996; and Unit 3 was closed in December 1999, as promised by Ukrainian President Leonid Kuchma.

In Lithuania, Ignalina Unit 1 was shut down in December 2004 and Unit 2 in 2009 as a condition of the country joining the European Union.

Test Description

The experimental procedure was intended to run as follows: [5]

1. The reactor was to be running at a low power level, between 700 MWt and 800 MWt

2. The steam-turbine generator was to be run to full speed

3. When these conditions were achieved, the steam supply for the turbine generator was to be closed off

4. Turbine generator performance was to be recorded to determine whether it could provide the bridging power for coolant pumps until the emergency diesel generators were sequenced to start and provide power to the cooling pumps automatically

5. After the emergency generators reached normal operating speed and voltage, the turbine generator would be allowed to continue to freewheel down

Operations Actions

Before pressing the AZ button, used to initiate an emergency shutdown, the operators were immersed in the conduct of a special test. The procedure was designed to prove that the reactor would be provided with sufficient cooling water even if a complete loss of power to the large electric generating complex occurred while the emergency cooling system was inoperable. [3]

According to engineering calculations, the inertia of the plant's big 500 MW electric turbines would allow them to generate enough electricity to keep cooling water pumps operating during the 30 to 50 second delay required to start the emergency diesel generators.

The engineers who designed the test were specialists in electric generators, not in nuclear reactors. The historical record indicates that there was little consultation with nuclear reactor specialists during the procedure preparation. The test was planned for a time when the plant was to be shut down for routine maintenance and its power output was not needed for the national electrical grid.

Establishing the initial conditions for the test proved difficult and more time consuming than initially planned. The first problem was that the grid needed the power longer than expected. It was after midnight when the plant was finally allowed to begin the test, and a new shift of operating personnel had just taken over. The new shift was not very familiar with the test and did not get a complete briefing by the off-going shift operators.

The actions of the off-going shift operators had put the plant into an unusual situation because the power history and the resulting concentration of fission product poisons was different than any situation considered during the design of the control system.

The man in charge of the test, the deputy chief engineer of the plant, had been involved in the test preparations and in setting the initial conditions. The new operators deferred to him for decisions, because of his experience, his official position and his familiarity with the specific test protocol.

Much has been made of the fact that RBMK reactors can develop what is known as a positive void coefficient of reactivity. What that long phrase means is that increasing boiling caused by increasing core temperature can lead to an increase in core reactivity, an increase in core power and even more boiling. This positive feedback mechanism is assiduously avoided in most reactor plant designs.

What has not been so well understood is that the shutdown button of an RBMK could, under very special initial conditions, initiate a short-term inverse response that could increase core temperature rapidly enough to cause a steam explosion. No nuclear reactor plant can explode in a manner similar to an atomic bomb, but, as boiler operators have known for well over a hundred years, a steam explosion can destroy a boiler.

Chernobyl Process Safety Management Lessons

Late Night Operations

One does not function the same at 2 AM as 2 PM. Many accidents happen when startups and transient operations are conducted late at night or early morning. Studies has shown that from 2 AM to 6 AM, productivity is very low and safety risk is high. Many maintenance turnarounds now run of two 10-hour shifts instead of two 12-hours shifts and avoid the 2 AM to 6 AM window.

A. In 2000 two operators were killed lighting a boiler in Singapore at 2 AM

B. In 2005 fifteen contractor were killed while commissioning a refinery unit in Texas City, Texas starting at 1 AM, across multiple shifts.

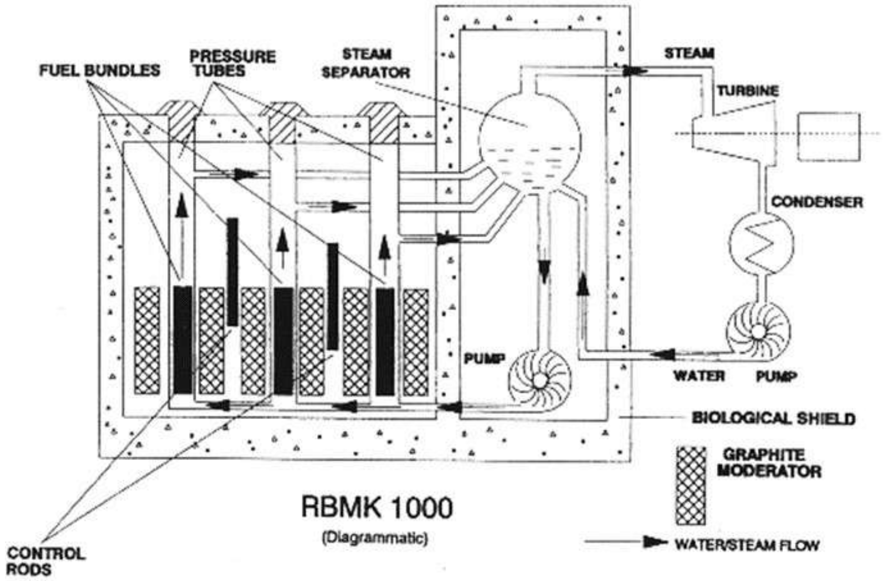
Lessons for Learning

Any time there is a new procedure, transient operation or commissioning of a unit, these items should not be conducted after 11 PM. It is best to postpone the work until the next morning.

First of a Kind and Transient Operations

Many incidents happen in initial unit commissioning, first-of-a-kind trials and transient operations. Special reviews and very senior people need to be involved in these types of operations. Written procedures should be developed for these types of operations and training should be conducted.

This exercise was to test a modified safety system, and determine how long the reactor's steam turbines would continue to power to the main coolant pumps following a loss of main electrical power supply. Three such tests had been



conducted since 1982, but had failed to provide a solution.

On this fourth attempt, the test was delayed by 10 hours, so the operating shift that had been prepared was not present. The test supervisor then failed to follow procedure, creating unstable operating conditions that, combined with inherent RBMK reactor design flaws and the intentional disabling of several nuclear reactor safety systems, resulted in an uncontrolled nuclear chain reaction It was certainly true the operators placed their reactor in a dangerously unstable condition, in fact in a condition, which virtually guaranteed an accident. It was also true that in doing so they had not in fact violated a number of vital operating policies and principles, since no such policies and principles had been articulated in the 1980s.

Lessons for Learning

A. Initial Unit Commissioning Procedures should be developed for the initial startup.

B. First of a kind test should have a Job Safety Analysis which includes a Hazard review such as a "What If" study.

C. A Transient Operation should have a Transient Operation HAZOP.

D. Written Procedures should be developed for Special Operations

E. Operations groups should be trained on the procedures

F. If the operations groups are not trained on the procedures, the test should be halted

Automatic Shutdown Systems (ESDs)

One of the layers of protection in a plant safety design are automatic shutdown system also call emergency shutdowns. Since 1998 due to the implementation of Process Safety Management, there are strict guidelines for the by passing of ESDs.

At Chernobyl, in order to achieve the test conditions, automatic shutdown devices were bypassed and the emergency core cooling system shutdown. There were at least two issues here;

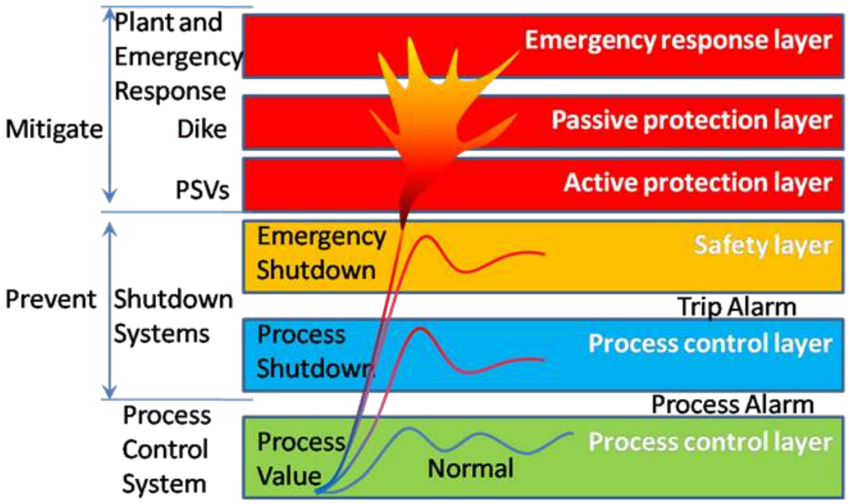
This action was particularly high risk because the particular RMBK-1000 reactor design is unstable at the low power levels being tested.

There was a fundamental lack of understanding for the ESDs and the proper analysis to by-pass them.

The test supervisor failed to follow procedure, creating unstable operating conditions that, combined with inherent RBMK reactor design flaws and the intentional disabling of several nuclear reactor safety systems, resulted in an uncontrolled nuclear chain reaction

During preparation and testing of the turbine generator under run-down conditions using the auxiliary load, personnel disconnected a series of technical protection systems and breached the most important operational safety provisions for conducting a technical exercise.

The operator error was probably due to their lack of knowledge of nuclear reactor physics and engineering, as well as lack of experience and training. According ton one analysis, at the time of the accident the reactor was being operated with many key safety systems turned off, most notably the Emergency Core Cooling System (ECCS), LAR (Local Automatic control



system), and AZ (emergency power reduction system).

The reactor operators disabled safety systems except for the generators, which the test was really about. The main process computer, SKALA, was running in such a way that the main control computer could not shut down the reactor or even reduce power.

Normally the computer would have started to insert all of the control rods. The computer would have also started the "Emergency Core Protection System" that introduces 24 control rods into the active zone within 2.5 seconds, which is still slow by 1986 standards. All control was transferred from the process computer to the human operators.

The last human action completely broke the most important safety limit. It was determined that 204 control rods out of 211 regular ones (i.e. more than 96%) had been drawn out from the reactor core. The reactor safety regulations required that "When the operational reactivity margin be reduced to 15 rods, the reactor should be shut down immediately"

Personnel had an insufficiently detailed understanding of technical procedures involved with the nuclear reactor, and knowingly ignored regulations to speed test completion.

The developers of the reactor plant considered this combination of events to be impossible and therefore did not allow for the creation of emergency protection systems capable of preventing the combination of events that led to the crisis, namely the intentional disabling of emergency protection equipment plus the violation of operating procedures.

Thus, the primary cause of the accident was the extremely improbable combination of rule infringement plus the operational routine allowed by the power station staff.

Unfortunately, we also apply this double jeopardy rule in a formal HAZOP. In many incidents double failures have occurred.

Lessons for Learning

A. There should be strict guidelines for bypassing ESDs that limit the ESD outage.

B. There should be an understanding by the operations personnel of the underlying design and reasoning for the ESDs

Shift Handover

Any time there is an initial unit commissioning, first-of-a-kind and transient operations it would be a good idea to hold over at least one lead operator to the next shift to make sure there is a smooth shift hand over. Most operators at the end of a shift are looking to return home, not to stay and explain in detail the operations state.

Three such tests had been conducted since 1982, but had failed to provide a solution. On this fourth attempt, the test was delayed by 10 hours, so the operating shift that had been prepared was not present. [2]

Lessons for Learning

A. Plan in advance any issues at change of shift personnel.

B. You can plan shifts where there is a 4 hours overlap between complete shift change over.

C. Do not conduct an operational test without proper training

Low Rate Issues

All process equipment have minimum flow requirements to be stable. For pumps, it is typically 60%. A pump produces heat within the pump and the fluid being pumped removes this heat. Below a minimum flow, the pump will over heat and damage the pump. Many other unit operations are unstable at low operational rates.

The design and general reactivity characteristics of the RBMK Reactor made low power operation extremely hazardous. The operating organization had not been made aware either of the specific vital safety significance of maintaining a minimum operating reactivity margin.

Lessons for Learning

A. Understand that all process equipment have minimum stable operating rates. For many types of equipment this is about 60% of design

Safety Culture

The need to create and maintain a 'safety culture' is a precondition for ensuring nuclear power and chemical plant safety. The concept of 'safety culture' relates to a very general concept of dedication and personal responsibility of all those involved in any safety related activity at an operating plant.

Inculcation of a safety culture requires that, in training personnel for nuclear plants, particular emphasis be placed on the reasons for the establishment of safety practices and on the consequences in terms of safety of failures on the part of personnel to perform their duties properly. Special emphasis must be placed on the reasons for the establishment of safety limits and the consequences in terms of safety of violating them.

To have a good safety culture, safety must be clearly recognized as a value

(a) The high priority given to safety is shown in documentation, communications and decision making

(b) Safety is a primary consideration in the allocation of resources

(c) The strategic business importance of safety is reflected in the business plan

(d) Individuals are convinced that safety and production go hand in hand

(f) Safety conscious behavior is socially accepted and supported (both formally and informally)

Lessons for Learning

A. Documentation, Training and Decision Making must be high priority for a good safety culture

B. Understanding the reasons for the Emergency Shut Downs and when they may be by passed

Incident Investigation

The investigation of incidents is a critical part of learning from our past. Incident Investigation can prevent future accidents. Incident and near miss reporting is a two edged sword.

1. Incident and near miss reporting allows the operations, engineering and safety groups to place safety barriers to limit or reduce future incidents and accidents.
2. A large number of incident and near miss reporting indicate that the operating procedures and training need improvements, which may be viewed as a lack of proper management.

There is sometimes this dichotomy between;

A. The safety groups, which want to see every incident and near miss, reported and investigated.

B. Operations Management, which wants to show that they have the proper procedure and training in place and they sometimes view incidents and near misses as a negative.

Past Incidents in RBMK Reactor History

There was a similar accident at the Leningrad nuclear power plant back in 1975. There was no investigation or lessons learned.

A similar incident happened in Chernobyl in 1982, except that there was no release of radioactive material that time. There was no investigation or lessons learned.

In 1983, there was a power spike with initial insertion of control rods in the reactor at Ignalina Nuclear Power Plant. There was no investigation or lessons learned

General Consensus

Apparently, there was a widespread view that the conditions under which the positive emergency scram (emergency shutdown) effect would be important would never occur. However, the widespread view was wrong, and they did appear in almost every detail in the course of the actions leading to the (Chernobyl) accident.

Conclusions

In many major incidents, multiple things align to cause the incident. This is true for the Chernobyl Incident.

1. Operations did not understand the importance of the safety shutdowns.
2. Operations did not understand the importance of maintaining the minimum number of control rods.
3. Operations did not understand the importance of minimum operating rates.

Operating Procedures and Training are critical to safely operate chemical and nuclear plants. Still today, in many Process Safety Management Audits Operating Procedures and Operations Training are rated low. We should take the lessons from Chernobyl to help up improve the safety of our industries.

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Adding Value to the Crude Oil – Distillation Process Unit

Marcio Wagner

Introduction

Despite the efforts to reduce the consume, petroleum still represents the major part of the global energy matrix and have a strategic role to any nation that desire reach superior economic and technologic development.

The crude oil, as found in the reservoirs have few industrial use, to become useful and economically attractive is necessary to separate the fractions in products that have specific industrial interest like fuels (LPG, gasoline, kerosene, diesel, etc.), lubricants or petrochemical intermediates. To achieve this objective the crude oil is submitted to a series of physical and chemical processes aim to add value to the commodity, to the set of processes we called refining complex.

Crude Oil Distillation Process

In the refining complex, the first and principal process applied to add value to the crude oil is the distillation. This processing unit defines the processing capacity of the refinery and, normally the others process units are sized on the basis of his yields. Figure 1 shows a basic process flow diagram for a typical atmospheric crude distillation unit.

The crude oil is pumped from the storage tanks and preheated by hot products that leaving the unit in heat exchangers battery, then the crude oil stream receive an injection of water aim to assist the desalting process, this process is necessary to remove the salts dissolved in the petroleum to avoid severe corrosion problems in the process

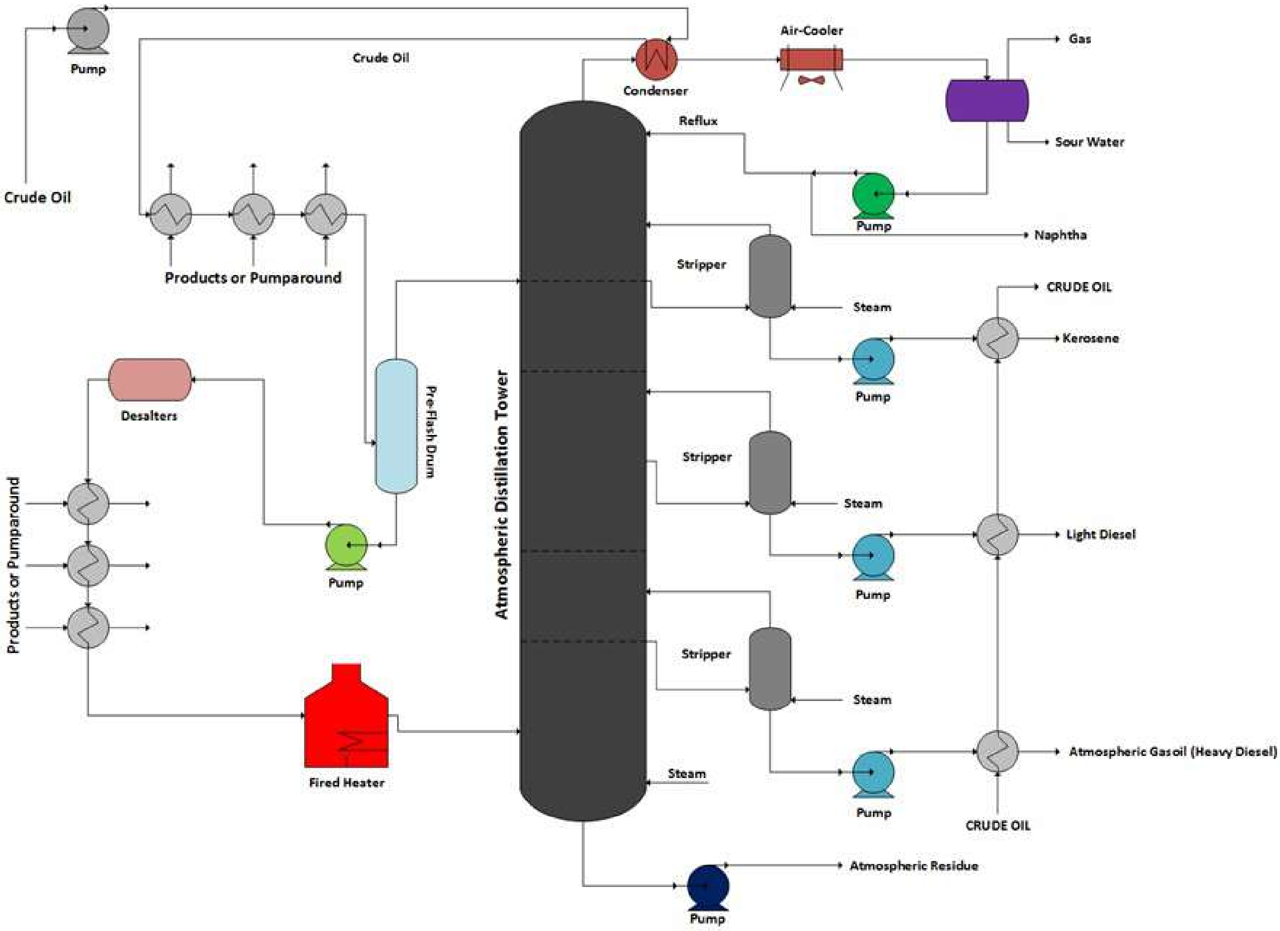

Figure 1 – Process Flow Diagram for a Typical Atmospheric Crude Oil Distillation Unit

equipment. The desalting process involves the application of an electrical field to the mixture crude oil-water aim to raise the water droplets dispersed in the oil phase and accelerate the decanting, as the salts solubility is higher in the aqueous phase the major part of the salts is removed in the aqueous phase effluent from the desalter, called brine. Normally the petroleum desalting process is carried out at temperatures among 120 and 160 oC, higher temperatures raise the conductivity of oil phase and prejudice the phase separation, and this can lead to drag oil to the brine and result in process inefficiency.

In the desalter exit, the desalted oil is heated again by hot products or pump around and fed into a flash drum, in this equipment the lighter fractions are separated and sent directly to the atmospheric tower, the main role of this vessel is reduce the thermal duty needed in the furnace. Following, the stream from the bottom of the flash vessel is heated in the fired heater to temperatures close to 350 to 400 oC (depending on the crude oil to be processed) and is fed the atmospheric tower where the crude oil is fractionated according to the distillation range, like example presented in Table 1.

At the exit of the atmospheric tower, the products are rectified with steam aim to remove the lighter components.

The gaseous fraction is normally directed to the LPG (C3-C4) pool of the refinery and the fuel gas system (C1-C2) where will feed the furnaces and boilers. The light naphtha is normally commercialized as petrochemical intermediate or is directed to the gasoline pool of the refining complex, the heavy naphtha can be sent to the gasoline pool and in some cases, this stream can be added to the diesel pool since not compromise the specification requirements of this product (Cetane number, density and flash point). Kerosene is normally commercialized as jet-fuel while the atmospheric residue is sent to the vacuum distillation tower, in some refining schemes it's possible sent this stream directly to the residue fluid catalytic process unit (RFCC), in this case, the contaminants content (mainly metals) of the residue need to be very low to protect the catalyst of the cracking unit.

Nowadays, face to the necessity to reduce the environmental impact of the fossil fuels associated with the restrictive legislations, difficultly the straight run products can be commercialized directly. The streams are normally directed to the hydrotreating units aim to reduce the contaminants content (sulfur, nitrogen, etc.) before being marketed.

In distillation units with higher processing capacity, normally the flash drum upstream of the atmospheric tower is substituted by a pre-fractionation tower. In this cases, the main advantage is the possibility of reduction of the atmospheric tower dimensions that implies in cost reductions associated with the unit implementation and improve the hydraulic behavior in the distillation tower, consequently with better fractionation. This arrangement is shown in Figure 2.

Fraction	**Distillation Range (^oC)**
Gases ($C_1 – C_4$)	$\leq$ 30
Light Naphtha ($C_5 – C_7$)	30 - 100
Heavy Naphtha ($C_8 – C_{11}$)	80 - 200
Kerosene ($C_{11} – C_{12}$)	170 - 280
Light Diesel ($C_{13} – C_{17}$)	220 - 320
Heavy Diesel ($C_{18} – C_{25}$)	290 - 350
Atmospheric Residue (C_{25+})	350 - 390

Table 1 – Example of Crude Oil Distillation Cuts

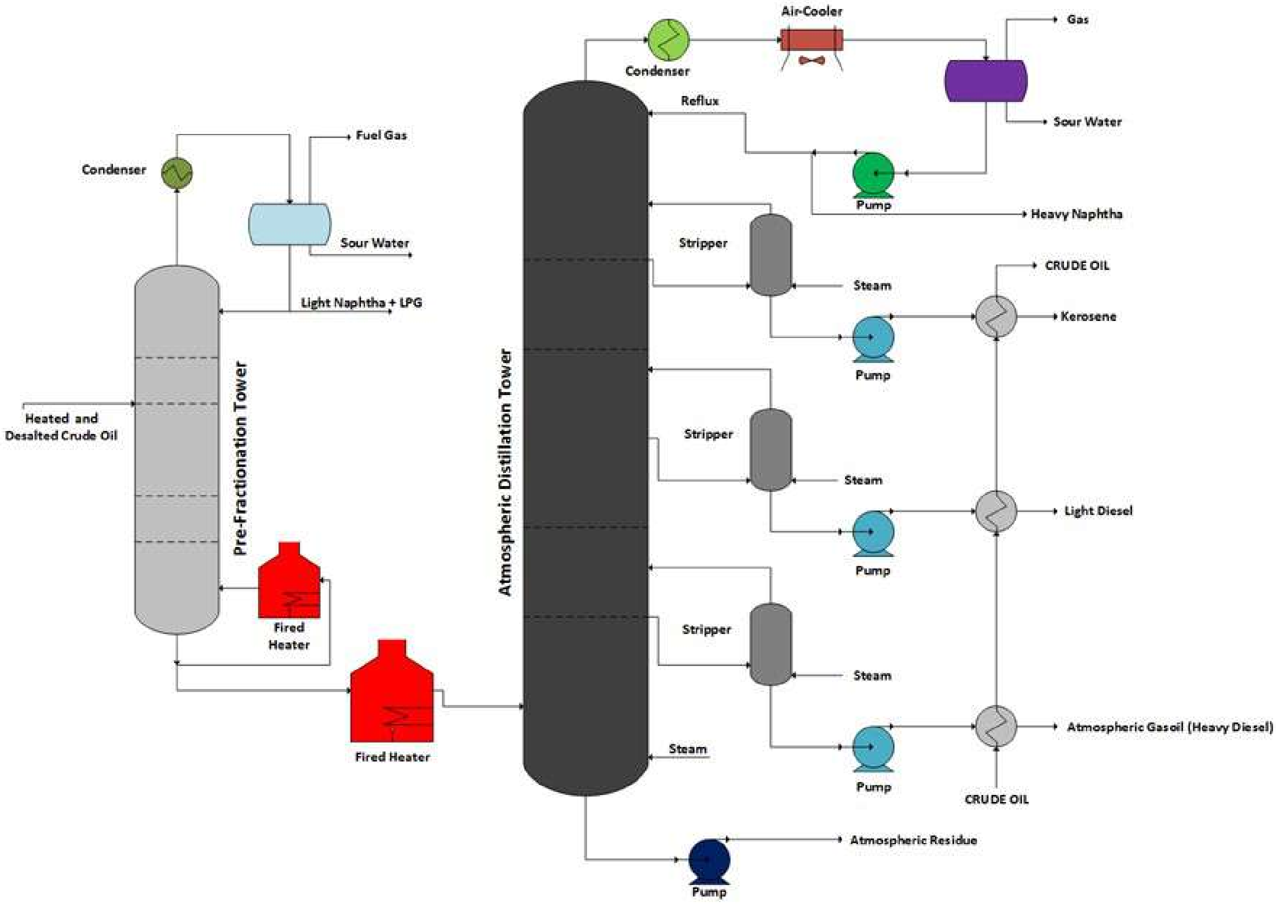

Figure 2 – Typical arrangement to Atmospheric Distillation with Pre-Fractionation Tower.

Like aforementioned, the residue from atmospheric distillation column is sent to the vacuum distillation tower, this strategy is adopted since under atmospheric column process conditions the continuity of heating lead to the thermal cracking of the residual fractions. In the vacuum distillation column, the atmospheric residue is submitted to reduced pressures aim to recover the lighter fractions that can be converted to the high- value products.

Figure 3 shows a typical process scheme of vacuum distillation unit focusing on producing fuels.

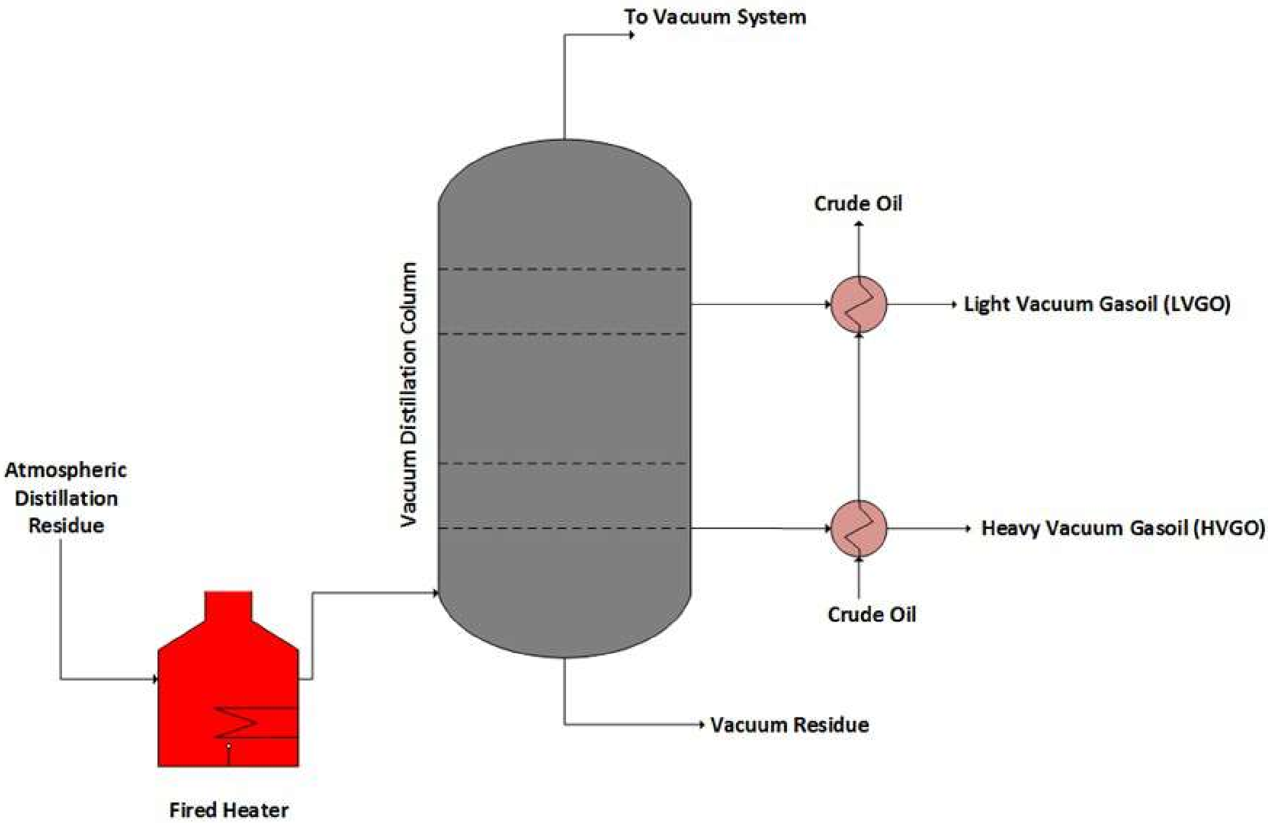

Figure 3 – Schematic Process Flow Diagram for Vacuum Distillation

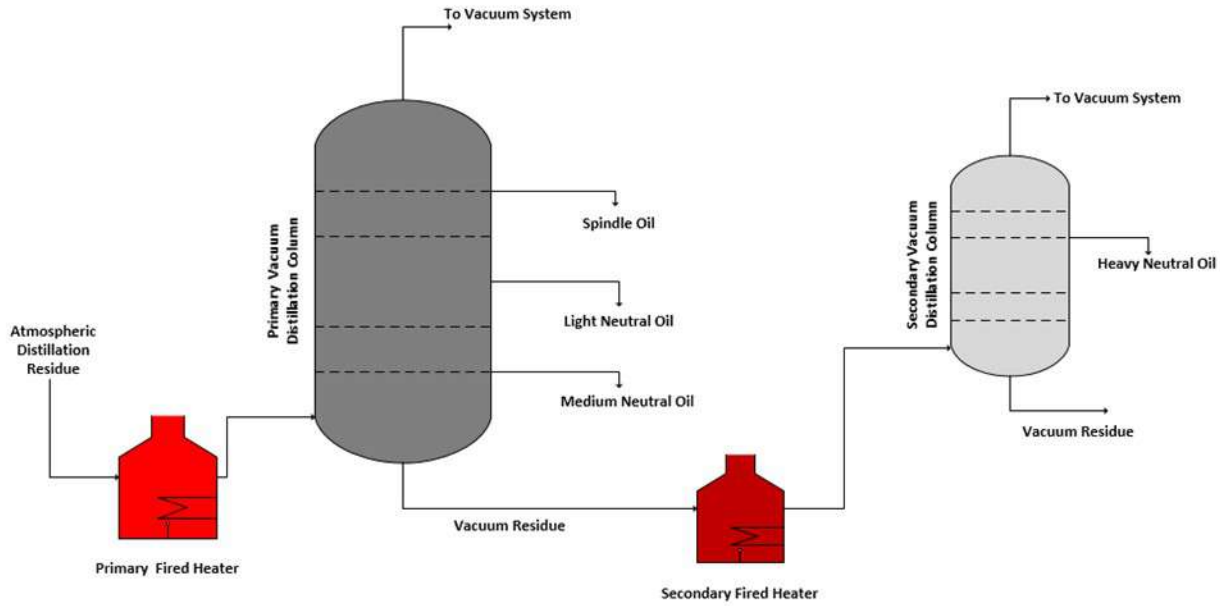

Figure 4 – Vacuum Distillation Process to Produce Lubricants

The light vacuum gasoil (LVGO) is normally sent to the hydrotreating units to be incorporated into the diesel pool of the refinery while the heavy vacuum gasoil (HVGO) is directed to catalytic cracking units or hydrocracking, depending on refining scheme adopted by the refiner, another possibility is to use this stream like dilutant to produce fuel oil. In some processes configurations, there is still a withdrawn of the stream called residual vacuum gasoil aim to keep the quality of heavy gasoil in relation of carbon residue and metals content to avoid the rapid deactivation of the catalyst of this unit.

The vacuum residue is normally directed to produce asphalt and fuel oils, however, in most modern refineries this stream is sent to bottom barrel units as delayed coking and solvent deasphalting to produce higher-value products.

In refineries optimized to produce lubricants, the distillation process is modified face to the paraffinic characteristics of the crude oil processed, mainly the vacuum distillation step. The necessity to separate the lubricants fractions requires higher fractionation quality in the column and some configurations rely on two columns, as presented in Figure 4.

The distillation unit design is strongly dependent by the characteristics of crude oil that will be processed by the refinery, for extra-heavy oils normally the crude is fed directly to the vacuum column. The design is generally defined based on a limited crude oil range that can be processed in the hardware (Contaminant content, API grade, etc.).

Innovative Technologies

The crude oil distillation is a consolidated technology, however, researchers and technology licensors have devoted his efforts to studies aim to mainly reduce the operational costs of the unit related to energy consumption and utilities. An example of this development is the technology called Progressive Distillation®, developed and licensed by the companies TECHNIP and TOTAL, as presented in Figure 5.

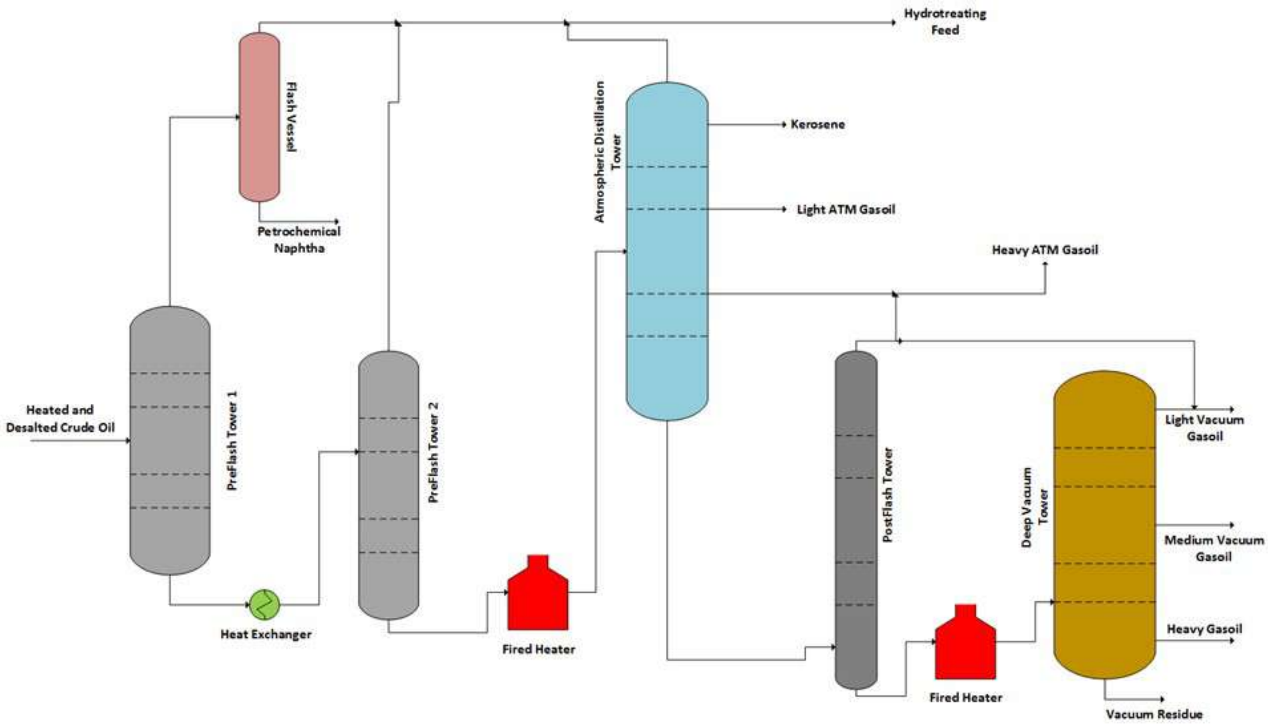

Figure 5 – TECHNIP-TOTAL Progressive Distillation Technology®

The progressive distillation technology applies a series of distillation columns at different temperatures, this configuration avoids that the lighter fractions are heated unnecessarily leading the save energy in the process unit, this reduces the atmospheric emissions (CO2), due to the lower quantity of fuel burned in the unit furnaces.

Conclusion

The distillation process is the first step of the crude oil is submitted, the others process units are strongly impacted by the quality of products from the distillation unit, mainly in relation to fractionation quality achieved in the distillation columns, a bad fractionation can lead to an off-specification products (color, Sulfur content, corrosivity, etc.) or irreversible damages to catalysts or process equipment, thus this unit requires special attention by the refiner once every chain of value generation to the crude oil processing depends on this process.

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Quarterly Safety Connector

For Engineers; Because Safety Is Part Of The Process! By: Chris Palmisano, MESH, IFSAC January 2020

Unlocking The 5 Basic Elements of a Safety Hazard.

Resolving these five basic elements can help to keep your organization from receiving a Serious OSHA Citation or fines.

Getting into the mind of an OSHA Compliance Officer is quite easy, when you understand what they look for and how their observations apply to evaluating potential safety concerns in your workplace.

Compliance Officers are strictly trained to use five basic elements to determine if an employer will receive a violation. Understanding the five elements of an OSHA citation is critical to whether or not you are in compliance. The greatest benefit of understanding these elements becomes evident in the mediation process with OSHA, once your company has already been cited. If you apply these 5 elements I'm about to share with you, to any potential hazards in your work place, you can reduce risks and avoid OSHA citations. OSHA needs all 5 elements to be solidly present in order to hold a citation against you. If you can remove just one of the five in a mediation, you are able to gain an advantage in having the citation reduce or otherwise removed from your record.

The 5 Elements I'm about to share with you, can apply to nearly any hazard exposures discovered in your workplace or any found by an OSHA Compliance Officer. You must understand that hazard conditions (in order to become citations) must first, have some type of employee exposure to harm and second, must violate laws, regulatory standards, consensus standards or the general duty clause to be valid. As a matter of clarity, consensus standards are industry written rules that OSHA recognizes as law, simply because they don't have a written government standard to follow.

Consensus standards become useful for OSHA in situations where they observe a workplace hazard but do not have a written doctrine on the operation, equipment or industry. Some good examples would be the ANSI (American National Standards Institute) rules, the NEC (National Electrical Code) such as 70E for Arc Flash Requirements, or perhaps the CGA (Compressed Gas Association) standards for safe handling of compressed gas cylinders.

Remember that hazard situations are dynamic in every work place. These 5 Elements can vary, depending on your industry and rules that govern your business and the type of work being done.

So, let's look at the 5 Elements of a Citation:

1. Is a hazard present?

Well, as an example, if a Compliance Officer witnessed one of your employees working on an electrified piece of equipment, without a Lock-Out Tag-Out procedure in place, then the answer would have to be yes, there is a serious hazard potential present. So this one is rather easy to unlock, simply by determining if a hazard is exist.

2. Is an employee or employees exposed to the existing hazard?

Have you ever wondered why Compliance Officers interview employees? This is one of the primary reasons they talk with your people. All the Compliance Officer needs is one, "yes, I was working on that piece of equipment today changing a blade", or "yes, I serviced that the machine last week without locking it out" or, "yes, I use that machine approximately three times a day and sometimes operate it while the guys are working on it". Once the employee validates the human exposure to the hazard, this element is locked in.

3. Is the hazard a violation of a law, regulation, standard or consensus standard?

This is a hard element to unlock. It is never wise to go toe-to-toe with a Compliance Officer on the interpretation of OSHA standards during an inspection. You will lose that battle. Research the laws after the inspection and save your battle for the mediation, if you think OSHA is wrong.

Compliance Officers are constantly in the regulation books. Your only hope is that perhaps the Compliance Officer's interpretation of your operation or the standard is wrong or, your operation may be exempt, as defined in the scope and application of the regulations.

I have a great example of how to unlock this element from a citation using the regulations as your leverage. A risk management consultant and colleague called me saying that one of his construction clients was cited by OSHA for a fall protection violation.

The employee was working approximately 14' from the ground. The OSHA 1926 construction standards say that if a construction employee is working over 6' from a solid surface the employee is required to have fall protection. I asked the colleague, "What was the employee doing at the time of the inspection"? He said, "Steel Erection". Well that just changed everything. The OSHA steel erection standards say that a steel erection employee working over 15' or greater must have fall protection. The 6 foot rule didn't apply! The serious citation was withdrawn at the mediation. OSHA did the right thing in this case, because the Compliance Officer made an error. And believe me, this doesn't happen often.

The best advice I can give any Safety Professional is to read the OSHA Regulations and Industry Standards relevant to your operation from cover-to-cover. Use a highlighter, make notes and tab the pages, so you can quickly reference safety topics as the needs arise in your workplace. Chance will favor the prepared mind when deliberating with OSHA against this element. On to #4

4. Does the Employer have knowledge of the existing hazard?

I always found this element to be fascinating. When asked this question, "Did you know that your employee was working on a hot machine"? Most employers are quick to respond with, "NO, I didn't know he was working on a hot piece of equipment"! Well, this type of response typically gets you another Citation for, "Failure to conduct frequent and regular inspections". Either way you lose.

In my experience, the only way to confront this element is if you can validate that the exposure was due to "Employee Misconduct". To do that you will need at-the-least the following:

Records of training, stating that the employee was taught that it is mandatory to Lock-Out all hot equipment before working on it.

Records of your inspections to prove that you audit employee's safety practices to assure that they are working safely and following the company lock-out tag-out rules.

Employee accountability or discipline records that indicates that this employee or others have violated rules in the past and have been disciplined for those actions.

Remember, if it's not documented, it didn't happen.

OSHA expects discipline to be served progressively. For example: First a documented verbal warning, then a written warning, then lost time and/or the ultimate fate, dismissal. I believe that workplace safety should be a condition of employment. That has always been my philosophy.

5. And finally, is the hazardous condition reasonably abatable?

In most situations the answer is always yes. The job safety analysis for each job in your workplace should spell out the hazards associated with all work tasks and should provide the controls your company has in place to minimize the risk of exposure to potential harm. The only way you can judiciously contest this element is if the abatement was unreasonable due to it be overly burdensome or financially because of an extraordinary high cost to mitigate.

In closing, we have discussed the 5 elements of an OSHA citation and learned that it is possible to unlock them in order to reduce the cost and severity of a citation. Also, we can use these elements in the work place, to help us understand if a hazard is present, if it is a violation of the law and how to remedy the situation.

Remember these 5 elements and if you can show that one or more of these elements are not present in a citation, you will have the leverage you need to fight the good fight in a mediation. Use these elements during your routine inspections. It will be a great learning tool for you and your employees and help everyone understand their responsibilities in reducing risks.

Chris is a Professional Risk Management Consultant, a former Philadelphia Fire Department Lieutenant and former OSHA Compliance Officer. He is the creator of the InSite GHS Hazcom Workplace Labeling System for Secondary Chemical Containers. https://stop-painting.com/ghs-secondary-labels-roll-of-100/ For questions about this article or his workplace chemical labeling system to meet the OSHA's GHS June 2016 requirement, you can reach Chris at: ChrisAPal@aol.com or at LinkedIn https://www.linkedin.com/in/chris-palmisano-696b3b6/

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