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SPECIAL FEATURES

How to Extract Profitability from Oil Residue Streams: Solvent Deasphalting Technologies

Understanding High Integrity Pressure Protection Systems

Getting it Right with Hydrostatic and Pneumatic Pressure Tests

IACPE
INTERNATIONAL ASSOCIATION OF
CERTIFIED PRACTICING ENGINEERS

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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.

LETTER FROM THE PRESIDENT

KARL KOLMETZ

Distinguished Practicing Engineer Nominations

Dear Friends,

I hope you are doing great. This month we are pleased to nominate the International Association of Certified Practicing Engineers 2018 Distinguished Practicing Engineers. We have a great group of people that have assisted and mentored their friends and colleagues.

Annually IACPE will recognize the outstanding accomplishments of engineering education and engineering technology through the "Distinguished Practicing Engineer" awards program. By their commitment to their profession, desire to further the association's mission, and participation in civic and community affairs, IACPE award winners exemplify the best in engineering education and engineering technology.

This award salutes leaders in engineering for their dedication to their field and their commitment to advancing the human condition through great engineering achievement and/or through innovation in engineering education and technology. There is an Academic Division, Technology Division, and Young Engineer Divisions. In the July *Engineering Practice Magazine*, we will nominate for each division and in the October issue we will recognize the 2018 group of awardees.

Look to the IACPE website (www.IACPE.com) for new training videos for the CPE levels and continuing education certification.

All the best in your Career and Life,
Karl Kolmetz

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Distinguished Practicing Engineer

Each year IACPE recognizes the outstanding accomplishments of engineering education and engineering technology through the "Distinguished Practicing Engineer" awards program. By their commitment to their profession, desire to further the Association's Mission, and participation in civic and community affairs, IACPE award winners exemplify the best in engineering education and engineering technology.

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In this issue IACPE is proud to announce the top candidates from each division and in the October issue the 2018 group of awardees will be announced.

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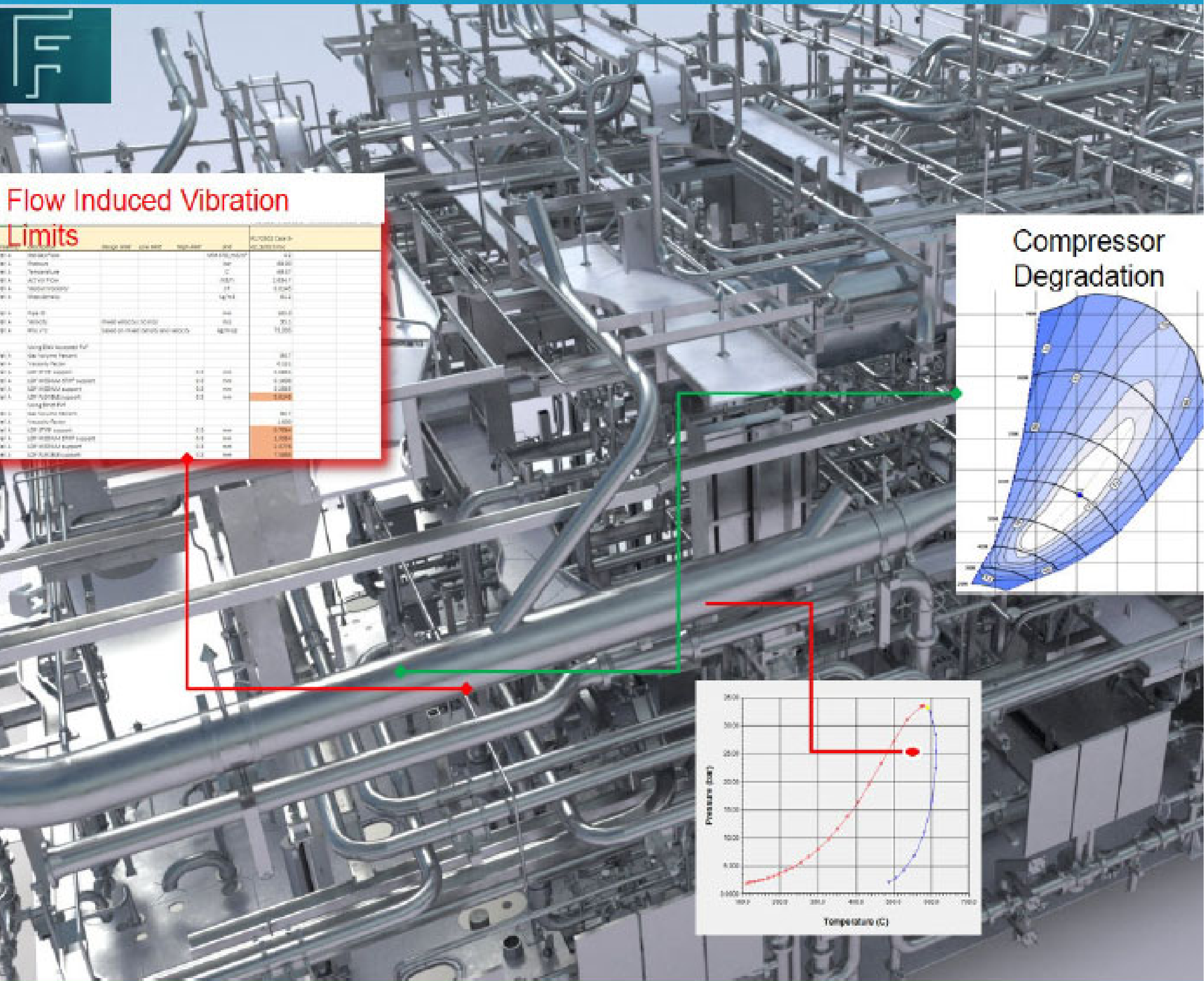

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How to Extract Profitability from Oil Residue Streams: Solvent Deasphalting Technologies

Introduction

In the last decades, restrictive environmental regulations allies with the technological development of processes and equipment which require petroleum derivates more environmentally friendly and with better performance reduced drastically the consumer market for residue streams. Currently, even bunker oils suffer severe contaminants restriction, mainly related to sulfur content.

In this scenario, process units called bottom barrel, able to improve the quality of crude oil residue streams (Vacuum residue, Gas oils, etc.) or convert them to higher added value products gain strategic importance, mainly in countries that have large heavy crude oil reserves. These process units are fundamental for to comply the environmental and quality regulations, as well as to ensure profitability and competitivity of refiners through raising refining margin.

Available technologies to processing bottom barrel streams involve processes that aim to raise the H/C relation in the molecule, either through reducing the carbon quantity (processes based on carbon rejection) or through hydrogen addition. Technologies that involves hydrogen addition encompass hydrotreating and hydrocracking processes while technologies based on carbon rejection refers to thermal cracking processes like Visbreaking, Delayed Coking and Fluid Coking, catalytic cracking processes like Fluid Catalytic Cracking (FCC) and physical separation processes like Solvent Deasphalting units.

Process Arrangement

The typical feedstock for deasphalting units is the residue from vacuum distillation that contains the heavier fractions of the crude oil. The residue stability depends on of equilibrium among resins and asphaltenes, once which they resins solubilize the asphaltenes, keeping a dispersed phase.

The deasphalting process is based on liquid-liquid extraction operation where is applied light paraffin (propane, butane, pentane, etc.) to promotes resins solubilization inducing the asphaltenes precipitation, that correspond to the heavier fraction of the vacuum residue and concentrate the major part of the contaminants and heteroatoms (nitrogen, sulfur, metals, etc.). The process produces a heavy stream with low contaminants content called deasphalted oil (Extract phase) and a stream poor in solvent containing the heavier compounds and with high contaminants content, mainly sulfur, nitrogen and metals called asphaltic residue (Raffinate phase).

Figure 1 shows a basic process flow diagram for a typical process deasphalting unit.

The vacuum residue is fed to the extracting tower where occurs the contact with the solvent leading

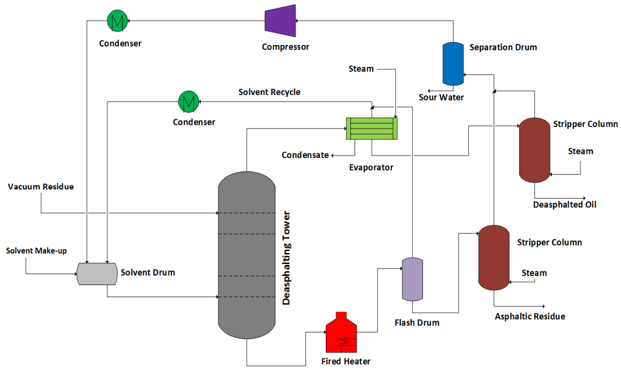

Figure 1 – Typical Arrangement for a Solvent Deasphalting Process Unit

to the saturated compounds solubilization, in the sequence, the mixture solvent/vacuum residue is sent to separation vessels where occurs the separation of asphaltic residue from deasphalted oil, as well as the solvent recovery.

The choice of solvent employed have fundamental importance to the deasphalting process, solvents that have higher molar mass (higher carbon chain) presents higher solvency power and raise the yield of deasphalted oil, however, these solvents are less selective and the quality of the deasphalted oil is reduced once heavier resins are solubilized which leads to higher quantity of residual carbon in the

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deasphalted oil, consequently the contaminants content raises too. As normally the deasphalting unit aim to minimize the carbon residue, metals and heteroatoms in the deasphalted oil, propane are the usual solvent applied, mainly when the deasphalting process role in the refining scheme is to prepare feed streams for catalytic conversion processes.

The main operational variables of the deasphalting process are feedstock quality, solvent composition, the relation solvent/feedstream, extraction temperature and temperature gradient in the extraction tower. Despite be a very important variable the extraction pressure is defined in the unit design step and is normally defined as the need pressure to keep the solvent in the liquid phase, in the propane case the pressure in the extraction tower is close to 40 bar.

Feedstock quality depends on crude oil characteristics processed by the refinery, as well as vacuum distillation process. Depending on the fractionating produced in the vacuum distillation unit the vacuum residue can be heavier or lighter, affecting directly the deasphalting unit yield. Using propane as solventthe relation solvent/feedstream is close to 8 and the feed temperature in the extraction tower is close to 70 oC.

In refineries focused in fuelsproduction (mainly LPG and gasoline), the deasphalted oil stream is normally sent to the Fluid Catalytic Cracking Unit (FCCU), in this case, the contaminants content and carbon residue needs to be severely controlled to avoid premature deactivation of the catalyst which is very sensitive to metals and nitrogen. In refineries dedicated to producing middle distillates, the deasphalted oil can be directed to hydrocracking units.

When the deasphalting process is installed in refining units dedicated to producing lubricants, the quality of deasphalted oil tends to be superior in view that the crude oil processed is normally lighter and with lower contaminants content.In this case, the deasphalted oil is directed to aromatic extraction unit or to hydrotreatment/ hydrocracking units, in the last case, the deasphalted oil quality is more critical because of the possibility of premature catalyst deactivation.

The asphaltic residue stream is sent to the fuel oil pool after dilution with lighter compounds (gas oils) orthe stream can be used to produce asphalt. Another possibility is sent the asphaltic residue to a Delayed Coking Unit. As the aromatics content in the asphaltic residue is high, the coke produced presents a very good quality.

Available Technologies

The principal step in the solvent deasphalting process is the liquid-liquid extraction which depends on strongly of the solvent properties, in this sense, some licensors developed deasphalting processes based on the solvent in supercritical conditions. Above of critical point, the solvent properties are more favorable to the extraction process, mainly solvency power and the vaporization and compression facility, which reduce the power consumer in the process.

The processes ROSE™ licensed by KBR Company, UOP-DEMEX™ licensed by UOP and the process SOLVAHL™ licensed by AXENS are examples of deasphalting technologies in supercritical conditions. Figure 2 presents a basic process scheme for a typical deasphalting unit under supercritical conditions.

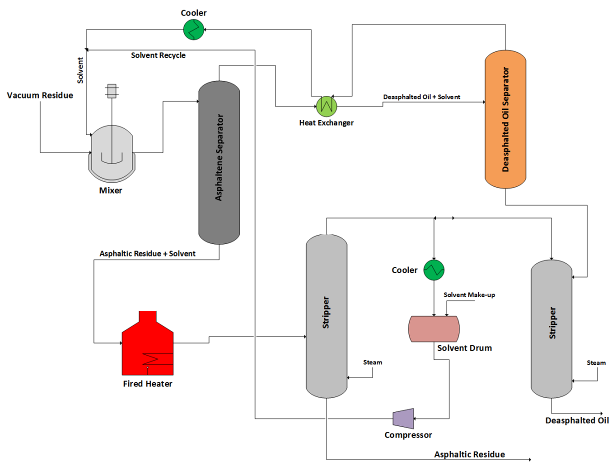

Figure 2 – Typical arrangement to solvent deasphalting unit under supercritical condition

In addition to the cited processes, the FOSTER WHEELER Company in partnership with UOP developed the process UOP/FW-SDA™ which applies solvent in supercritical condition too.

Conclusion

Like described earlier, the deasphalting process allows add value to residual streams as vacuum residue and, consequently, raise the refiners profitability furthermore the process can help in the production of higher quality and cleaner derivates.

As another residue upgrading technologies, the deasphalting process raises the refinery flexibility regarding the quality of crude oil processed, that can pass to process heavier crude oils that have normally lower cost, and this fact can improve the refining margin.

Currently, the deasphalting technology has lost ground in the more modern refining schemes to Delayed Coking units since these units can process residual streams producing streams that can be converted into products with high added value (LPG, Gasoline, and Diesel), without the need of previous feed stream treatment to removal contaminants. However, the products from delayed coking units need hydrotreatment to be commercialized which raises significantly the operational and installation costs to the refinery.In some refining schemes, the deasphalting and delayed coking units can be complementary technologies, like aforementioned.

The choice of residue upgrading technology by the refiners normally involves an economic analysis which takes into account the refinery production focus (middle distillates, light products or lubricants), the market that will be served and the synergy among the processes that will be applied in the adopted refining scheme.

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Understanding High Integrity Pressure Protection Systems

Jayanthi Vijay Sarathy, M.E, CEng,

Abstract

No chemical process facility is immune to the risk of overpressure to avoid dictating the necessity for overpressure protection. For every situation that demands safe containment of process gas, it becomes an obligation for engineers to equally provide pressure relieving and flaring provisions wherever necessary. The levels of protection are hierarchical, starting with designing an inherently safe process to avoid overpressure followed by providing alarms for operators to intervene and Emergency Shutdown provisions through ESD and SIL rated instrumentation. Beyond these design and instrument based protection measures, the philosophy of containment and abatement steps such as pressure relieving devices, flares, physical dikes and Emergency Response Services is employed.

High Integrity Pressure Protection Systems (HIPPS) are related to the third layer of protection whereby process shutdown can be initiated by shutdown valves that receive instructions from a logic solver which in turn are fed by pressure transmitters.

In the oil and gas industry, process facilities are often subjected to erratic fluctuations in wellhead pressure and flow trends. Such process systems in recent years are tended to for overpressure protection with the installation of HIPPS. HIPPS aid in shutting down well heads instead of having to flare sour gas through pressure relieving devices that are subsequently routed to a flare system.

The following article covers key guidelines and requirements for HIPPS from industry experience and, standards.

Introduction

With world gas demand increasing steadily over the years, High Pressure High Temperature (HPHT) environments are also increasingly becoming common. Standard design methods involve designing the entire well head to export systems to fully rated conditions (1500#, 900#, etc.) depending on the operating pressures and temperatures. However such methods would unnecessarily increase project costs and affect installation foot print depending on how flammable or toxic is the process fluid, sometimes to the point of not giving any viable cost benefits.

To attend to such unviable scenarios, the concept of de-rating Non-HPHT equipment in downstream operations with overpressure protection can be employed. For these purposes, HIPPS is treated as a Safety Instrumented System (SIS) that is based on a Safety Integrity Level (SIL). From an SIL perspective, HIPPS follows a minimum of SIL 3 rating where the Average Probability of Failure on demand is of the order between $\geq 10^{-4}$ to $<10^{-3}$. It must be noted that HIPPS is an SIS that aids more as risk reduction for prevention measure rather than a risk mitigation measure. The typical architecture of HIPPS is shown in the Figure below.

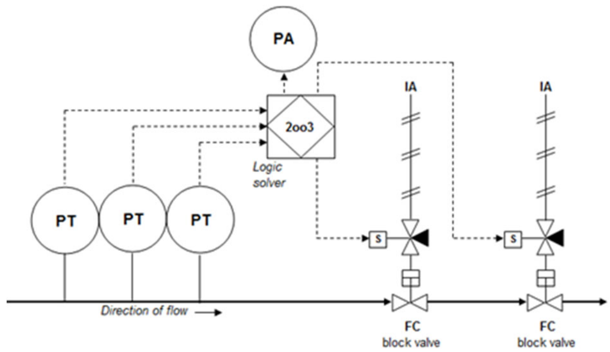

Figure 1. Example of HIPPS Architecture

HIPPS Operating Philosophy

A typical HIPPS architecture consists of three (3) pressure transmitters (PT) that constantly record the line pressure which are fed to a logic solver. In the event of an overpressure, the logic solver initiates a shutdown operation of two (2) consecutive Fail-close (FC) valves which are installed on the same line thereby shutting down fluid flow. A pressure alarm (PA) serves the purpose of informing the operation personnel. The purpose of installing the said number of transmitters and valves are as follows,

- To avoid compromising the HIPPS functionality due to failure of any one shutdown valve (SDV), a second valve is added to provide higher redundancy. Both valves are operated on a 1oo2 voting philosophy that decides which Fail -Close (FC) valve closes.

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- To avoid receiving a premature or false signal from the pressure transmitter, a 2oo3 voting philosophy is employed as against a 1oo3 voting philosophy. This means that unless 2 pressure transmitters concur that there is an overpressure scenario, HIPPS is not activated.

HIPPS Valve Selection

HIPPS Valves can be operated hydraulically or by solenoid methods. The two (2) types of valves used are either ball type or butterfly type. Ball valves provide the best shutoff conditions and can range from 2 inch to 56 inch depending on the manufacturer. Whereas butterfly valves can be provided from 2 inch to 100 inch, again depending on the manufacturer. For HPHT applications, the piping class can vary from as high as 2500# which can be provided in the ball class range with material ranging from carbon steel, stainless steel, duplex as well as special alloys. The typical stroke time for HIPPS valves should be of the order of <2 sec. Valve selection must also consider that HPHT applications can witness temperatures as high as 500^{0}C. HIPPS valves must also be able to cater to Partial Stroke Testing capability (PST), Tight Shut-off (TSO) (e.g., Class V or Class VI of ANSI FCI 70-2), Fast acting, Fire Safety tested to for example, API 607. Environmental constraints must also be met for fugitive emissions such as ISO 15848-1 standards.

HIPPS Engineering Standards

HIPPS can cater to many applications such as offshore/onshore well heads, flare headers and chemical process industries. ASME Section VIII, UG-140 (Overpressure Protection Systems) provides a range of applications for which HIPPS can be used, such as,

1. High Propagation Chemical reactions resulting in loss of containment prior to the relief device opening or processes that yield impractical large vent areas
2. Runaway Polymerization, Exothermic or Reactive reactions that produce large vapour rates rendering relief devices insufficient to cater to over-pressurization scenarios.

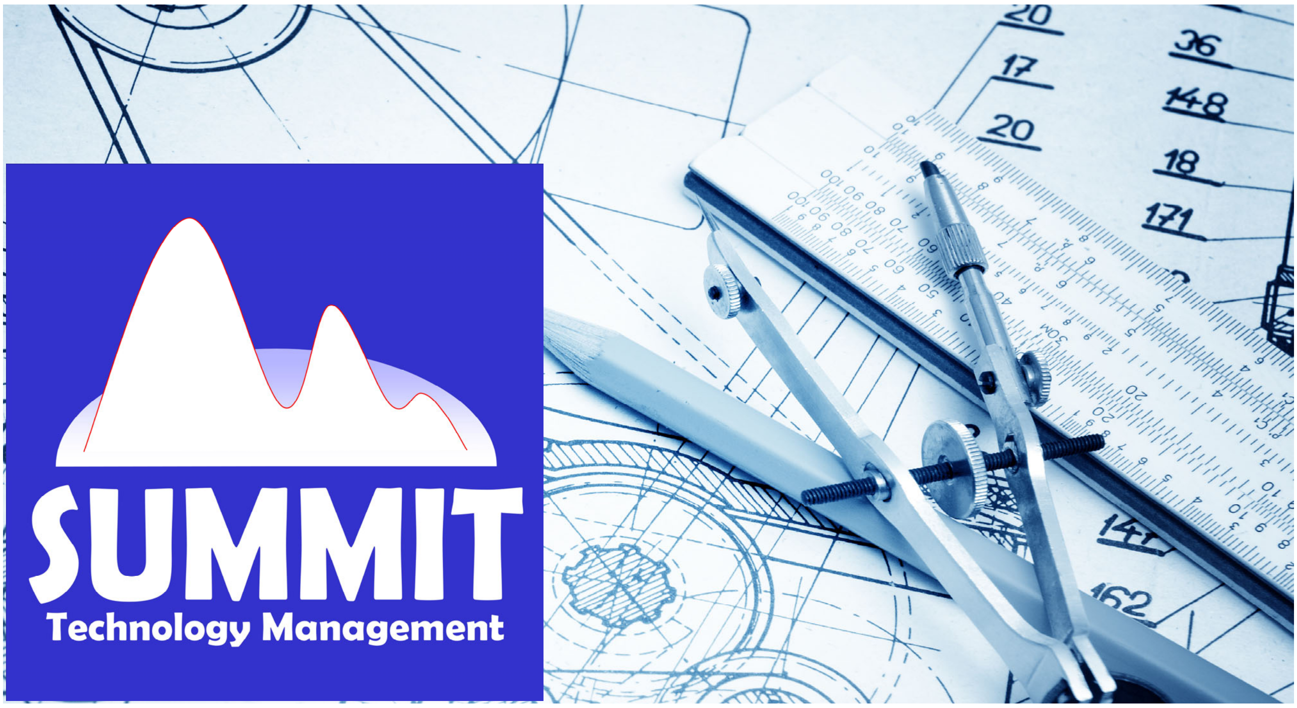
To keep the article brief, the focus is made on Oil and Gas applications. HIPPS for the Oil and Gas industry are based on two aspects – prescriptive and performance based. Standards such as API, ASME, ANSI to suggest a few are for design, manufacture and implementation and examples are API 14C (Recommended Practice for Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platforms), API 6A (Specification for Wellhead and Christmas Tree Equipment) for offshore applications, API 520/521, API 17O (Subsea High Integrity Pressure Protection Systems – HIPPS) to name a few. The other aspect is the IEC standards, chiefly IEC 61508 supplemented by IEC 61511 which are more of performance based standards that describe how to arrive at a solution rather than prescribing a solution. This would leave room for elucidation between different operators, contractors and suppliers thereby resulting in lack of commonly accepted industry specifications. The IEC 61508, for example focuses much on the functioning of the logic solver and touching minimally on the final control element. These gaps left in IEC 61508 regarding final control elements such as valves and solenoids are covered in IEC 61511.

IEC provides SIL ratings with Probability of Failure on Demand (PFD) and respective architecture not for individual components, but for the system as a whole which must include the actuators, initiators, final control elements and logic solvers. When different manufacturers assume certain architecture for HIPPS components provided, the individual components Probability of Failure on Demand (PFD) would not necessarily represent the overall system's PFD which is used to define the SIL rating. Therefore the PFD for a SIL assessment needs to always be investigated on a case to case basis prior to understanding the limitation on the SIL rating arrived at.

Pressure Relieving Devices vs. HIPPS

A point of contention arises when one asks, if when a piece of equipment is equipped with multiple relieving devices to deal with overpressure scenarios, wherefrom arises the necessity to install a HIPPS. To suggest so, means a justification is required to install HIPPS. For any successful implementation of HIPPS, an examination of applicable regulations, standards, local codes and insurer's requirements that may mandate the need for relieving devices is required. This is to be followed up by a Hazard Analysis (HAZAN) by a multi-disciplinary team. The process risk needs to be evaluated based on frequency and consequence such that the HIPPS proposed can demonstrate that the mitigated risk is lower than the risk tolerance criteria, to allow for the removal of associated relief devices from flare load calculations.

Traditionally, pressure vessels are equipped with pressure relieving devices that are routed to an industrial flare. However when the flare load capacity is insufficient to deal with excess capacities, HIPPS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The requirements of a relief device covered by UG-125 to UG-138 are to be designed as per API 521. For cases where the requirement of a relief device can be overcome is based on UG-140(a) and UG-140 (b) of the said code which pertains to Inherently Safe Design and HIPPS based design under specific cases respectively. Industrial use of HIPPS certainly provides the option of installing a smaller sized relieving device but cannot eliminate the necessity of relieving devices, although in certain specific cases, the need for PRV's can be eliminated.

As per API 521 and Code Case 2211 of ASME Section VIII, Division 1 and 2, HIPPS is allowed in lieu of a Pressure relieving device provided HIPPS meets or exceeds the protection that would have been provided by the PRV. However as per, ASME Section VIII, Division 1, para UG-125(a) Section VIII, Division 2, para, AR-100, it is required to install a pressure relieving device on all pressure vessels.

Therefore the question of whether a PRV is necessary in tandem with HIPPS depends on identifying credible overpressure scenarios in the operating system prior to installing relieving devices. HIPPS typically can be found in applications where hazardous gases are part of critical operations. Any addition of a relieving device acts more like insurance to the safety of the process.

HIPPS Procurement Life Cycle

HIPPS system which consists of various components such as logic solvers, actuators, valves, pressure transmitters can be supplied by various manufacturers. A Request for Quotation (RFQ) is placed with different manufacturers by the procurement division of the EPC contractor which in turn is provided to the engineering teams such as process, piping, Instrumentation and Safety departments.

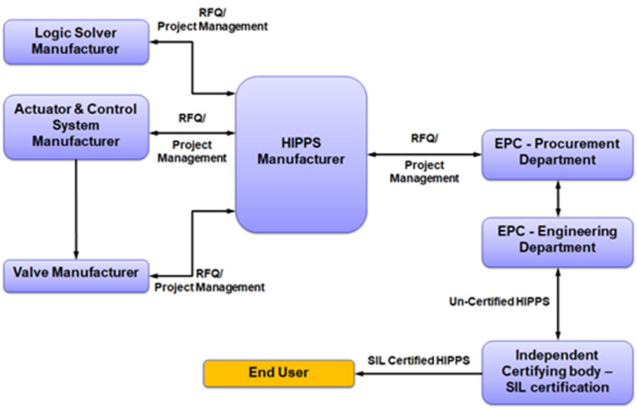

Figure 2. HIPPS Procurement and Certification Life Cycle

The EPC procurement team has to perform an additional task of project management to ensure all associated items in the bill of quantities (BOQ) are received and handed over to the engineering team. The integrated HIPPS components would then require a SIL certification by an independent certifying body for SIL 3 requirements before being implemented at the End User's facility.

The disadvantage of employing multiple suppliers causes increased lead time as well as procurement costs. An alternative would be to source HIPPS from a single manufacturer who can provide all individual components and have it certified by an independent SIL certifying body. This reduces the lead time required for procurement as well as costs associated.

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Getting it Right with Hydrostatic and Pneumatic Pressure Tests

Wiroon T.

Pressure test has been one of the most confusing and misunderstood issues for many engineers. Most engineers think they already know how to conduct a pressure test correctly while they actually do not. Follow the guidelines in this article to conduct pressure tests safely and correctly. Neglecting the guidelines may result in property damage and even injury or death of relevant personnel.

Foreword

Pressure test is a mandatory activity to test strength and leaks of any vessel or piping system after fabrication or modification. Pressure test medium can be either water or safe liquid (hydrostatic test/ hydrotest) or using air or safe gas (pneumatic test). The test medium pressure is raised to a certain set pressure and held for a certain period of time to ensure that the test equipment pressure can withstand the design pressure with sufficient safety margin without visual leaks.
The author's project experience suggests that this seemingly simple test has been done incorrectly and unsafely because engineers tend to blindly follow plant's inherited practice or other senior engineers' practice or just do what plant's mechanical engineers tell them to do. The author suggests the readers to correctly follow pressure test guidelines in ASME Boiler and Pressure Vessel (BPV) codes, ASME piping codes, and API standards that are applicable to your specific plant and equipment whenever doing the pressure test. This article is focused on refinery and petrochemical plants which mainly refer to ASME BPV Code Sec. VIII Div.1 [1] and ASME B31.3 Chemical Plant and Petroleum Refinery Piping [2]. Major issues with pressure tests that the author often found are:

1. Pressure test confusion with leak test
2. Unnecessary use of dangerous pneumatic test instead of safe hydrostatic test
3. Incorrectly set test pressure with different type of system or different version of ASME code used
4. Failure to account for liquid static head in test pressure gauge reading
5. Failure to account for the difference in allowable stresses atoperating temperature and pressure test temperature when setting the test pressure
6. Incorrect pressure test procedure
7. Inappropriate testing medium used
8. Incorrect application of pressure test concept to shell and tube heat exchanger design pressure setting.

The article will cover the above issues and guide readers to conduct pressure tests safely and correctly. A good reading on this topic is in [3].

Why Are Pressure Tests Required?

Every type of equipment subject to 15 psig or more internal pressure is considered to be a "pressure vessel" according to ASME Code VIII Div.1. Before putting any pressure vessel or piping in a specified operating pressure, it must have passed a pressure test by methods specified by the ASME Code.

First, there are some terminologies that the readers need to understand before discussing about pressure test.

- Normal operating pressure (OP) – pressure that equipment is normally operated or controlled at.
- Max operating pressure (MOP) – max pressure that equipment can be operated under normal operation.
- Design Pressure (DP) – pressure with a certain safety margin above design pressure. Design pressure means pressure at the top of equipment. If that equipment has a sizable height, it should be designed to withstand static head imposed by max liquid level inside the vessel as well as pressure imposed by solid bed such as catalysts.
- Max Allowable Working Pressure (MAWP) – pressure that equipment can withstand with the actual thickness of fabrication. This is because a commercially available standard steel plate thickness may be larger than that required by mechanical design calculation at a design pressure, thus allowing the vessel to withstand higher pressure than the design pressure.
- The relation is that: MAWP > DP > MOP > OP (Figure 1).

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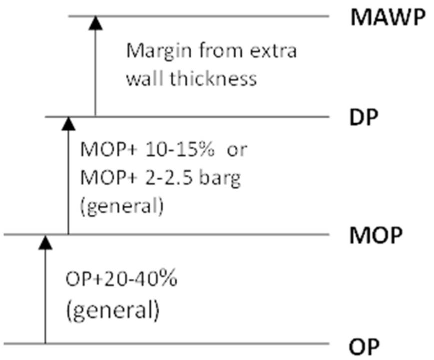

Figure 1: Concept of Pressure Levels

The concept of pressure test is to put the test equipment under pressure that are higher than max operating pressure in order to confirm mechanical integrity of the equipment over the entire run until the next inspection and maintenance.

The objective of pressure test is to ensure mechanical integrity after all hot works have been done on the equipment. The hot works include everything related to welding or post-weld heat treatment (PWHT). In case some modifications requiring hot works need to be made, it calls for a retest per code.

Two major types of pressure tests are:

- Hydrostatic test– a pressure test using incompressible fluid such as water or safe liquid
- Pneumatic test– a pressure test using compressible fluid such as air or inert gas or other safe gases

Pressure tests should not be a substitute for non-destructive testing (NDT) such as radiographic tests (X-ray), ultrasonic tests, magnetic particle tests, and liquid penetrant tests. NDT should be completed before the pressure test. For old equipment that has been in service for a certain period, it is recommended to conduct a wall thickness inspection and thorough check of cracks especially in high stress areas before the pressure test. A good practice is to visually inspect for leaks and structural deformation as a part of the pressure test. The pressure test can be done either at the fabrication shop (e.g. vessels) or at construction site (e.g. piping).

Pressure Test vs. Leak Test

Pressure test is often confused with "leak test" or "tightness test". ASME Code VIII Div.1 defines hydrotests and pneumatic tests as "pressure tests", whereas ASME B31.3 defines them as "leak tests".

Another possible definition of the leak test is a tightness test to confirm that all flanges, instruments, and piping connections have been connected tightly before plant commissioning. It is not to check the quality of hot works. Tightness tests are normally done at the plant site. Nitrogen gas should be used for flammable fluid systems such as hydrocarbons. For non-flammable fluid systems, filtered and oil-free air can be used. The tightness test pressure is generally limited to utility supply pressure (7-10 barg) except in special cases where mobile liquid nitrogen unit is brought in to test leaks of a specific system at close to system design pressure. The tightness test pressure will be held for a certain period of time to ensure system pressure could be maintained in an acceptable range.

ASME Code VIII Div.1 also refers to the leak test as a test to visually inspect for leaks after the pressure test. After a piece of equipment is held at a test pressure for a specified holding time, then the test equipment pressure will be reduced to design pressure to visually inspect for leaks and structural deformation.

Hydrostatic Tests vs. Pneumatic Tests

A vessel foundation may not have been designed for a water load or the process does not tallow contamination with water. Project management's argument is that the vessel was designed for a gas pressure so a pneumatic test, to verify the soundness of the modification, should not be a concern.

However, from safety point of view, all vessels and piping systems should be fully hydrotested rather than pneumatic-tested. Examples of exceptions when pneumatic tests may be preferred over hydrotests are:

1) Possibility of damage due to freezing (e.g. cryogenic system operating at subfreezing temperature) or too cold test water temperature
2) Possibility of the operating fluid or piping material adversely affected by water.
   (a) Hydrostatic test would damage linings (e.g. refractory) or internal insulation or electrical system.
   (b) Hydrostatic test would contaminate a process, causing hazards, corrosion, or inoperability in the presence of moisture.
   (c) Test equipment is not designed for full water condition and it is difficult to support the weight of water with additional temporary supports.
3) The time required for removal of all traces of water prior to placing the system into operation could impede the startup process
4) The cost of water disposal is too high due to water contamination.

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In case pneumatic testing cannot be avoided, it should require approval by the system owner as well as rigorous safety and risk evaluations. Pneumatic testing shall be performed using compressed air (filtered and oil-free) or non-flammable gas. For tracer tubing, nitrogen and instrument air lines, their own fluids may be used instead of the air or gas. The gas temperature in pneumatic testing must be confirmed not to cause brittle fracture on the equipment at a too low test temperature.

The potential damage to surrounding equipment and personnel resulting from a failure during a pressure test is far more serious when using a gaseous test medium. An explosion is a sudden release of energy, causing a destructive pressure wave. If equipment under test pressure cracks and bursts, the burst energy as a result of this will be much higher when test fluids are compressible. Burst energy is generally defined in terms of TNT equivalent (4.52 MJ/kg). At high pressure, the stored energy of compressible fluids such as air and gas used in pneumatic testing is generally a few hundred times higher in magnitude than that of incompressible fluids such as water used in hydrotesting. Burst energy of a gas-filled vessel can be estimated by Brode's method in Eq. (1):

$$E = (p_b - p_a)V_G / (k-1) = (TNT)*(4.52 \times 10^6) \quad (1)$$

Where E is the maximum energy release (J), V_G is the volume of gas in the vessel (m^3), p_b is the burst pressure of the vessel (bara), p_a is the pressure of surrounding air (bara), k is the ratio of specific heats (-), TNT = TNT equivalent in kg. 3 other methods to estimate burst energy are available in the literature [4].

Test Pressure

The hydrotest pressure should be set above design pressure. The correct hydrotest pressure setting has been an argument for engineers and vendors because there was a change in test pressure setting practice by ASME. If that equipment was designed using ASME Code VIII Div. I before 2001, then the hydrotest pressure should be 1.5 times of design pressure. However, if that equipment was designed using the later or current ASME Code VIII Div. I, the test pressure should be only 1.3 times of design pressure. The factors 1.5 and 1.3 are the yield strength safety factors specified by ASME. Thus, we need to check whether that equipment was designed based on which version of ASME code to confirm the correct yield strength safety factor.

Test pressure for hydrostatic test

= 1.3 x design pressure (ASME BPV Code from 2001-Present)

= 1.5 x design pressure (ASME BPV Code before 2001)

= 1.5 x design pressure (ASME B31.3)

Test pressure for pneumatic test

= 1.1 x design pressure (ASME BPV code)

= 1.1 x design pressure (ASME B31.3)

Test Pressure Gauge Reading vs. Test Pressure

Pressure gauge reading is the sum of test pressure + static head pressure if the pressure gauge is located below the top of the test equipment (for water, 10 m static head = 1 bar).

Temperature Correction for Test Pressure

When an equipment max operating temperature is much higher than the test temperature, the test pressure should be corrected to a higher value to account for lower allowable stress value at higher temperature. Temperature correction is by far the most overlooked factor in pressure test.

Pressure test is normally done at ambient temperature (63068 DEG C) where steels will have higher strength and thus higher allowable stress. To compensate for this drop of allowable stress at higher operating temperature, we need to increase the test pressure to a higher value according to Eq. (2).

$$P_t = K P_d \frac{S_t}{S} \quad (2)$$

Where P_t = test pressure, P_d = design pressure, S_t = allowable stress at test pressure, S = allowable stress at max operating temperature, K = yield strength safety factor (1.5 or 1.3)

Example

A pressure vessel made from A285 Gr. B was designed using ASME Code before 2001 at design pressure = 10 barg and max operating temp = 350 DEG C. This steel has an allowable stress = 13,100 psi at 350 DEG C and 14,300 psi at the test temperature (30 DEG C). What should be the test pressure?

$$P_t = 1.5 \times 10 \times \frac{14300}{13100}$$

= <u>16.4 barg</u>.

Medium for Pressure Tests

- Do not use water colder than 4 DEG C as a test medium because it can cause brittleness especially for equipment with thick walls. Add anti-freeze to the water if freezing is a concern in cold weather.
- Do not use water with chloride content > 50 wppm as a test medium for austenitic stainless steels (e.g. Type 304, 316, 317). These stainless steels will be cracked under tensile stress in contact with chloride, which is called "Stress Corrosion Cracking (SCC)". Use demineralized water or boiler feed water because of negligible or low chloride content.

Procedure for Pressure Tests

The procedure should include preparation step and testing step. Common preparation steps for both hydrotests and pneumatic tests are:

- Isolate the test equipment from other systems with a spade or a blind.
- Make sure all required piping stress relief, weld examinations, and welding documentation have been completed and acceptable.
- Install a calibrated test pressure gauge (preferably 2 gauges to compare the reading at a safe distance from the system being tested).
- Install sized and calibrated relief valves
- Block off the area and avoid irrelevant personnel's access to the test area
- Remove or block off all instruments and safety valves so that they will not be exposed to the test pressure.
- Always check all test equipment and accessories (e.g. test pump, flexible hose, valves) and that all test connections are tight.
- Check the following:
  ⇒Completed and torqued flanges with no missing bolts or gaskets
  ⇒All gravity supports installed
  ⇒Proper pipe routing
  ⇒Correct valve type and orientation (e.g. check valves)
  ⇒All valves in the test boundary are in open position.
  ⇒Tagging and lockout of any valves used to isolate the test boundaries is in place to protect both the testing personnel and any other who may be on site
  ⇒All joints, including welds and flanges, of the portions of the system to be tested are left uninsulated and exposed for inspection

<u>Hydrotest Additional Preparation:</u>

- Make sure that the equipment, foundation, and supports have been designed for full-liquid condition
- Install a high-point vent and a low-point drain to allow proper filling and draining
- Provide damage protection for all spring supports and expansion joints
- Eliminate trapped air from the test equipment

<u>Hydrotest Procedure:</u>

A general procedure is as follows:

1. Fill the test equipment with water from bottom.
2. Raise the pressure slowly with a test pump until reaching the test pressure.
3. Hold the pressure at the specified test pressure according to the code used. ASME pressure vessel code specifies a minimum of 30 minutes. ASME B31.3 specifies a minimum of 10 minutes. In any case, the holding time should not be too long because overpressure can result from thermal expansion of a fully-filled liquid vessel.
4. Slowly reduce the test equipment pressure to design pressure to start the visual inspection for leaks or structural deformation. The test personnel should stay far enough from the test equipment at the test pressure, and be allowed to access the equipment to inspect for leaks only after the test equipment pressure has been reduced to the design pressure.
5. After completion, open the top vent before draining all liquid from bottom before disconnecting.

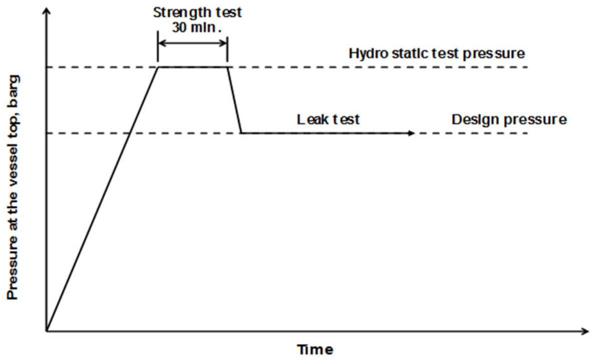

Figure 2: Hydrotest Procedure

<u>Pneumatic Test Additional Preparation:</u>

- Install a high-point vent with a pressure gauge to allow depressurization.
- If it is considered unacceptable for personnel to be close to the test equipment, prepare a sonic detector to identify leak at a safe distance from the test equipment
- If verification of a leak rate is required, prepare flow meters or totalizing meters to monitor the test. These may be placed between the pressure source and the piping system.

Pneumatic Test Procedure:

A general procedure is as follows:

1) Raise pressure slowly until pressure is around 170 kPag (25 psig) and inspect for leaks with a leak identifier (e.g. soap solution). If leakage is found, vent the system before repairs or adjustments.
2) Raise pressure slowly until half of the test pressure
3) Raise pressure with a step of 10% of test pressure until reaching the test pressure, and then hold the pressure for a given period
4) Reduce pressure down to design pressure and inspect for leaks again with a leak identifier.
5) After completion, open the top vent slowly to depressurize the system before disconnecting.

Shell and Tube Heat Exchanger Design Pressure Setting

Many engineers do not realize that hydrotest pressure setting is related to design pressure setting of shell and tube heat exchangers. The concept is that the shell side hydrotest pressure should be equal to or greater than the tube side design pressure. If the shell side was tested at 1.5 times of design pressure, then "two-thirds (2/3)" rule would apply to call for a shell side design pressure of at least "two-thirds" of the tube side design pressure to ensure the shell has been hydrotested to withstand overpressure by tube rupture (up to tube side design pressure). However, if the shell side was tested at 1.3 times of design pressure, then 10/13 rule would apply instead. If shell side design pressure is below that required by two-thirds or 10/13 rules, then a pressure relief valve is required on the shell side to protect the heat exchanger shell from overpressure by tube rupture.

Common Issues of Pressure Tests

Make sure equipment and piping flanges are rated for the test pressure to be used. Check the flange rating by ASME B16.5 or B16.47. If the flange rating cannot withstand the test pressure at the test temperature, it is a safe practice to consider using one step higher rating for the flanges that will be blocked to hold pressure during the pressure test. The recommended practice is to use standard blind flanges as per ASME B16.5 or B16.47.

- Make sure that test blind and spade dimensions are correct and thick enough to withstand the test pressure.
- Make sure the drainage rate does not exceed allowable drainage system capacity.
- Open all vents before draining the test medium to avoid vacuum condition.
- Relieve pressure in temporary piping and instrument connections and downstream of check valves before disconnecting.

Closing Thoughts

Conducting pressure tests safely and correctly will help prevent damage to life and properties. Not only the test personnel and those surrounding the test equipment will be safe but also the test equipment itself will be protected from unforeseen damage. Engineers should always confirm that they perform safety critical activities (e.g. pressure tests) according to safe and correct engineering practices based on acceptable engineering codes and standards such as ASME and API standards (or acceptable local regulations). They should not blindly believe that existing plant practices are correct. If company's or in-house engineering standards are used, make sure that they are equally or more stringent than common engineering standards.

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Biography

Mr. Wiroon is an outstanding chemical engineer specialized in process design/development, process technology scale-up, basic & detailed process engineering, and energy improvement. His areas of specializations are petrochemical ethylene plants and refining processes. He has had several publications including 3 international papers in Chemical Engineering Science journal and 4 industrial articles published in AIChE Chemical Engineering Progress (CEP), ChE, and Hydrocarbon Processing magazines. He also has a technology patent for alkenes (Bromine Index) removal process. He also has vast knowledge on basic and detailed engineering aspects due to his familiarity with design standards (e.g. ASME, API, ASTM, NFPA) and design practices of major global oil companies. He was elected by SCG Chemicals to get a one-year intensive technology training at GTC Technology US LLC in Houston, Texas, USA. He was invited to be a special lecturer for a Process Plant Design Course (senior year) at Naresuan University and for a Chemical Engineering Scale-Up Course at Chulalongkorn University 2013. He was 1 out of only 5 scholarship winners of a highly competitive Japanese Government scholarship nationwide, where he spent 7 years in Japan for Bachelor and Master degrees in Chemical Engineering. Mr. Wiroon founded "ChemEngEdu" (Chemical & Engineering Education) (2015) which is intended to be a hub of knowledge for engineers around the world.

Quarterly Safety Connector

For Engineers; Because Safety Is Part Of The Process!

By: Chris Palmisano, MESH, IFSAC **April 2018**

Are you really working for a safe workplace or, have you just been lucky?

You've probably received safety training for years, never really thinking that it could happen here. Then, a coworker is seriously injured and all the sudden, employees are immersed into reality. As a Safety Professional, my reality is that it can happen anywhere, at any time, to anyone.

Accidents affect all of us. Witnessing an injured employee's physical pain, emotional stress from an injury, loss of income and general sadness of their family, can sometimes be overwhelming. You may say to yourself, after a serious accident, "our attitude has to change". You make a good point. It's unfortunate that it takes a sad event for employees to suddenly be willing to accept suggestions that weeks ago, went in one ear and out the other.

Why does this happen? Plain and simple, it's "ATTITUDE". When something is out of site, it's out of mind. A positive attitude toward safety pays off in countless ways. Everyday your operation goes without an injury is a win. Your good attitude towards safety should be grounded by your organization's success, not as a result of failure. Today is the best time to get started and develop a good attitude toward safety, not after an accident.

A good attitude is a habit that can be learned! There are three basic elements to a safe workplace. They are **Attitude, Awareness & Action**, simple concepts that are worth thinking about. If you choose to ignore these three basic elements of safety you are just rolling dice.

ATTITUDE - requires focus on the tasks and the controls needed to promote safety. You must take the time needed to plan on how to do a job safely, with willingness to do what's right. Others may want you to take short cuts or cut corners but a good attitude means you have the intestine fortitude to do the right thing.

Accountability is also important. It means you care about safety and you believe in the cause and you do the hard work. Being accountable is safety means that you must always think of yourself as part of a team, better yet, a family. After all, we are a family. We spend more time with coworkers in our lifetime than we spend with our own families.

AWARENESS: Louise Pasture said, *"Chance will only favor the prepared mind".* Awareness is the ability to directly know, perceive, or be cognizant of possible outcomes through knowledge. More broadly, it is the state of being conscious of something through learning or studying. Therefore, Awareness is best achieved through education. The most successful safety professionals I've ever met in my career were those that were well educated in safety and regulatory compliance. We can only apply what we know to avoid unpleasant outcomes. The less we know the less effective we are.

Aside from the classroom, a great way to spread your awareness is face-to-face, through training, during frequent and regular inspections and task observation in the workplace. Talk to employees, don't be the safety police. A Safety Professional must be a trusted advisor in the workplace, not a finger pointer.

ACTION: Finally, action is the process of doing something to achieve an aim. Simply said, safety takes stretch and hard work to be effective. Measuring effectiveness in safety is unique from other jobs. Our greatest days as Safety Professionals are based on a "naught outcome", when everyone goes home in one piece. In my opinion, "zero accidents" is the greatest reward a safety professional can have.

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. 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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