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Refining eHandbook

Tackle Refining Industry Challenges

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Refining Industry Rises to the Challenges

Focusing on performance, sustainability and safety has helped navigate a volatile market

By Sheila Kennedy, contributing writer

THE DOWNSTREAM oil sector has had more than its share of ups and downs recently. Market dynamics, regulatory forces, and advancing technologies are keeping the refining industry on its toes.

A recent slowdown in global oil demand growth is expected to be short-lived. Fuel economy gains have kept gasoline consumption below its peak, but higher employment rates and growing car ownership in China, India, and other developing countries are boosting gasoline purchases. "We remained confident that in 2016 global oil demand will grow by 1.2 mb/d," says the International Energy Agency (IEA), Paris, in its April 2016 Oil Market Report Highlights (Figure 1).

Crude oil prices rallied to a four-month high in mid-April but are still far below the 2008 record. The refining industry adapted relatively well to the slide. "Overall, the current depressed crude prices have not hurt downstream refiners as much as their upstream (exploration and production) counterparts," says Peter Reynolds, an analyst with ARC Advisory Group, Dedham, Mass.

Maintaining a tight focus on performance, sustainability and safety has helped the industry to navigate these market trends.

PERFORMANCE

Plant automation and control systems, data analytics, and "smart" equipment leveraging the industrial internet of things (IIoT) are increasingly being deployed to improve process efficiencies, production, and capacity utilization.

"Refining has traditionally been one of the major users of automation and other operational technology (OT). However, the generally risk-adverse nature of the industry tends to make owner-operators slow to adopt newer, 'bleeding-edge' technologies," says Reynolds. Advanced process controls and gradually increasing interoperability between the OT and IT domains are among the investments being made.

At the same time, a more strategic approach to cyber security is required. New technologies for detecting and mitigating cyber risks are helping to confront this challenge.

SUSTAINABILITY

Sustainability remains a pressing need driven by regulatory mandates and growing investor and public demand. Requirements from regulatory bodies and enforcement agencies are in a constant state of flux, as evidenced by recent changes by the U.S. Environmental Protection Agency to its Refinery Sector Rule, MACT 1 and MACT 2 emission standards, New Source Performance Standards (NSPS), and National Enforcement Initiatives. Refineries are adapting their infrastructure and processes accordingly.

To minimize hazardous air pollutant emissions, advanced emission monitoring and control technologies

and electronic reporting methods are being implemented. Classic water management approaches are being supplemented by innovative wastewater treatment and reuse practices and zero discharge technologies. New hazardous waste handling, treatment and minimization methods also are being explored.

Energy management is another investment area. London-based IPIECA says oil refining activity accounts for about half of all the energy consumed by the oil and gas industry as a whole, but efficiency improvements have reduced the average energy intensity of the refining industry segment over the past three decades.

SAFETY

Finally, human and environmental safety hazards remain under constant scrutiny due to the vast consequences of failure. A 2015 refinery explosion in California that sent four workers to the hospital and spewed a cloud of ash on the community resulted in slashed output, citations and penalties, and an uphill battle to restore trust. Proactive investments in safety research and protective measures are helping to reduce such incidents.

Overall, the refining industry is taking the steps required to meet today's challenges and embrace tomorrow's opportunities.

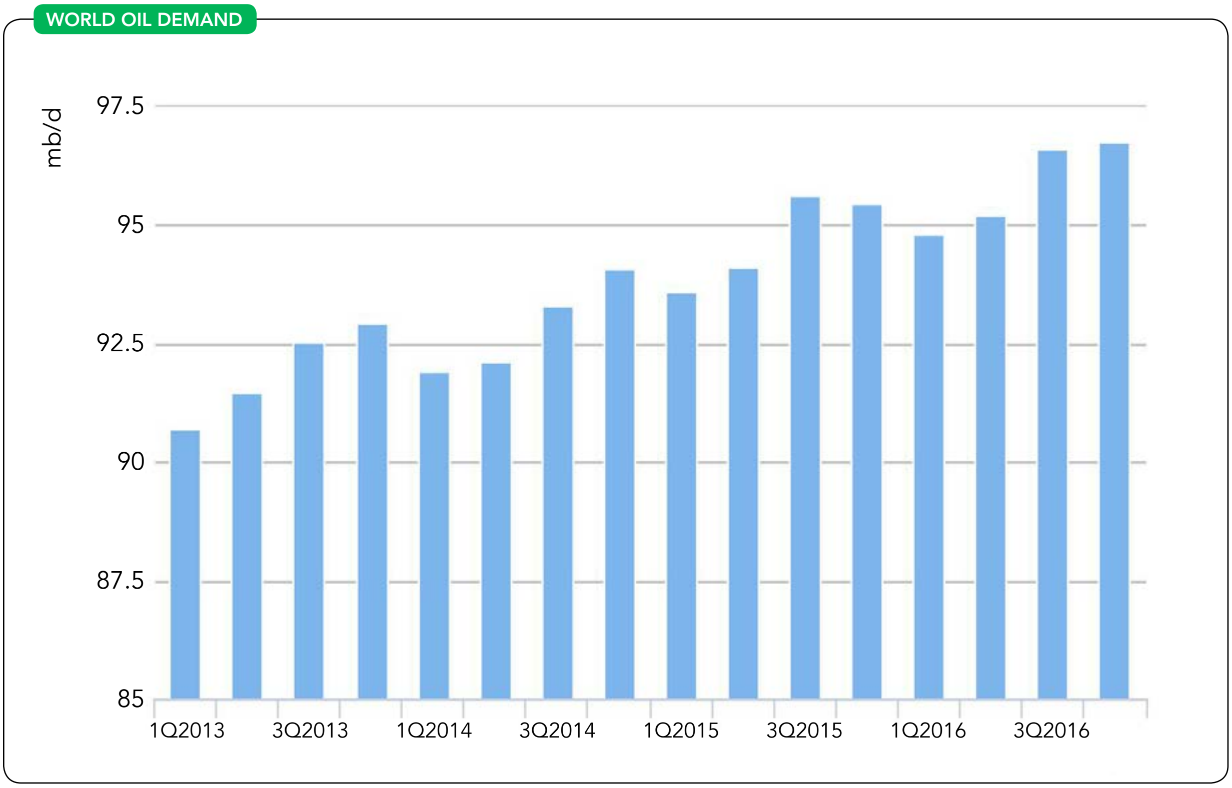

Figure 1. Global oil demand in 2016 is expected to grow by 1.2 mb/d. *Source: International Energy Agency.*

Tame Your Transient Operations

Use a special method to identify and address potential hazards

By Scott W. Ostrowski and Kelly K. Keim, ExxonMobil Chemical Company

A DISPROPORTIONATE percentage of process safety incidents have occurred during transient operations, which include those conducted infrequently such as startups or shutdowns as well as abnormal or emergency events. A typical refining or petrochemical facility will spend less than 10% of its time in transient operations — yet 50+% of process safety incidents occur during these operations (Figure 1) [1–3]. Deficiencies in procedures and employee training often are cited as root causes of these incidents. The increased reliability and extended turnaround intervals of plants result in less familiarity with tasks outside of normal operations. So, while it's critically important to follow procedures during transient operations, a high percentage of procedural violations are found to occur during them.

Here we present a Hazard and Operability (HAZOP) methodology designed to verify that hazards of transient operations are identified and adequately controlled. The approach already has proven its value at ExxonMobil sites.

TYPES OF TRANSIENT OPERATIONS

The HAZOP process must consider two categories of operations that have potential for an acute loss of containment, resulting in a higher consequence incident:

1. *Non-routine operations or planned operations that infrequently occur.* Such events include: startup of a major unit, including from total shutdown; shutdown or startup of major equipment within a process; operating with a non-standard equipment configuration on a unit, such as a major pump or compressor out of service, inventory shortages or excesses, boiler unavailable, and non-routine testing of a critical device with potential to shut down a unit; and unique or unusual feedstock or grade changes (throughput or quality).
2. *Abnormal or unplanned operations.* Examples include: operations outside of equipment's design specifications; those past the point where routine corrective actions will work, e.g., reactor runaway; unplanned

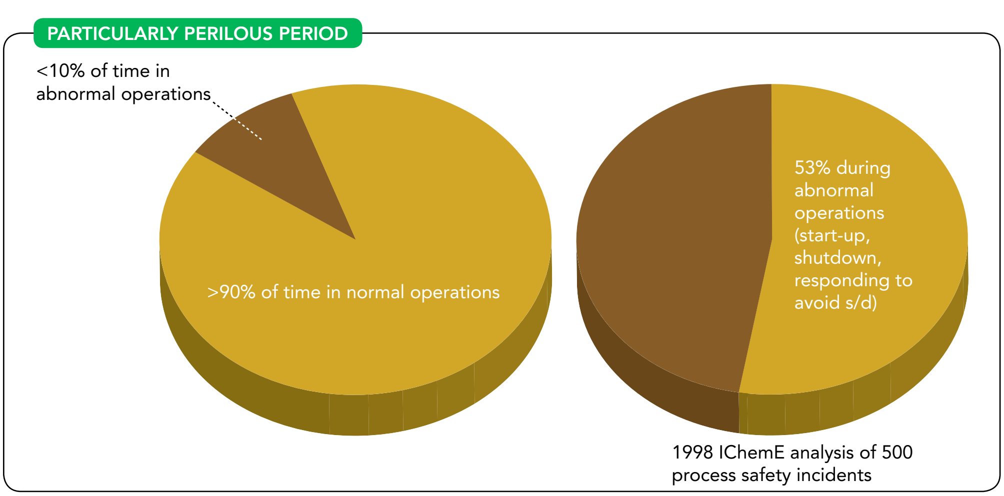

Figure 1. A disproportionate percentage of safety incidents typically occur during abnormal operations. *Source: Reference 1.*

abnormal equipment configuration; unscheduled unit shutdown; emergency operator actions, including responses to "SHE [safety, health, environmental] critical" alarms; and a loss-of-containment event.

Transient operations may include catalyst change-out or regeneration, decoking, fired heater lighting or other non-routine or abnormal chores.

A common element in transient operations is the requirement for increased human interaction with the process. Often the operator and procedural controls are the key layer of protection for preventing an incident. Reduced operator experience — because of retirements, longer turnaround intervals, and more reliable units — frequently results in more reliance on procedures as a source of information and a critical layer of protection against process hazards.

In the U. S., OSHA 1910.119, "Process Safety Management of Highly Hazardous Chemicals," requires that an initial process hazard analysis (PHA) completed on a covered process be updated and revalidated at least once every five years [4]. Given a sound management of change (MOC) system to identify, evaluate and ensure the adequacy of controls managing risks associated with the newly introduced hazards, historically a significant reduction in HAZOP findings occurs after two to three cycles of a traditional "redo" HAZOP/PHA. Figure 2 illustrates an example of these diminishing returns.

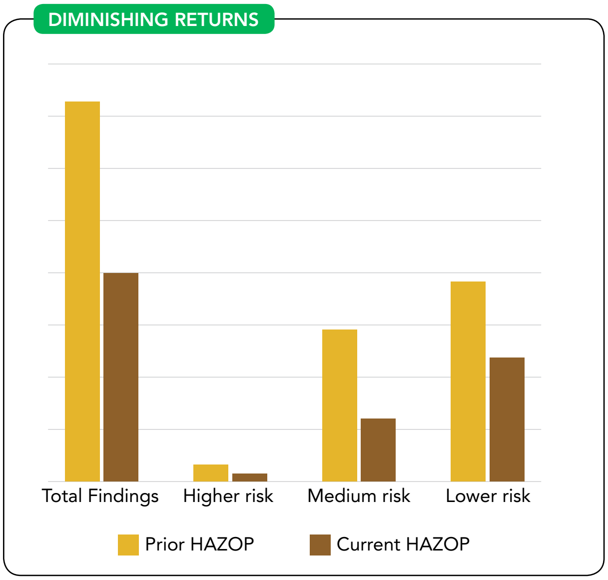

Figure 2. Conventional follow-up HAZOPs generally identify fewer total risks.

A DIFFERENT FOCUS

The Transient Operation Procedural Focused HAZOP (or Transient Operation HAZOP for short) differs from a conventional HAZOP. It focuses on operational tasks and procedural controls, which are believed to yield greater returns, specifically in the third or later cycle of a more traditionally focused HAZOP.

The Transient Operation HAZOP (TOH) process centers on identification of required unit-specific activities (tasks) with a potential for an acute loss of containment and an in-depth review of the procedural controls needed for safe and successful completion of those tasks. Timely identification of hazards, adequacy of procedural and design controls to ensure correct sequencing, early feedback of potential errors, clarity and completeness of transient operations are carefully assessed. The technique uses a combination of knowledge and experience of a cross-functional team, guide words and reference lists to drive a disciplined approach to identify and suggest enhancements for procedural and design-related issues.

The TOH process offers manufacturing sites a number of potential benefits:

- an in-depth fresh look at "higher risk" transient operations requiring human intervention where procedural controls manage residual risk;
- more-complete and easier-to-follow procedures where

procedural controls are key to safe operations during the transient condition/phase or state of the process;

- increased operator awareness of hazards, design controls and potential consequences of not understanding the operation and procedural controls of a transient condition;
- greater consistency in procedural controls as well as potential identification of needed additional design controls for transient process conditions; and
- experience in applying procedural controls that can be applied beyond transient operations.

The TOH approach can provide stand-alone analysis prior to a planned transient operation. It also can be used in conjunction with a traditional HAZOP based on mechanical flow diagrams (MFDs) or piping and instrumentation diagrams (P&IDs). Finally, it can support revalidation of an MFD- or P&ID-based HAZOP/PHA for units needing revalidation.

THE APPROACH

The TOH method involves several distinct steps.

Team formation. The team's composition and experience requirements are the same as for an MFD- or P&ID-based HAZOP with the following exceptions:

The leader should be trained in the TOH process and should have participated in a TOH run by a qualified leader. This person is responsible for facilitating the work process and producing the final report.

The operations (process) representative(s) should be qualified in both field and control console operations, and be intimately familiar with the tasks being reviewed — particularly how they actually are completed in the field. While one person with adequate experience in both areas would suffice, having a second operations representative (preferably from a different shift) likely will add substantial depth and breadth. We recommend having two operations representatives. The operations representative(s) walks the team through the details of transient operations under review and may be assigned to capture "redlined" changes to procedures.

The process design/technology representative must know the type of process and equipment being studied as well as the company's design standards and practices. This helps in communicating design intent of the equipment. The process design/technology representative is responsible for following the operation under review on the MFDs or P&IDs.

Unit startup, shutdown, emergency operator intervention and other transient activities often involve flaring, thermal oxidizers, scrubbing systems, generation of more or different waste streams, etc. As a result, part-time support from an environmental engineer will provide value and typically is justified.

Pre-selection of unit activities and related procedures. The leader, operations representative(s), and process design/technology representative should conduct a first-pass screening of all required unit activities and related procedures to identify those that meet the criterion of a "higher risk" transient operation. This will streamline subsequent review and ensure consistent application of the HAZOP technique.

Assembly of reference documentation. The team must have access to the same information that's required for a traditional HAZOP study, including: material safety data sheets (MSDS), simplified flow diagrams, detailed MFDs or P&IDs, electrical area classification drawings, pipe specifications, facilities siting studies, unit operations, maintenance, and emergency procedures, incident reports on the unit, and a list of employee concerns.

Solicit comments and concerns from employees and affected contractors — involve the first-line supervisor and other line management in the communication process. Focus on potential loss of containment and human factors issues. Place special emphasis on the experience of operators during abnormal and non-routine operation but consider all concerns during the HAZOP process.

TRANSIENT OPERATION GUIDE WORDS

Guide Word	Meaning/Explanation
Who	Is it clear who and how many individuals are needed to perform the step? Have minimum staffing levels for this sequence been established, documented and communicated? This is particularly important for field/console interaction issues. It may be obvious for the more experienced and knowledgeable individuals, but is it appropriate for the "average" operator?
What	Is the broad objective stated for the series of steps? This allows the people involved to adapt to changes that might be happening versus what the procedure writer experienced before or expects. This is where the team picks up missing steps, actions and unanticipated situations — for example, nitrogen purge of a large flare line isn't called out before commissioning.
When	Is the timing or order of the task important? This comes into play if related parts of the unit are being operated on by different crews — for example, one crew commissions the flare line and another is pressuring up equipment.
How Long	Is the duration or length of time for an action, e.g., purging or agitation, to continue important?

Table 1. Guide words such as these help team members take advantage of their knowledge and experience.

Final selection of unit activities and related procedures for review. This is the full team's responsibility. During its initial meeting provide a "HAZOP Kick-off Summary" to introduce the team to the TOH's purpose, scope and methodology. After the kick-off, the entire team should look over all incident report summaries assembled for the unit under review. Focus on process safety and environmental incidents and near misses. Review in detail reports on incidents that involve transient operations with an actual or potential release of hazardous materials to identify operations to include in the scope of the review. Next, the team should assess all identified employee concerns, to determine operations and related procedures with which employees may have issues. Carefully consider this information when selecting operations and tasks to include in the scope of the review. Finally, the team leader and process design/technology representative should inquire about higher-risk unit activities and practices that may not be documented. Capture findings where procedures or adequate procedural controls aren't in place on the HAZOP worksheet as follow-up items and risk-assess them, with potential improvements documented for consideration.

The entire team should review the first-pass screening of all documented unit activities and related procedures to be included in the study. Team discussions then can lead to adding or removing items from the list.

Conducting procedural review. The leader should orient team members lacking training in the TOH approach. Often this means explaining the guide word sheets and discussing examples (see Table 1). Review each guide word and corresponding explanations. Typically this activity requires about 30 minutes. The 20 guide words serve as

REFERENCES

1. Duguid, I. M., "Analysis of Past Incidents in the Oil, Chemical and Petrochemical Industries," *Loss Prevention Bulletin*, No. 142, p. 3, Institution of Chemical Engineers, Rugby, U.K. (1998).
2. Duguid, I. M., "Analysis of Past Incidents in the Oil, Chemical and Petrochemical Industries," *Loss Prevention Bulletin*, No. 143, p. 3, Institution of Chemical Engineers, Rugby, U.K. (1998).
3. Duguid, I. M., "Analysis of Past Incidents in the Oil, Chemical and Petrochemical Industries," *Loss Prevention Bulletin*, No. 144, p. 26, Institution of Chemical Engineers, Rugby, U.K. (1998).
4. "Process Safety Management of Highly Hazardous Chemicals," 29 C.F.R. § 1910.119(e)(6), U.S. Occupational Safety and Health Administration, Washington, D.C. (2008).

memory joggers to bring out the knowledge and experience of the team. The TOH methodology uses this knowledge and experience as well as documented procedures to guide the team through the unit and facilitate identification of hazards.

The operations representative(s) should go over with the entire team a summary of required operational activities (tasks) associated with the specific transient operation. The review should use unit MFDs, P&IDs and procedural sequence flow diagrams, as appropriate, to assist team understanding. Typically a second member of the team (usually the process design/technology representative) will follow the operation under review on the MFDs or P&IDs. Discuss any potential procedural or equipment-related questions as they are identified.

The team should gain an understanding of required operator actions, hazards and potential higher-consequence loss-of-containment risks associated with the operation, and all preventing, alerting and mitigating controls in place. The team should test to ensure procedures have been developed and are up-to-date for the transient operation under review, personnel responsible for conducting the operation have been adequately trained, and risks have been adequately controlled through application of hardware and procedural controls.

The team initially should scan the procedure as a whole, looking for items contrary to good format, e.g., use of warnings, cautions and notes, sequencing of activities, confirmation that steps begin with action verbs, etc. Group deficiencies, as applicable, and note them as finding(s) for the individual procedure.

Next, the team should break every procedure into a sequence of related steps. For each sequence, ask the question, "Will a deficiency in this sequence of actions potentially lead to a higher-consequence outcome?"

If there is no potential, mark that set of steps in the right or left margin vertically with a highlighter to document the section has been reviewed.

If a risk exists, evaluate each step separately. Start by asking: "Will a deficiency in this step potentially lead to a higher consequence outcome?" If the answer is "no," move on to the next step. If the response is "yes," evaluate the step using the knowledge and experience of the team, aided, as necessary, by guide words. The evaluation should identify ways to improve the procedure to reduce the potential for an incident to a very low probability.

Determine if a procedural control is the most effective means to ensure activities are safely and reliably conducted. Improvements may be a change in wording, addition of a caution or warning box, or even additional facilities or controls to mitigate the risk. Document findings as a redlined change to the procedure or as a follow-up item on

the HAZOP worksheet. It's best to use a computer projector to display the current procedure and the recommended change to the full team. Finally, highlight in the margin each line of the steps evaluated to indicate it was discussed in detail.

Subject any place in a procedure with an existing caution or a warning box to a more detailed evaluation. Confirm or add a caution or warning box, as appropriate, for the potential consequence. Check each precautionary statement to ensure it:

- alerts the operator to the hazard;
- includes a description of the necessary actions to avoid the hazard; and
- details the potential consequences of ignoring the warning.

Once the entire procedure is reviewed, repeat the review steps for the next procedure until all chosen for review are complete.

Documentation of findings. Capture follow-up items as redlined revisions to the procedure — if a change is simple, well understood and can be addressed by the team's suggested wording. Note on the procedure's master review copy follow-up items that can't be addressed by a simple rewording with an item identifier, just as is done to drawings in redo HAZOPs (e.g., S-1, E-2, O-3).

Indicate on the HAZOP worksheet any finding identified for further consideration as a follow-up item. If the team can't achieve consensus on procedural controls or improvements to those controls, it may consider enhanced training, process automation tools or facility changes to reduce the risk. Risk-assess any findings that call for facility changes and prioritize them for follow-up. Document recommended additional controls.

Unit tour. Conduct a screening-level walk through the unit, to spot-check effectiveness of SHE-related management systems and to identify SHE hazards and operational issues not previously pinpointed by the team. Such a tour typically takes 2–4 hr. During this phase, the team must:

1. Test supporting systems in place to ensure transient operations are completed in a safe and effective manner;
2. Scan the unit for general process safety issues within the scope of the review; and
3. Identify any potential human factors issues that could potentially contribute to a significant consequence event. Check features such as:
   - labeling of important equipment and lines;
   - location of crucial valves;
   - arrangement of valves that need to be operated in critical sequences;
   - placement of manual control valves and their associated local meters;
   - whether equipment and lines can be located and safely isolated during an emergency; and
   - whether the design adequately addressess environmental factors, such as visibility and access.

It may be preferable to schedule this tour later in the study, to better assess issues identified as a part of the procedure review. The team should consider any issue with potential to contribute to release of a highly hazardous material as a finding.

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"Rethink Your Approach to Process Safety," http://goo.gl/wwudPo

"Collar Hazards with a Bow-Tie," http://goo.gl/RSCrRa

Documentation. The reporting phase of the TOH process involves documenting the scope of the review, team composition, documentation reviewed, redlined copies of all procedures reviewed, as appropriate, identified follow-up items and associated risk assessment, as applicable. Include following lists in the final documentation of the completed HAZOP:

- team members, responsibilities and years of experience;
- procedures reviewed;
- incident investigations scrutinized; and
- other documentation examined, as appropriate — e.g., summary of MOC metric data, facility siting studies, process flow diagrams, P&IDs, MSDSs, electrical area classification drawings, safety relief review studies, and SHE critical equipment lists.

SUCCESSFUL USE

ExxonMobil has rolled out the TOH method at manufacturing operations worldwide. More than 90% of manufacturing sites globally have finished initial TOH application. The TOHs completed to date are identifying findings of significance and providing value to the business. In addition to recommended procedural controls, application of the TOH methodology has determined the need for, and recommended, potential additional hardware and software hazard controls. The TOH methodology truly is more than just a procedures review.

ExxonMobil Refining and Supply and Chemical Companies have systematized its application through their global manufacturing operations integrity management system practice, ensuring a unit HAZOP specifically focused on transient operations is completed after the second HAZOP cycle. Additionally, global reliability system elements include milestone-driven application of the methodology during turnaround planning and specific abnormal and non-routine operations.

In late 2008 about 1,200 findings from 27 completed TOH studies were analyzed. Learnings were communicated, as appropriate, through the organization. The ultimate goal is to enhance organizational knowledge so risks associated with process hazards can be consistently controlled to acceptable levels across the business.

A VALUABLE TOOL

The TOH methodology can serve as a powerful supplement to traditional HAZOPs. Its focus on infrequently performed operations that require an increased level of human interaction with the process addresses situations that generate 50+% of medium- and higher-risk process safety incidents. The outcome is more-complete and easier-to-follow procedures for managing the process through transient states; increased operator awareness of hazards, design controls and the potential consequences of mal-operation; and experience in applying procedural controls that can be applied beyond those procedures covered in the TOH process.

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Understand Steam Ejector Hybrid Systems

Such crude and vacuum distillation units can save operating costs and reduce greenhouse gas emissions

By Raj Bhatnagar, Gardner Denver Nash LLC

TODAY'S REFINERY crude and vacuum distillation unit (CDU/VDU) systems use vacuum to extract and capture light hydrocarbons that disassociate from the crude oil. Vacuum is achieved by either an all-steam jet system or a "hybrid" system that typically combines two vacuum technologies. Hybrid systems can be used in both new and existing installations to save operating costs and reduce greenhouse gas (GHG) emissions.

This article will explain what hybrid systems are, why use them, where they can be used, what to consider when designing a hybrid system, how hybrid systems can be optimized and which design standards should be used.

WHAT ARE HYBRID SYSTEMS?

Hybrid systems combine different technologies to offer high efficiency. Examples of system combinations include:

- Steam ejector and liquid ring pump
- Air ejector and liquid ring pump
- Blower and liquid ring pump
- Blower or rotary vane and liquid ring pump
- Blower and dry vacuum pump

These technologies are combined to optimize a system to meet operating conditions, while running reliably. Because each process has a unique set of operating conditions, each hybrid system must be customized to meet application requirements.

Selecting the right hybrid system option depends on process knowledge and the equipment being used. Each technology listed above has its own mechanical, thermodynamic and economic limitations. For crude tower vacuum installation, we will focus on hybrid systems that combine steam jet ejectors with liquid ring pumps.

WHY USE HYBRID SYSTEMS?

Steam jet ejectors are the simplest of the vacuum technology family as they have no moving parts. Ejectors are mass flow devices that operate on the principle of momentum, as shown in Figure 1.

If the process gas and motive steam conditions are constant, they operate reliably. However, ejectors have a narrow operating range to maintain stable operation. Any changes in the process gas composition or flow rate or in the motive steam will affect the jet's performance and stability. In a multi-jet system, instability in one jet will cause a waterfall effect in the downstream jets, resulting in instability in the entire system.

In addition, steam jets are inefficient to operate. Typically, a fossil fuel is burned to produce the motive steam, which causes GHG emissions. Depending on the fuel cost, a stream jet's operational costs can quickly surpass the energy costs of other vacuum technologies.

Liquid ring pumps are positive-displacement (volumetric) devices that operate on the principle of a liquid piston. They have only one moving part and have been operating in various process industries for more than 100 years. A liquid ring pump's performance depends primarily on the seal liquid's characteristics. The liquid seal's vapor pressure, as well as the process gas constituents' solubility and miscibility, must be considered when sizing and selecting a liquid ring pump for an application. Unlike steam jets, the liquid ring pump can operate over a range of vacuum levels.

Combining a steam jet ejector's high vacuum capability with a liquid ring pump's stability can provide a system with stable operation during process upsets, increased reliability and lower total operating and installation costs.

To help illustrate these advantages, here are some things to know about hybrid systems:

1. *Reduce GHG emissions.* Refineries contribute 35% of the total GHG emissions in the United States. They must purchase or offset over 90% of their regulated GHG emission. *Hydrocarbon Processing* magazine published a case study in June 2010 featuring a steam jet and liquid ring pump hybrid system on

STEAM JET EJECTOR DIAGRAM

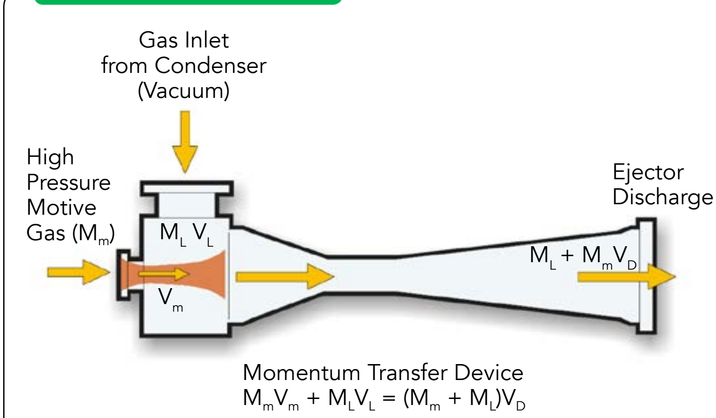

Figure 1. This mass flow device operates on the principle of momentum.

a CDU for a 150,000 BPD refinery. The project saved 10,679 lbs/hr. of steam, which equates to 6,649 metric tons per year of GHG emissions. Savings from the modification from GHG will be $60,721 at a cost of $10/metric ton. Typical GHG costs vary from $7 to $23 per metric ton. This cost savings does not include operating cost savings. This upgrade to the CDU along with other modifications in the refinery brought down the GHG within the limit.

2. *Reduce operating costs.* As an example, utility costs in India vary from $50 to $60 per ton of steam, and power costs vary from $0.12 to $0.20 per kWh. A hybrid system's payback could be less than one year because of operating cost savings. Combining the GHG cost savings with the operating cost savings gives hybrid systems an economic advantage.

3. *Greater reliability.* The ability of hybrid systems to handle excessive back pressure, operate in on/off design conditions and tolerate fluctuating cooling water temperatures in system inter-condensers make them reliable alternatives to all ejector systems on crude vacuum tower applications. Many users have found that operating cost savings have paid back the original investments many times over.

WHERE CAN HYBRID SYSTEMS BE USED?

Hybrid systems can be used in any industry or application in which deep vacuum is required and system reliability is critical. Process or application knowledge is key in selecting the correct combination of technologies for an effective hybrid system. Design engineers must be experts in multiple technology operations and know both equipment limitations to determine which technology is best for a particular application.

Common applications include:

- Refinery CDU/VDU applications,
- Geothermal power plants,
- Ladle degassing in steel mills,
- Polyester and polystyrene production in chemical/petrochemical plants, and
- Deodorization in processing edible oil.

DESIGNING A HYBRID SYSTEM

Keep the following in mind when designing a hybrid system instead of an all-ejector system:

- Systems with a high non-condensable gas load.
- Scarcity or cost of steam.
- Increases in system capacity where adding a steam ejector to an existing liquid ring pump will handle the additional gas load at minimal cost.

Ejector manufacturers need to have knowledge of multi-stage ejector systems and what aftermarket and technical services are required to support the system during its expected lifecycle. Pump manufacturers need to have the correct products in their portfolio to meet customer and market needs, as well as in-house expertise of aftersales product and system knowledge.

HOW CAN A HYBRID SYSTEM BE OPTIMIZED?

Hybrids can be optimized in many combinations based on initial cost, payback period or utility limitations. Table 1 shows how existing systems can be optimized several different ways. Figure 2 illustrates these methods.

OPTIMIZING A HYBRID SYSTEM

System Change	Impact
Replace last stage ejector with a liquid ring vacuum pump.	Reduced steam consumption. Reduced energy costs. Greater system stability.
Replace existing 2nd stage ejector with redesigned 2nd stage ejector.	Reduced steam consumption.
Replace 2nd and 3rd stage ejectors with liquid ring vacuum pumps.	Reduced steam consumption. Reduced energy costs. Higher system non-condensable load. Greater system stability.

Table 1. Hybrids can be optimized in many combinations based on initial cost, payback period or utility limitations.

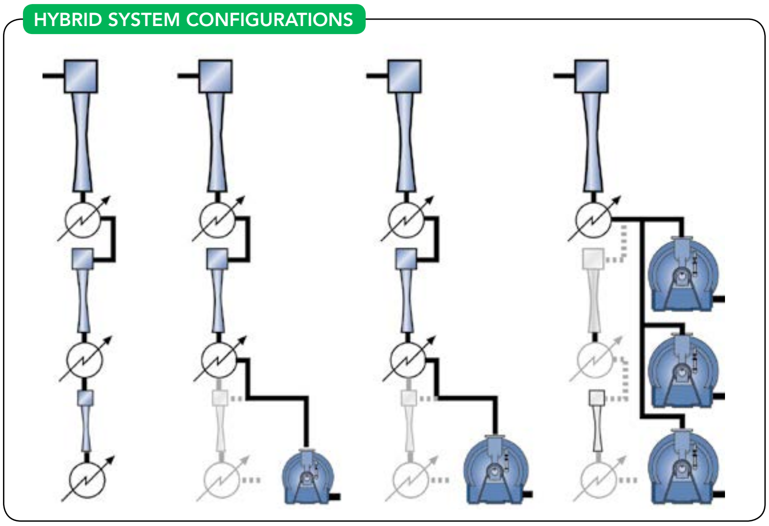

Figure 2. Hybrid systems can be optimized in various ways.

SYSTEM COMPARISON

Components	SJAE System 030-2-SSS	SJAE/LRVP System 030-2-SSP
First Stage	Three (3) 36 × 36	Three (3) 36 × 36
Intercondenser	Three (3) 72 × 240 AXS	Three (3) 72 × 240 AXS
Second Stage	Two (2) 16 × 16	Two (2) 16 × 16
Aftercondenser	Two (2) 37 × 168 AES	Two (2) 37 × 168 AES
Third Stage	Two (2) 8 × 8	Two (2) XL500 LRVPs
Aftercondenser	Two (2) 29 × 144 AES	
Additional Hybrid Cost		$ 1,600,000

Table 2. While components remain the same in the first two stages, the third stage differs between the all-ejector and hybrid systems.

ECONOMIC ANALYSIS

Components	SJAE System 036-3-OSS	SJAE/LRVP System 036-3-OSP	Variance
Equipment capital cost		$1,600,000	**$1,600,000**
Steam consumption (pph)	68,079	54,497	**13,582**
Cooling water usage (gpm)	14,570	10,273	**4,297**
Power consumption (bhp)	–	388	**(388)**
Steam cost	$4,055,330	$3,246,277	**809,053**
Cooling water cost	$57,951	$40,860	**17,091**
Power cost	–	$179,056	**(179,056)**
Total operating costs	$4,113,281	$3,466,193	**$647,087**
Payback: (Capital cost variance/ operating cost variance)			**2.47 years**

UTILITY COSTS

Utility	Cost
Steam	$6.80/1,000 lbs
Water	$.000008/gallon
Power	$.0393/kWh
	Annual hours: 8,760
	Availability: 100%
	Annual operating hours: 8,760

Table 3. While components remain the same in the first two stages, the third stage differs between the all-ejector and hybrid systems.

ECONOMIC COMPARISON OF STEAM JET SYSTEMS

Tables 2 and Table 3 compare the economics of a refinery crude tower vacuum system using an all-steam jet ejector system (SJAE) (Figure 3) and a steam jet/liquid ring hybrid

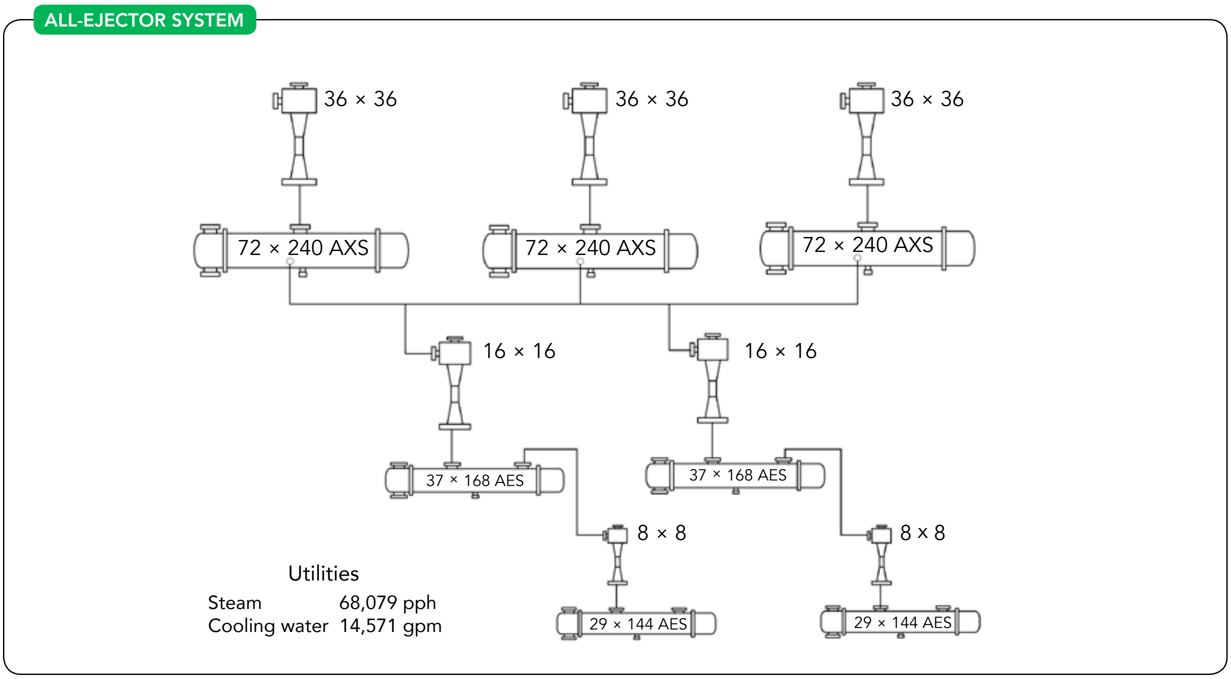

Figure 3. Schematic outlines all-ejector system and its components.

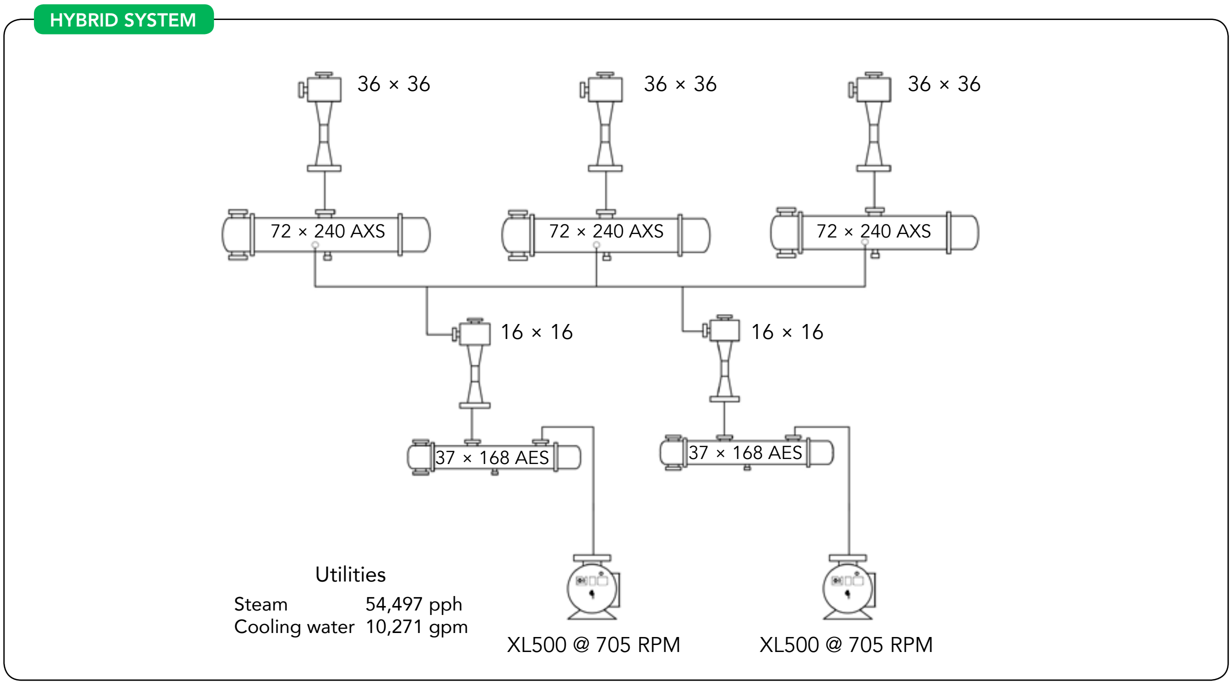

Figure 4. Schematic outlines hybrid steam jet and liquid ring system and its components.

(SJAE/LRVP) system (Figure 4). System parameters include suction pressure of 30-mm HgA, suction temperature of 185°F, and discharge pressure of 958-mm HgA. Gas composition/flows include:

NCG	1,143/2,626 Kg/hr.	MW 28.82
Water	15,000/ 9,722 Kg/hr.	MW 18
Hydrocarbons	1,824 Kg/hr. API 35	MW 72

Utility costs will vary depending on the region, which will determine the justification of a hybrid system for your application.

WHICH DESIGN STANDARDS SHOULD BE USED?

Proper design standards must be considered in designing and manufacturing complex hybrid systems used in refineries. With many non-condensable gases (some of them soluble in water), hydrocarbons and pseudo-components, it becomes impossible for end users to verify a system's design. Compliance with these minimum standards is recommended:

- HEI standards for ejector design and testing
- HTRI standards for condenser design

Ejectors should be performance-tested on the test floor to guarantee reliability. However, if utilities limit the performance on the test stand, a pilot test for the actual design conditions can be conducted and the ejector designed based on the pilot test results.

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Minimize Oil and Gas Refinery Downtime

Shutdown and turnaround logistics become easier to coordinate with operational planning tools

By Patrick Zirnhelt, IFS North America

SHUTDOWNS AND turnarounds are a necessity in the refining industry. They are huge, expensive undertakings, affecting hundreds of processes and thousands of people both inside and outside the refinery walls. Careful planning, organization and adaptation are key to ensuring success.

THE TICKING CLOCK

Shutdowns and turnarounds are not new for refineries in the oil and gas sector, but the bottom line remains the same—an inefficient turnaround means dollars lost. One plant estimated the cost of a shutdown at $10 million per day.

The recent fall in oil prices has increased pressure for refineries to find cost savings, rendering project management around shutdowns and turnarounds critical to bottom-line success.

The moment operations cease, time becomes money. The end goal is, of course, to get operations up and running in the shortest possible time, but with health and safety standards intact.

Most savings can be found by driving efficiency, but real efficiencies can be achieved only by careful asset and workforce management at all stages of what is a complex and continuous process. The enterprise resource planning (ERP) or enterprise asset management (EAM) system must be agile and flexible enough to deal with these complexities to achieve efficiencies.

ESTABLISHING A SINGLE POINT OF TRUTH

No one-size-fits-all plan exists to facilitate a shutdown or turnaround. Planning is a dynamic event. It's a continuous task that requires rethinking and rescheduling, even after the process has begun.

The planning problem begins with the complex nature of oil and gas refineries — more specifically, the vast amount of data streams being fed into the ERP or EAM system. These data streams can come from various platforms such as Microsoft Excel spreadsheets, database programs or third-party software.

To control the overall shutdown and turnaround process, many refineries also run a number of separate IT systems that are not integrated or aligned. This makes it difficult to control and report on project deliverables — from engineering specifications to commissioning, all of which must include health and safety and risk perspectives.

Establishing an overall "single point of truth" to plan a shutdown or turnaround becomes challenging when data exists in varying formats and comes from different IT systems. This disjointed data feedback can derail planning efforts, resulting in a longer lead time ahead of any shutdown and turnaround. ERP and EAM systems must be able to integrate all this data to provide the information necessary to plan effectively and accommodate complexities.

WORKFORCE LOGISTICS

One such complexity is workforce scheduling and management. Planning shutdowns and turnarounds requires coordinating thousands of people inside and outside refinery walls. This includes arranging for external contractors who come with their own work schedule requirements and roadmaps. These external requirements can affect the refinery's internal staff.

Refinery planners need to project how many people are required to complete a shutdown and turnaround in a set-time period, but this depends on many workforce factors that

range from suitability to availability. They need to consolidate data from contractors, multiple systems and applications to get an accurate, single point of truth. This data can be fed into the project program, further consolidating progress, cost and changes to measure against an execution plan.

THE PRESSURE COOKER EFFECT

The scope of a shutdown and turnaround can become stressed in the window before execution because demands may conflict as everyone tries to optimize that time period. Many subcontractors and refinery personnel want to maximize the window of opportunity and are working to tight deadlines. However, they have different agendas, which can create a pressure cooker situation. Using appropriate software can minimize conflicts and help to release that pressure.

A POSSIBLE PANDORA'S BOX

In a shutdown and turnaround, organizations are working in a timebox, so planners determine the time frame in which to complete the work. To optimize execution, they synchronize the material, work orders and resources ahead of time and update them as necessary after the process has begun.

For example, personnel may have a work order to perform maintenance on a particular piece of machinery. The long lead times required result from the machine's complexity, so from a material point of view all possible parts and new equipment need to be procured beforehand.

During the shutdown and turnaround's execution, organizations risk opening Pandora's box on a piece of equipment. Unforeseen machinery problems can arise that require further engineering expertise or even new health and safety considerations. This generates subsequent work orders that need to be scheduled, resulting in shutdown and turnaround process repercussions.

The complexity of all this revised data being fed back and forth between fragmented IT systems makes it difficult to provide a planner with a real-time point of truth during execution.

All these factors carry the threat of extremely high revenue loss resulting from inefficiency during the time the refinery spends offstream. Add to this third-party contractors who may introduce their own roadmaps and systems, not aligned with the refinery planner's, and integrating these fragmented systems can become complex and costly.

CURRENT IT SYSTEM LIMITATIONS

Some refineries are integrating third-party tools and existing ERP and EAM software to plan shutdown and turnarounds, while other organizations are using simple project planning tools.

The issue with these tools is that they are static project planning tools — long lists that can become outdated before they are used. Unanticipated problems routinely are found during machinery maintenance, for example, causing delays and requiring new calculations to the planner's original schedule. Starting with an incorrect picture of the shutdown's planning stages will exacerbate its execution as problems arise and plans deviate.

The maintenance plan might be located in a Microsoft Excel or Primavera document, while purchasing orders and inventory are handled in the ERP system. Companies now are relying on printouts and planners' brain power to coordinate changes, paving the way for potential errors and delays.

Nothing is definite in the lead-up to and execution of a shutdown or turnaround. Basic project planning tools or integrations struggle to cope with this changing environment once begun, leading to inefficiency and dollars lost.

The project execution method with integrated third-party systems can be cumbersome and document-driven and does not take advantage of newer, database-driven techniques and data-sharing. It provides no real tool to synchronize project work and pre- and post-maintenance work.

Refinery planners need a system that supports them during both the planning and execution phase of a shutdown or turnaround. These systems need the agility to adapt and

replan to minimize downtime caused by unexpected changes to the existing schedule.

OPERATIONAL PLANNING TOOLS

Operational planning tools have been developed specifically to assist companies in optimizing shutdown and turnaround processes by helping to bridge the planning and execution stages.

These tools analyze key variables such as equipment structure; work orders; preventive maintenance plans; and the availability of staff, materials and tools to produce an optimal plan for a shutdown or turnaround. When linked with other applications, the tools may identify potentially critical situations requiring action and enable planners to produce work orders that can be executed immediately with the resources available. They may visualize planned downtime together with planned maintenance and allow for the sourcing of staff, materials and equipment necessary for specialized maintenance activities well-ahead of execution.

MINIMIZING DOWNTIME UPS PROFITABILITY

Planners carry out their jobs in a pressurized and dynamic environment. Profitability depends on minimizing downtime — outages need to be as brief as possible and managed carefully.

These tools help to enhance the planning and execution process by uniting all the variables into a single system, making it easier to respond to changes in the shutdown or turnaround process and to identify potential roadblocks.

INCREASED "WRENCH TIME"

Operators aspire to high levels of "wrench time," the amount of time that maintenance personnel spend carrying out maintenance tasks as opposed to chasing materials and equipment. It's not uncommon for personnel to be issued with a work order, only to find that the materials needed are not in stock or on-site. Operational planning tools help to ensure that work orders are not issued without the necessary materials and resources at hand, enabling maintenance engineers to complete their assigned tasks.

Increased wrench time means more proactive and efficient maintenance during day-to-day refinery operations, which can translate into engineers spending less time turning around equipment. Keeping equipment well-maintained during operations limits the time refineries spend offstream.

REFINING FUTURE SHUTDOWNS AND TURNAROUNDS

Falling oil prices require oil and gas companies to increase efficiency, reduce operation costs and maintain quality services. Savings must be found by optimizing existing processes, particularly the costly offstream period associated with a shutdown and turnaround.

A new generation of software that bridges both planning and execution, that integrates planning and asset management and that gathers variables into a single solution makes it easier for planners to manage and adapt in a dynamic execution environment.

Such software allows planners to respond to changing maintenance tasks in real-time, working around delays or faulty parts. It can save refineries money by streamlining a shutdown and turnaround, enabling operations to begin again as quickly as possible.

Looking further forward, this new breed of integrated software will enable a more proactive approach to maintenance while refineries are operational—reducing the amount of maintenance required during the shutdown and turnaround process in the long term.

All this feeds back into increased wrench time and greater efficiency. Getting operations back up to speed as quickly as possible is paramount. Refinery planners need software that supports them before, during and after a shutdown or turnaround so they don't have to face that costly bill of $10 million a day.

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Take the Guesswork Out of Corporate Safety

Several key elements help drive long-term success of world-class safety programs

By John Doswell, RedGuard

SAFETY CAN often mean different things to different people. Even within the same company, one person's opinion on what's considered "safe" may prove to be completely different from that of the person they work beside each and every day. To ensure that everyone is always on the same page, it's important that companies institute an in-depth safety program that will develop common beliefs and supports a culture that — above all — values the well-being of everyone who steps foot within the operation.

Companies that strive for and have world-class safety programs share several common beliefs that drive their continuous success long term. Some of the most important elements are:

- They have an exceptional desire and expectation company-wide to always exceed compliance in all areas of their business, i.e., OSHA, EPA, Quality/ISO, etc.
- They are passionate about maintaining and growing their core culture to ensure future success and make their company great.
- They are both committed and engaged from top to bottom in their safety program.
- They practice and live their safety program at work with their employees, at home with their families and on the road to keep everyone safe.

This is far from a complete list of success factors for any company, but to become one of the best and safest companies, each employee must embrace and practice each of these qualities. It is truly up to each employee to have the desire, expectation, passion, commitment and engagement for safety.

At RedGuard, safety is the first element of our culture and plays a role in each of our core values of courageous character, entrepreneurial spirit, pride in our work and esprit de corps. This means that we believe that a truly comprehensive safety program, one that will provide an organization with the best opportunity for long-term success, should promote the following:

1. An understanding that safety starts with the individual's behavior and acknowledgement of how their state of mind can lead to a critical error.
2. A common language that's used among all employees to eliminate communication barriers and help us analyze mistakes and near misses.
3. Employee-to-employee and manager-to-employee conversations about their state of mind and unsafe behaviors, conducted without judgment or fear of discipline.
4. Employee empowerment to act and initiate corrective action.

5. Regular communication through individual discussions, group meetings and print and digital materials.
6. A full integration of safe practices that extends beyond the areas of production, service and maintenance into areas traditionally seen as less dangerous (accounting, human relations, etc.).
7. A sense of personal accountability.
8. Situational awareness while driving, walking and performing other routine tasks.

The most important aspect of any safety program comes down to its implementation. It's one thing to have a program in place and it's another to actually use it. A program like the one mentioned above isn't something that employees can just attend a presentation on or skim through a manual and automatically "get." It's something that has to be practiced to be fully integrated into everything they do. Once it is, employees will have a complete understanding and accountability of the work they do, a greater respect for the importance of exercising good personal judgment, an ongoing consideration for the people who depend on them (family, friends and coworkers) and a constant reminder that one risky action could mean an accident from which they might never recover.

Because statistics prove that most injuries occur away from work, it's important to note that the benefits of such a program don't end once an employee clocks out for the day. They are tools that employees can carry with them into all aspects of their lives and share with family and friends. Armed with the right information and regular daily practice, these people will be less likely to make the same mistakes they've made in the past and more likely to pause and consider their state of mind ("Am I rushing, frustrated, fatigued or complacent?") to avoid a critical error.

Employees are the backbone of every successful company — if they're hurt, the entire operation suffers. But beyond that, the people we work with are our friends and our family and it's important that we look out for them, take care of them and provide them with a safe environment in which we can all thrive. This is what our safety culture is all about: Nobody gets hurt … here, home or on the road.

JOHN DOSWELL is director of safety and quality at Wichita, Kansas-based RedGuard. He can be reached at jdoswell@redguard.com.

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Improve Vacuum Tower Performance

Advanced temperature measurements can help increase yield and product quality

By Robert Torgerson, WIKA-Gayesco

VACUUM TOWER revamps and internal upgrades can improve the yield and product quality of vacuum distillation units (VDU) — a must in today's competitive markets. These modifications, though, require a considerable influx of capital. Improvements in cross-sectional tower temperature measurements allow evaluating the effectiveness of the tower's original internals, verifying yield and product quality, and helping to decide if an upgrade is financially justified.

However, even new process equipment doesn't reduce the need for careful operational control and accurate field measurement of parameters to ensure optimal conditions. Proper operation of VDUs will increase their lifetime, minimize shutdowns and downtime, and protect the big investment associated with this type of implementation.

To improve yield and quality product, modern designs for tower internals emphasize even distribution of the vapor feed and elimination of liquid entrainment, the undesirable liquid that forms from residue droplets and resists separation from the vapor feed as it rises in the vacuum tower.

Well-planned VDU revamps now include low-cost, high-value field instrumentation such as advanced, flexible, temperature measurement systems above the wash oil distributor to detect and control wash bed coke formation and identify rogue residue entrainment approaching the heavy vacuum gas oil (HVGO) draw-off. These relatively inexpensive additions ensure that the vacuum tower works effectively and that unnecessary shutdowns are avoided.

THE SYSTEM

The feedstock to the vacuum tower/vacuum distillation column is a superheated, two-phase stream coming from the bottom ends of the atmospheric crude distillation column. Upon entry into the vacuum tower, the feed separates into a rising vapor stream and a falling liquid stream. The rising vapor stream is separated into two or three vacuum gas oil cuts that feed downstream catalytic conversion units. The falling liquid stream, or residue, contains measurable amounts of nickel and vanadium metals along with hydrogen-deficient molecules, Conradson Carbon Residue, or CCR. During the separation of the two-phase vacuum tower feed, a portion of the liquid residue doesn't fully separate from the vapor and rises along with the vapor stream. This entrained, contaminated stream, if allowed to reach the first HVGO draw-off, will have poisonous effects on the catalysts of downstream conversion units.

Vacuum towers have a vapor distribution system consisting basically of a distributor and a wash bed and wash oil distributor that enhance feed vapor distribution and help eliminate liquid residue entrainment from the passing vapor stream. This distribution system is the primary defense against entrained residue liquids reaching the HVGO draw-off.

The wash bed, comprised of a packing set below a wash oil distributor, is below the HVGO draw-off. The wash bed packing provides significant surface area for the vapor to pass along and deposit the entrained residue. As long as the packing maintains a proper level of wetness, it will de-entrain effectively, helping prevent coke formation caused by dry out from the passing vapor. The packing is wetted by a cool stream of wash oil reflux moving downward against the vapor flow and distributed over the wash bed packing. The cool reflux facilitates condensing and separation of the entrainment while allowing the super-heated vapor to continue its rise through the column.

COKE FORMATION

The wash bed packing must keep a proper level of wetness to de-entrain correctly and avoid coke formation. A cool wash oil reflux is introduced above the wash bed through a wash oil distributor to facilitate condensation of the rising vapor stream and to maintain the minimum level of liquid on the packing. If the rate of wash oil distributed over the wash bed is too high, the wash bed risks condensing both the entrainment and significant portions of the vapor stream intended to condense later in more elevated sections of the vacuum tower. Such "over condensation" reduces the VGO product quantity leaving the wash bed. On the other hand, if the rate of wash oil reflux is too low, the super-heated vapor overpowers the cooling effect of the cool wash oil, creating dry outs at locations where the wash oil wetting is below proper levels. Once a section of the packing is dry, condensed entrainment droplets can quickly form coke on the wash bed packing.

Coke formation attracts and redirects vapor flow to the coked region, creating localized, above average flow rates of the super-heated vapor and liquid entrainment to the already dry and coked section. Such process not only exacerbates coke formation in certain areas but also disturbs vapor distribution and can reduce the efficiency of the downstream fractions in the top parts of the vacuum tower. As the distribution worsens, the vapor flow rate increases to a point when the wash bed can no longer de-entrain the liquid contaminants, which then bypass the wash bed and enter into the HVGO draw-off pool. This maldistribution continues past the wash bed/wash oil distributor. An uneven distribution of the vapor flow causes an uneven temperature differential across the cross section above the wash oil distributor.

Coke formation, if not properly controlled, escalates and will require the shutdown of the vacuum tower, affecting downstream conversion units and causing downtime and associated financial losses. This series of events can occur over an extended period of time or quite rapidly, but they can be prevented.

DETECTING MALDISTRIBUTION

Early knowledge of maldistribution of vapor flow above the wash bed allows changing wash oil feed rates and vapor feed rates into the vacuum tower and controlling coke formation.

If the vacuum tower operator can measure the trending temperature differential (delta-T or ΔT) at different points of given cross-sectional areas above the wash oil distributor, the operator can detect maldistribution of the vapor through the wash bed caused by coke formation. Using this early warning sign, the operator can then make adjustments and modify wash oil and other feed rates into the vacuum tower, effectively preventing coke formation and poor de-entrainment. When designed and installed properly, an advanced temperature measurement system is a reliable tool for identifying differential temperatures with certainty, allowing adjusting the wash oil feed rate as necessary, based on analysis of the trending data over an established period of time.

Measurement of cross-sectional temperature differentials in high-temperature refining, petrochemical, and chemical applications is best accomplished with a flexible multi-sensor temperature measurement system.

An advanced temperature measurement technology, flexible multi-sensor systems support optimal operation of the unit by permitting as many as 45 measuring points to be inserted at specific locations along an elevation/cross sectional area through a single DIN-75 (3-in.) nozzle.

With proper installation of a flexible multiple sensor system above the wash bed, operators can take advantage of the relationships between coke formation, maldistribution of vapor flow, and differential temperature trends to control certain aspects within the vacuum tower. They can then modify wash oil rates, preventing potential reductions in yield and product quality, ensuring the VDU works under optimal conditions and protecting your investment.

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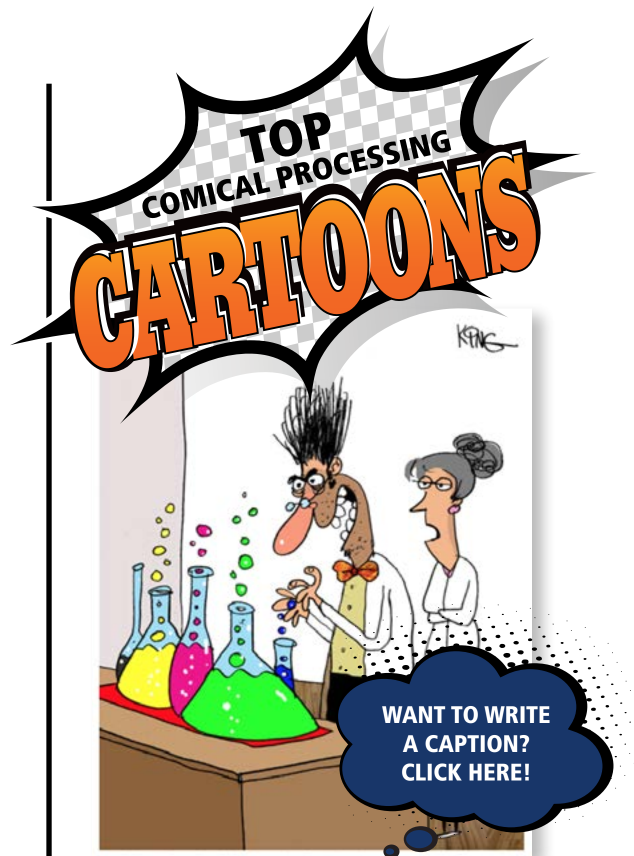

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