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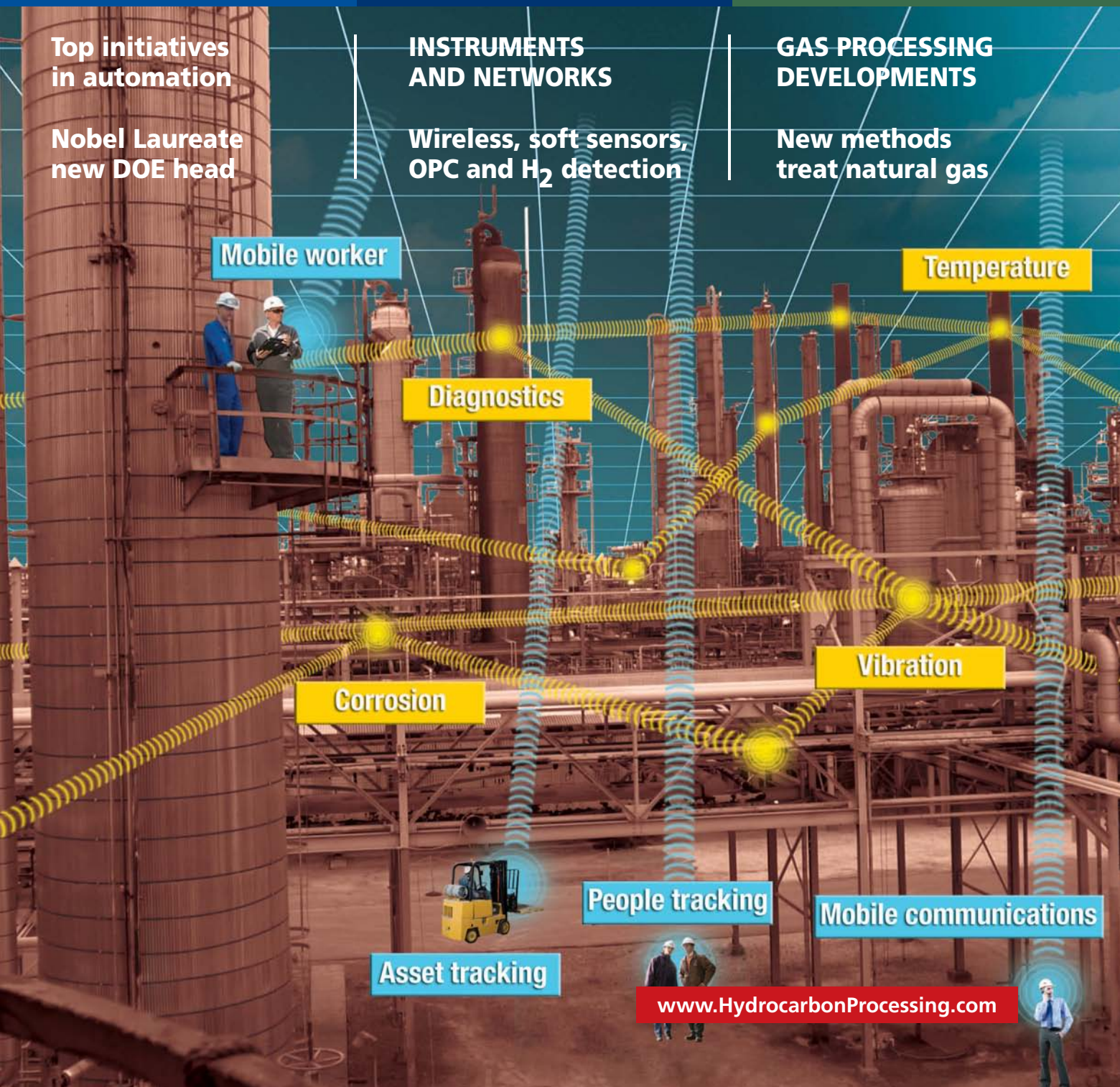
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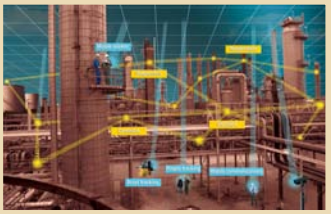
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Cover Illustration courtesy of Emerson Process Management. See related article, "Wireless networks improve refinery operation," page 29.

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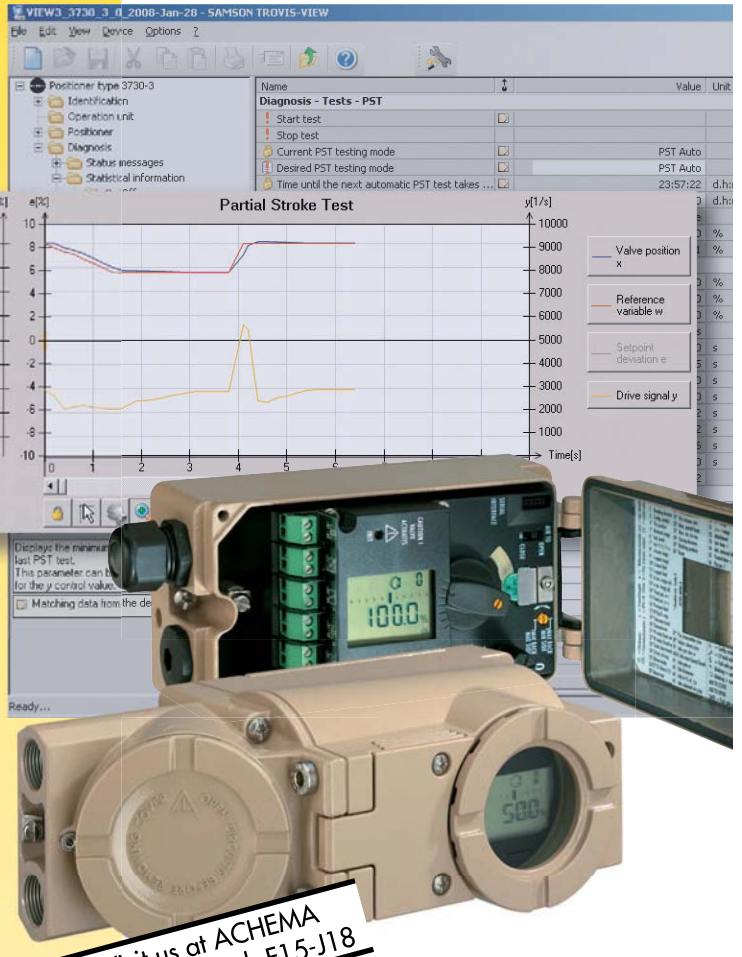
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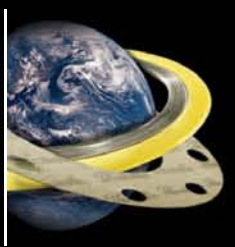


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WENDY WEIRAUCH, MANAGING EDITOR

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Report monitors Canadian oil sands projects. The recent unprecedented shifts in crude oil's price and the weakening global economy is impacting smaller companies proposing oil sands projects. "When we couple the weak economy and volatile price of oil with continued rising costs for oil sands operators, the margins for greenfield producers are shrinking," says a new study from the Canadian Energy Research Institute (www.cera.ca). Margins for producers are being absorbed by continued cost increases, much of which is due to professional and skilled labor, materials and equipment, and greenhouse gas emissions costs. Under present economic conditions, global oil prices need to be closer to C$90 WTI to support new proto-typical oil sands projects over the next 30 years, according to this analysis.

North American LNG imports are set to rise, according to one recent analysis. In light of recent history, and the longer term outlook for growth in domestic US shale gas, many industry commentators and analysts are suggesting that the outlook for LNG imports into North America is bleak. "However, while it is fair to say that regas capacity has undoubtedly been overbuilt, Wood Mackenzie believes that the medium-term outlook for LNG in North America is not as dire as other commentators are suggesting," says a company study (www.woodmacresearch.com). The new forecast projects growth for LNG imports into North America from 2009 to 2014. Wood Mackenzie predicts that the medium-term outlook for LNG in North America is that LNG imports will increase from 1.7 Bcfd in 2009 to 4.2 Bcfd in 2014.

How will new US administration influence energy stocks? Analysts with Casey Research have examined potential policies that Washington could implement and how these might affect a particular industry sector. "A bull market will come for the traditional energies in the long run; the problem lies in the shorter term, in the instability of America's energy portfolio," says this investment viewpoint. The coal industry could be in for a hard time under President Obama. His proposed tough 100% cap-and-trade system will make coal plants uneconomical to run. "As natural gas is already one of the cheapest power technologies available, the industry would weather a cap-and-trade system better than coal," according to this research.

US demand for specialty additives used in gasoline and other fuels is forecast to increase 2.9%/yr to $1.3 billion in 2012. Above-average growth for deposit control agents—the largest segment of fuel additives—will continue to support the market, according to a new study from The Freedonia Group, Inc. Regulations are forecast to boost demand for cold-flow improvers, which are necessary to increase the performance of ULSD and biodiesel in colder climates. Corrosion inhibitors are also expected to show steady growth through 2012 as these additives are needed to counteract the effects of higher oxygenate levels in fuel. Corrosion inhibitors and additives used in diesel fuel, such as cold-flow improvers, will show the fastest growth, says this report.

Maintaining capital project competitiveness in a slow economy. Over the past three to four years, the engineering and construction industry has struggled with how to get a massive number of complex domestic and international projects completed safely, on time and within budget while providing quality deliverables. The single most influential negative aspect of projects during this time (as defined by benchmarking from CII, IPA, ECC and others) was the lack of skilled resources at all levels—within both the owner and contractor organizations. "Many economic forecasts indicate that the capital project industry will be down for approximately two to three years and then jump to levels similar to 2006–2008," according to Stephen L. Cabano, president of Pathfinder LLC, a project management consultancy. He cautions that the industry would be best served by investing in training and mentorship to ensure that project teams have the skill sets and tools for addressing the challenges of 2010 and beyond. HP

Multinational oil perspectives

There is a "renewed need to react" to supplying global demand when worldwide economies pick up, said Jesus Reyes Heroles, director general of Pemex. He presented his views at the CERAWeek conference, held recently in Houston. Pemex is committed to increasing Mexico's refining capacity and avoiding engaging in "stop and go" behavior on project investments.

Mr. Heroles said that his company is searching for new "modalities" to cooperate with other national and international oil companies. He also stressed the urgency in retaining valuable human resources so as to counter the past few years' critical workforce shortages.

Jiping Zhou, vice president of China National Petroleum Corp. and president of PetroChina Co. Ltd., gave his perspective on the state of the industry to the conference attendees. He noted that the long-term fundamentals for product supply and demand have not changed by the present global slowdown. Calling this a "temporary difficult time," he projected an upswing in his country's economic activity in late 2009. His company intends to maintain its "moderate increase" of industry investment.

Tony Hayward, group chief executive of BP, in his address, stressed the importance of looking through the here and now to the longer term of improved economic activity and, consequently, heavier global oil and product demand. "The future is not canceled," despite present dreary business headlines, he affirmed. His company's business strategists are operating under the "important reality" that 80% of the world's energy will be coming from fossil fuels in 2030.

Mr. Hayward supports a cap-and-trade system for lowering emissions, and also emphasized the importance of a step-change in energy R&D investments. HP

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HEINZ P. BLOCH, RELIABILITY/EQUIPMENT EDITOR

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Unreliability, global procurement and you

Allow us to suggest that you engage in a "reality check" on the subject of equipment unreliability, global procurement and your own role in the matter. Please examine, realistically and objectively, the direction in which much of industry seems headed. Then, take action if the danger signs we bring to your attention pertain to you.

To begin with, we hope that your contributions to the safety, profitability and sound utilization of the employer's (or shareholder's) assets are highly valued. However, if you have decided or are being asked to keep your reliability concerns to yourself, it may be time to readjust your thinking. We believe a true reliability professional must let others know about valid concerns and must then take discrete steps to have these reliability and uptime issues properly addressed and resolved.

Suppose you are consistently making solid contributions and these are neither valued nor acknowledged. In that case you might consider updating your resume and seek work at a location where experienced reliability engineers are in demand. On the other hand, start with an honest appraisal of the real value of your own contributions. Acknowledge that there is room for improvement with every human being. Are you having a positive influence on others? Are you really adding value to the enterprise every step of the way?

For example, it would make little sense if you were to confine your contribution to telling management that you're "concerned" that synthetic lubricants might be incompatible with certain paints, or if you merely challenged the recommendation that synthetics should be put into your cooling tower gearboxes. If you were to voice similar "concerns" on about two-dozen other peripheral issues you will have added no value and will have nudged your employer closer to becoming a second-tier, low-profitability company. Instead, follow up on your concerns and establish whether or not these are justified. Along these lines, and as an example, it should take you no more than 10 minutes to ascertain that the synthetic gear oil under consideration really only attacks acrylic house paint, and that your gearbox interiors are painted with a highly stable epoxy paint not prone to those attacks. In researching the matter, you might uncover that most of your competitors have, for decades, used one of the synthetics being considered, and that their cooling tower fan gears have accrued an average life of 20 years. So, understand the life cycle cost implications and become an advocate of change instead of a skeptic voicing unspecified or vague concerns passed down by word-of-mouth.

Living with global procurement. If your company is presently involved in global procurement of critical machine components, take note of a few very important facts and draw the right conclusions. Global procurement often implies buying from the lowest bidder or from parties that offer rapid delivery. If your company favors this simple version of a global procurement approach and includes certain OEM parts (such as compressor bearings and seals) in global procurement, here's why you should brace for potentially very serious trouble.

The dimensional and material property-related accuracy of spare parts that have an impact on the plant's safety and reliability must comply with rigorous specifications and quality control. Therefore, start by identifying the approximately 5 to 7% of parts and components in your critical machinery that have such reliability impact and assume your manager will be pleased with your doing this identifying. Next, take tangible remedial steps. Alert others to the urgency of only consenting to global purchasing of these parts after appending or invoking rigorous specifications and quality control.

Unless proven otherwise, you should assume that the lowest bidder utilizes neither quality control nor exacting specifications. Perhaps this explains why it is the lowest bidder. You must provide and sometimes personally write a specification for these critical parts. Once critical spare parts (even the ones originating from vendors accepting your specifications and professing to have quality control) are delivered to your facility, the job is far from finished. You must add value by personally verifying the full specification compliance of these parts. Alternatively, take responsibility by arranging for competent inspectors that verify specification compliance of the critical spare parts received. These parts should be accepted by the storeroom clerk only after compliance has been verified. The clerk can then proceed to tag and preserve the parts for future use.

Understand your role and carry out your duties. The role of a true reliability professional has been spelled out in many books and articles. A professional is not just "a pair of hands." The ones that have become top contributors in their area of expertise participate in reliability audits, engage in structured root-cause failure analyses that culminate in eliminating repeat failures, develop repair specifications and condemnation limits, i.e., parameters beyond which parts can no longer be repaired, assemble work processes and procedures to match best-of-class competition, perform life cycle cost analyses and propose training plans for themselves and future reliability engineers. It would seem logical that reliability professionals become familiar with how their best-of-class colleagues function in these roles and have been able to keep their jobs in good times and in bad times. HP

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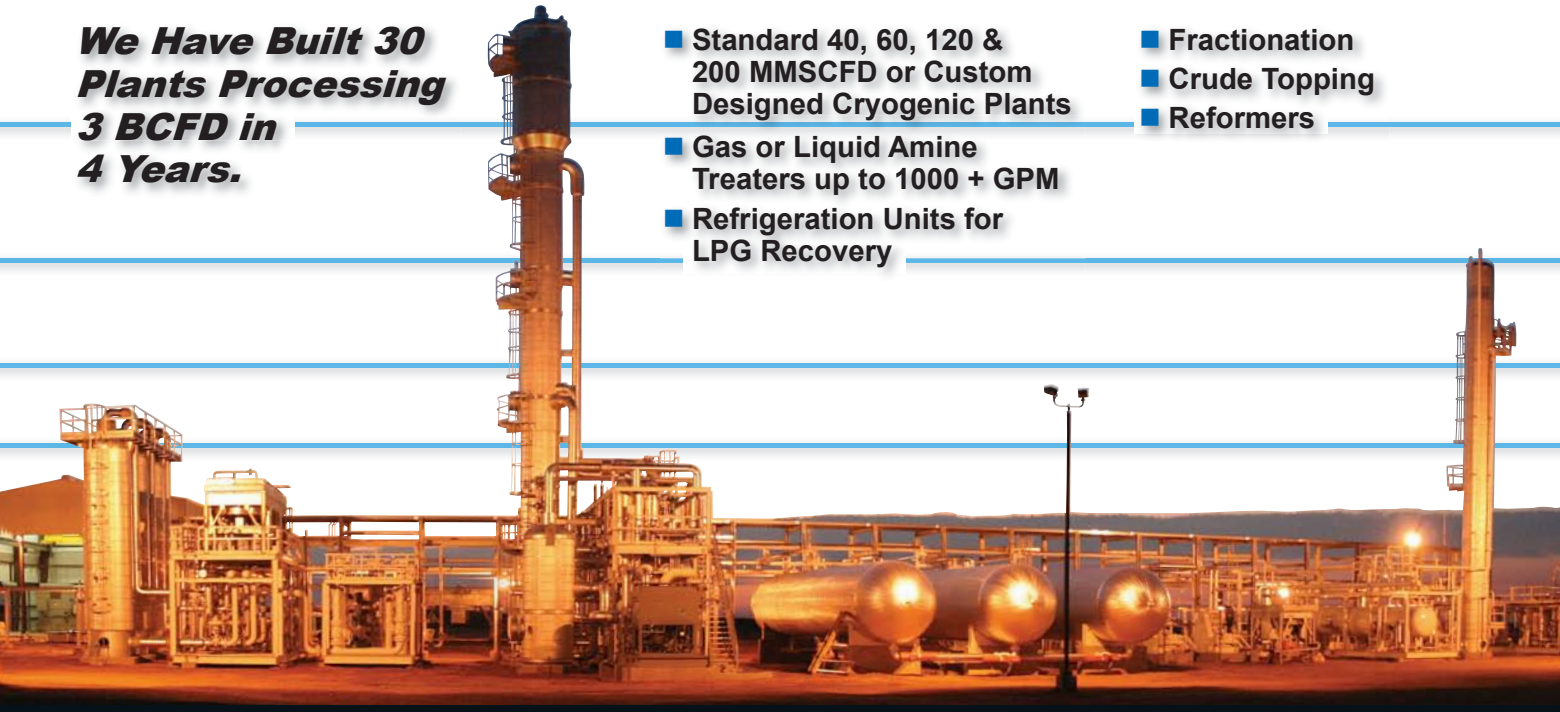
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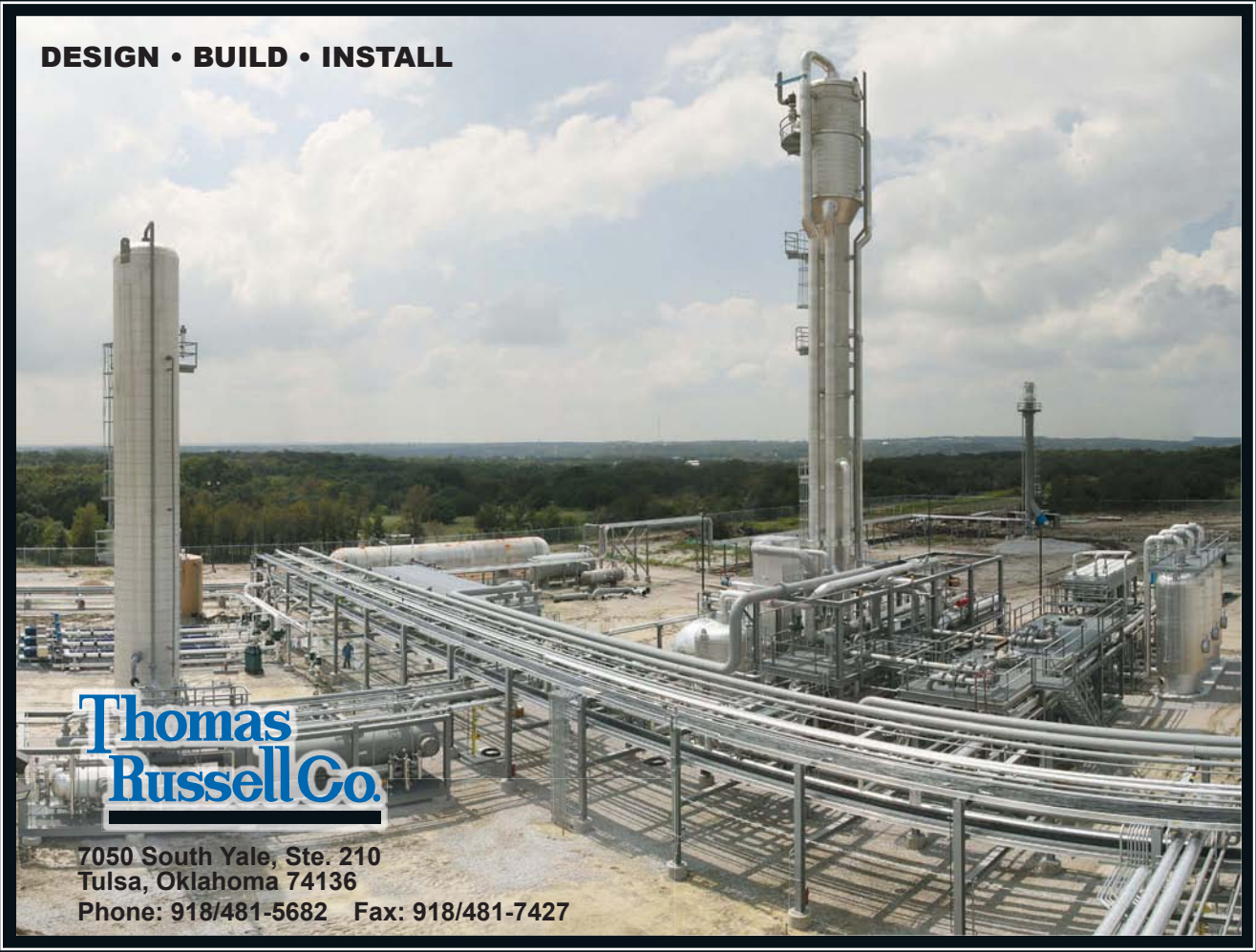
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TIM LLOYD WRIGHT, EUROPEAN EDITOR

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Sacrificed to the money system: engineering workforce

Because of the shortage of an artificial commodity known as money, people who produce a real commodity known as oil will shortly be losing their livelihoods and, quite possibly, their homes.

We're used to this cycle, but does it really have to be this way? Those of us who worked in or near the oil industry through the 1990s already have the scent of what's coming. Mergers, consolidation, cost-savings and canceled projects all mean that any time soon job cuts are due in a corridor near you.

ConocoPhillips, the first of many perhaps, has announced that it is cutting 4% of its overall workforce, slashing capital spending by 18% and writing off $34 billion in assets because of falling energy prices. So, there it is, at least 1,300 job cuts on the table for starters. We're just in that part of the economic cycle.

As my six-year-old daughter Thalia would say: "Why?" She has a charming, although on occasions, somewhat testing way with the word "why." It is simply inserted at the end of each presumed answer until, if the interviewee is willing, the conversation turns to matters of principle or the nature of things more deep and fundamental than ice cream or why a third viewing of *Tom and Jerry* is not okay.

Father and daughter discourse. Alas, that such intellectual rigor isn't more common in the adult. Just *why* people in the energy industry are losing jobs is a question well worth asking.

After all, does the world no longer need energy? Are engineers and chemists, geologists, project managers and the supporting infrastructure not performing a function as critical today as last summer when a metric ton of heating oil cost in excess of $1,000, and the stuff it was made from famously hit $147/bbl?

In spite of all the warnings heard about security of supply, are we really so sure of ourselves that we can begin to dismantle the infrastructure for providing it? Of course, the knee-jerk answer is "It's the market, stupid," but I think we need to scratch deeper.

The new head of the UK's Financial Services Authority, Lord Turner, seems to think that we all should apply some of young Thalia's rigor. He says: "Across the world, there has been an intellectual failure to understand that we were building a system which has huge systemic risks."

I propose using Thalia's infinitely recurring why and a dialogue between father and child for the rest of this month's column. I'm not saying the father has all the right answers, but in common with many of us, he's put in some study since the banking system collapse began.

Pappa Tim: I can't come up and cut paper shapes with you right now. **T:** Why?

PT: I'm writing an article about people losing their jobs in the oil industry. **T:** Why?

PT: Well, the oil companies don't have enough money any more to pay them their wages. **T:** Why?

PT: Well, the companies and the consumers who are their customers don't have as much money as before, and so the price they get for what they sell is falling. **T:** Why?

PT: Companies and consumers usually borrow money to buy, build or make new things—and that uses energy—but now they can't. **T:** Why?

PT: Well, the banks aren't lending money like they used to. **T:** Why?

PT: Too many people or companies are defaulting on loans they made in the past. In a modern economy, the way to supply money for repaying loans and the interest is through the writing of new loans. **T:** Why?

PT: Well, when banks write loans, the government allows them to use that *promise of the borrower to repay* to create new money at that point. In a process that the economist J.K. Galbraith described as "so simple the mind is repelled," that's where money comes from. It enters the money supply of the nation, formerly as privately issued paper derivatives of the assets in the bank's safe. These are known as private bank checks, but today the credit of the bank is legally interchangeable by the bank with the fiat currency of the nation… the pounds, dollars or pennies we use to buy things. The borrower repays the bank and must pay interest to the lender, but that creates a shortage in the money supply. **T:** Why?

PT: The private bank checks—today just numbers typed into the borrower's bank account—are created and convertible to ordinary currency, but the interest is not created. That means the amount of loans issued and fiat currency created must always grow. **T:** Why?

PT: Without more and more borrowing, there won't be enough money generally available for the repayment of the interest on the loans. A growing proportion of the borrowers, represented in economics by the formula $I/(P+I)$, will be foreclosed by the bank, transferring their assets to the bank. **T:** Why?

PT: Well, to cater for the repayment of the interest, there must be continuous, exponential growth in the economy so that new loans are taken and money is created. Recently, this borrowing has had to be undertaken by governments. But if the number of foreclosures reaches a certain point, people get in a panic and stop issuing loans altogether. **T:** Why?

PT: Banks know what economist Irving Fisher knew, that banks don't lend money; they, in fact, lend "promises to supply money they do not possess." If this promise looks like it may not be met because wholesale lending is founded on bad loans, then that's a problem and the system can come crashing down, leading to a situation where there is no longer enough money to facilitate the essential functions of society—including developing and providing energy resources. And that's why people are losing their jobs. HP

The author is *HP*'s European Editor and has been active as a reporter and conference chair in the European downstream industry since 1997, before which he was a feature writer and reporter for the UK broadsheet press and BBC radio. Mr. Wright lives in Sweden and is founder of a local climate and sustainability initiative.

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A good alarm management strategy

The ISA S18.02 standard provides a much needed, standardized framework for implementing an effective and sustainable alarm management strategy in refineries, petrochemical plants and other process plants. Alarm management continues to be a serious issue for process automation end users. According to NIST, an average of $20 billion is lost in the US manufacturing industry every year due to abnormal conditions. Forty percent of these incidents can be directly attributable to human error. When you consider that alarm systems are the critical point between emerging abnormal situations and the operator action required to alleviate those situations, it becomes obvious that a refinery's alarm management strategy can have a huge impact on throughput and profitability.

Once it has been finalized, this standard has the potential to greatly reduce the number of incidents in process plants and will have a major impact on unplanned downtime and profitability.

The state of process alarm management. To date, there has been little in the way of standards activities in the area of alarm management. Certain groups, such as EEMUA and NAMUR, have outlined best practices for alarm management, but there have been no formal standards development activities. You may ask, "Why is a standard even needed?" It's needed because the overall state of the process alarming strategy at most owner/operator companies is shabby at best. There's no cost associated with adding alarms to today's DCSs. As a result, end users are swamped with alarms, only some of which require any real action to be taken. Many operators have reached the point where they spend a disproportionate amount of time dealing with alarms. The situation is only going to get worse as alarms and alerts start coming in from plant asset management systems, intelligent field devices, fieldbus-based safety systems and so on.

What is ISA S18.02? The ISA S18.02 standards development activity provides owner/operators and other end users with a blueprint for developing an effective alarm management strategy. Once it has been finalized, this standard has the potential to greatly reduce the number of incidents in process plants and will have a major impact on unplanned downtime and profitability. ISA S18.02 is directed at people who use control systems and prescribes a life cycle-based approach to managing alarms. It guides end users through the whole process of establishing a life cycle program where alarms are set up and rationalized in a consistent way and reviewed for effectiveness.

ISA S18.02 does not tell automation suppliers how to design their alarm systems, but it does help them make modifications to their alarm management solutions that will allow end users to put together their own alarm management program or strategy. The next generation of alarm management solutions will provide more metrics, offer improved identification of alarm floods and provide easier hooks to metrics that will allow users to access the data they need.

ISA S18.02 outlines best practices for alarm strategy development for both new and existing facilities. ISA S18.02 covers all aspects of alarm strategy development, from alarm philosophy to rationalization, detailed design, implementation, operation, maintenance, management of change, monitoring and assessment, and auditing. The standard also builds on the fine work already done by the Abnormal Situation Management Consortium (ASM), the Engineering Equipment and Materials Users Association (EEMUA) and NAMUR. To date, the EEMUA has had the closest thing to a best-practices document that can address common issues surrounding today's alarm systems. In fact, there was a formal liaison between NAMUR and the EEMUA committees when establishing the S18.02 standard.

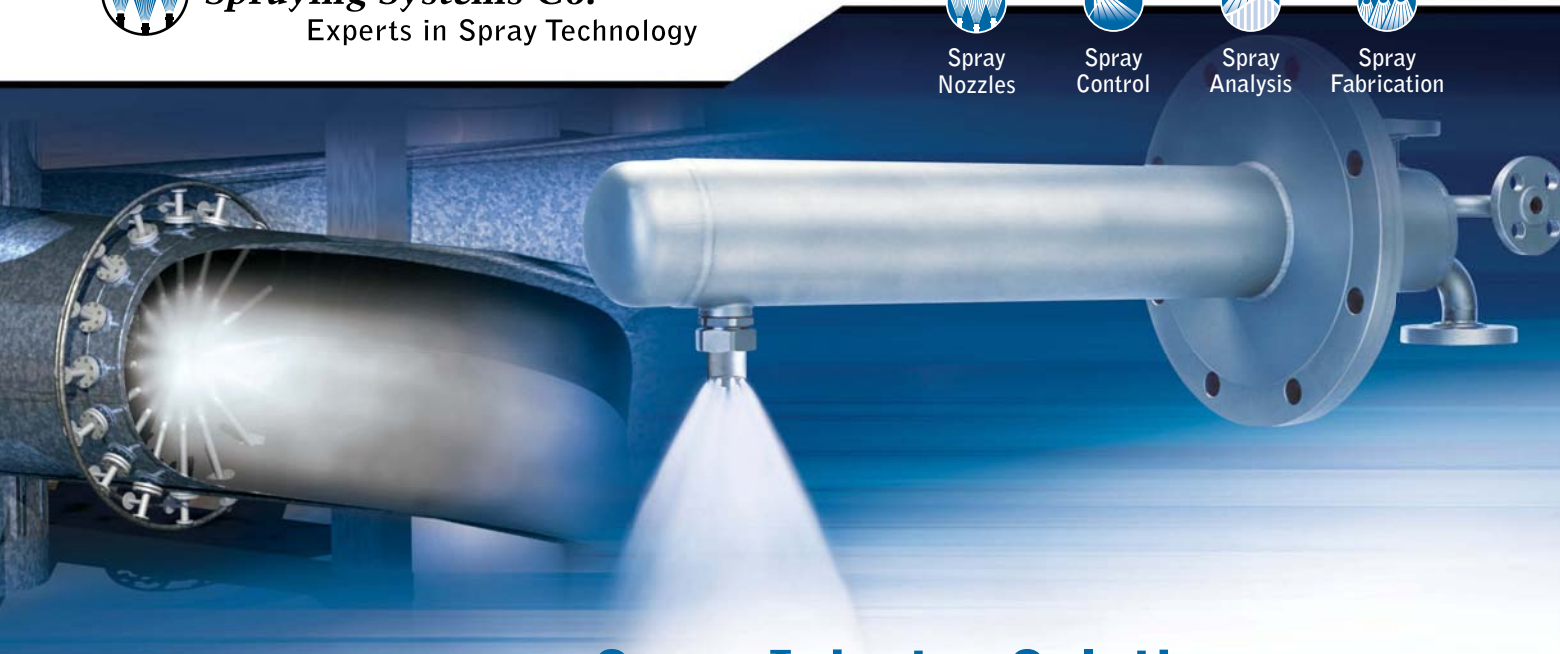
State of the standard. The ISA S18.02 standard is very close to becoming finalized. The most recent ballot results at the October 31st meetings showed that 74% of responding members approved the standard and it has been provisionally approved by the committee, pending incorporating comments. The final standard could be available by the end of the summer this year.

Adopting ISA S18.02 to measure customer methods. ARC anticipates that regulatory bodies, the insurance industry and other health, safety and environment-related concerns, such as HSE in the UK or OSHA in the US, will adopt ISA S18.02 as a basis for examining customer practices in alarm management as they relate to overall process safety and sustainability. These organizations have not yet had a standard against which to measure company performance in alarm management. Don't be surprised if your insurer comes into your plant and asks how you are managing your alarms according to the ISA S18.02 standard so your operators are not getting flooded with alarms. **HP**

The author is part of the automation consulting team at ARC covering the process industries, and an *HP* contributing editor. He is responsible for tracking the market for process automation systems (PASs) and has authored the PAS market studies for ARC since 1998. Mr. O'Brien has also authored many other market research, strategy and custom research reports on topics including process fieldbus, collaborative partnerships, total automation market trends and others. He has been with ARC since January 1993, and started his career with market research in the field instrumentation markets.

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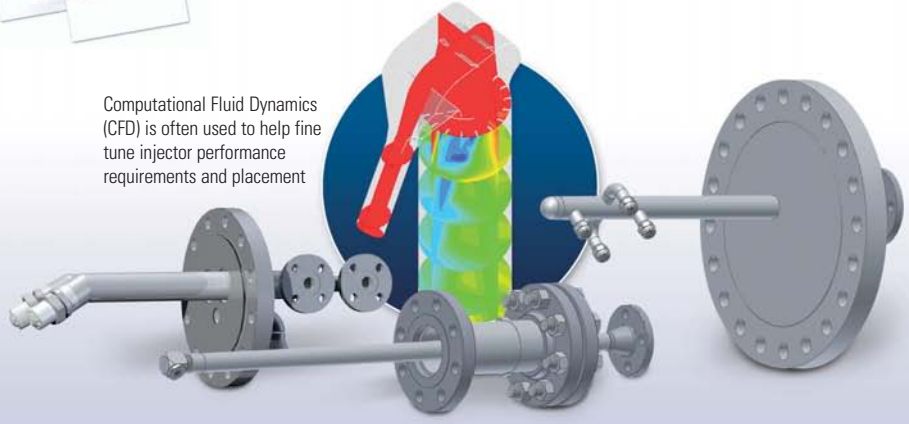


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Association news in brief

2009 Industrial Automation Safety and Security Symposium

The 2009 Industrial Automation Safety and Security Symposium will take place April 22–23 at the Marriott Houston Hobby Airport in Houston, Texas. This event is produced by the International Society of Automation (ISA). The symposium will address technical and business issues associated with identifying and mitigating safety hazards in industrial environments. Additionally, this year's symposium will include additional technical focus on cyber security threats to industrial environments and design considerations engineers must consider when designing industrial processes and safety instrumented systems. The symposium will provide an in-depth look at today's safety technologies and procedures. The event is intended to create a forum where paper presentations and panel discussions transfer information from the leaders and experts on safety and control to industry professionals.

Technical theme areas include: safety instrumented systems, alarm management, industrial security and lowering cost of capital and return on investment through safety and security projects. To register, visit www.isa.org/safetysymposium.

GPA convention seeking young professionals

The 88th annual Gas Processors Association (GPA) convention takes place March 8–11 in San Antonio, Texas. Any midstream young professionals that will be at the convention are encouraged to participate in an event called "Fueling Your Future." The event features a special discussion with John Gibson, CEO of ONEOK. Following Mr. Gibson's remarks will be a panel of industry experts ready to field questions about career opportunities and options. The panelists are expected to be long time veterans of the gas processing industry and should have the ability to answer any questions proffered, no matter how technical or far-fetched. The GPA believes this event will combine two crucial facets to any successful gathering—a learning component and networking opportunities. Following the panel discussion, there will be a dinner for attendees at the Casa Rio restaurant on the Riverwalk.

Houston BMA luncheon

At the Houston Business Marketing Association (BMA) luncheon in January, three speakers delved into educational and perceptional outreach efforts from the energy industry to students, educators, members of the media, legislators and the general public.

Bill Pike spoke first, as a representative for the Society of Petroleum Engineers (SPE). He discussed the SPE's educational website, www.energy4me.org. He then described other outreach efforts, including an energy education kit for K–12 classrooms and an oil and natural gas book for students. According to Mr. Pike, SPE distributed 6,500 books in 2008 and plans on translating the book into multiple languages in 2009.

Susan Ganz, an American Petroleum Institute (API) member and marketing executive for Schlumberger, was next on the program. Her remarks were about API's education strategy. According to her, a survey from August 2007 rated the energy industry 20th out of 21 industries in serving customers. With that in mind, API developed an e-advocacy goal of bringing more balanced media coverage of the industry while also raising energy literacy levels. One element of this approach was founding a communications center to tell the industry's story, with capabilities of rapid response to correct inaccurate information. Outreach by company CEOs was also encouraged and chats were arranged with influential audiences.

Ms. Ganz said the specifics of the strategy involved 120 events in 55 markets. These events included keynotes, panels and a partnership with *Newsweek* that sometimes utilized "influencer salons." She was also proud of a touring interactive technology exhibit that has visited 20 state capitals.

The website from which much of the outreach is managed is www.energytomorrow.org. Ms. Ganz said the outreach efforts can be considered a success. After evaluating the tone of coverage and level of engagement, she thinks the media, public and lawmakers were forced to reconsider some opinions. For instance, in June 2007, the tone of monitored media stories and blog postings was 2–1 against the energy industry. By August 2008, this tone was flipped, with coverage 2–1 in favor.

Tommy Lyles, a communications manager at Chevron, concluded the program by speaking about a game his company had developed with an eye toward educating middle school and high school students about energy policy. Called "Welcome to Energyville," the game can be accessed by visiting www.willyoujoinus.com/energyville.

SPAR conference to take over Denver

SPAR's 2009 conference convenes March 30-April 1in Denver, Colorado. The focus of the conference includes 3D laser scanning, mobile surveying, asset management, CAD/GIS integration and security planning. Charles Matta, director of federal buildings and modernization for the General Services Administration (GSA), will give a keynote presentation on the GSA's use of 3D scanning for its BIM initiatives. The Shaw Group's Andy Guard will offer a case study on how his firm is using laser scanning for industrial plant applications. On the education side, there is much talk about the 3D laser scanning boot camp, which will be delivered by SPAR's advisory board.

New exhibitors at SPAR 2009 include: ClearEdge3D, CSA, IXSEA Land and Air, TechSoft 3D and Velodyne. There are also several association sponsors, including the ASTM, the American Society of Civil Engineers, CyArk, the International Association of Forensic and Security Metrology and the Society of Piping Engineers and Designers. HP



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Networking, alarm management, security among top initiatives

ISA recently conducted an online survey to find out what automation industry observers and practitioners felt that near-term trends were going to be.

When survey participants were asked which technology their facility would rely on for 2009, the top choice was networking at 21%. "With wireless being the rage throughout the industry, you would think it would score higher, but alarm management was second at 15% and predictive maintenance and security third at 14%," says Gregory Hale, editor of ISA's *In Tech* magazine. Wireless's rank was 13%, and enterprise interoperability came in at 7% (Fig. 1).

Down the road though, the future looks brighter for wireless. About 22% of those responding to the survey said that wireless would be the technology industry users will adopt over the next five years. Asset management was second at 15%, while networking and predictive maintenance scored at 14%. Alarm management and security came in at 12%, while enterprise interoperability had 10%.

Regarding communication, in a turnaround from last year, 53% of respondents said the plant floor is currently able to communicate data through the enterprise to the executive suite, while 47% said they did not. That is the opposite from last year. In 2008, 47% said they could communicate, while 53% said they did not.

At his refinery, Peter Mitchell, process controls engineer at the ConocoPhillips Bayway refinery in Linden, New Jersey, commented that the refinery wanted all departments to be on the same page. "We are looking at advanced controls projects to integrate more of the refinery's units together," Mr. Mitchell says.

Others simply just want to understand what their equipment is telling them.

"We need to move into OPC to get more data," according to Robert Dusza, project and tech support manager at Manchester Water and Sewer in Manchester, Connecticut. "Since we buy from the lowest bidder, we can't standardize on a PLC. We have different brands, and they have their own protocols, and that becomes a headache. By implementing OPC, the data all look the same."

Business factors. When asked what they see as the biggest business challenge for the coming year, 45% of survey respondents said the recession. The next closest answer was related to the recession: profitability, which came in at 14%. Energy costs and workforce-development challenges ended up at 9%, and the aging out of the workforce came in at 7%.

"There is a lot of emphasis on controlling costs from what we are told," according to Mr. Mitchell. "We will work toward saving on energy costs. We are focused on energy cost reduction, and we will do that moving forward." Between the extra costs for a plant turnaround that the company has scheduled for this year and the economy, it will be tight times at the refinery. "We will not spend where we don't have to spend," he says.

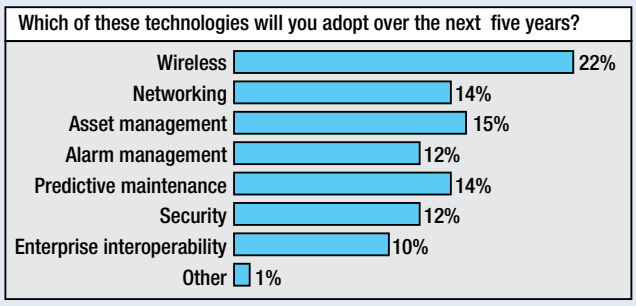
Looking through the crystal ball, respondents do not see the recession lasting; they said that the biggest business challenge over the next five years will be workforce development, followed closely by aging out of workers and profitability concerns. "Baby Boomers" leaving the industry remains an issue.

Outlook in Europe. In economic terms, the 2009 outlook for the European control and instrumentation sector seems slumping, with layoffs and project cancellations becoming widespread. "There are some bright spots, however. Several European refineries remain committed to adding biodiesel lines, and these plans have not changed," according to ISA's Cris Whetton.

Construction of stand-alone biodiesel plants is more or less at a standstill, and ethanol plants have never attracted the attention they have in the US, but biodiesel integrated with an existing refinery seems to be growing in popularity.

The big growth area is biogas—methane produced from biological waste and either used locally or injected into a national utility. This is a major growth area in Germany, Switzerland and Central Europe.

Another major growth segment is expected to be security systems. In this area, wireless solutions are in favor. "For obvious reasons, few are prepared to be specific about their plans, but as utilities continue to suffer from copper thefts, they are seeking wireless solutions, including RFID, for access control," says Mr. Whetton.



Source: ISA, *In Tech*, January 2009

FIG. 1 Automation and control professionals respond to a recent survey.



FIG. 2 A 400-ton coke drum on barge for delivery to Texas refinery.

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Coke drum delivery marks project milestone at Texas refinery

TOTAL's refinery in Port Arthur, Texas, recently achieved a significant project target: the arrival of the centerpieces for its $2.2 billion Deep Conversion Project. Four massive coke drums—considered to be the heart of the project—were delivered to the plant from Spain in late January. Each drum is 12 stories tall, 32-ft wide and weighs 404 tons.

The company invited *HP*, other media representatives and guests to observe this construction milestone.

"This project reflects our strategy of investing to enhance the efficiency and competitiveness of our large refining hubs worldwide, while at the same time reducing our environmental footprint," according to Michel Bénézit, TOTAL's president of Refining and Marketing worldwide.

The Deep Conversion Project includes a 50,000-bpd coker, a desulfurization unit, a vacuum distillation units and other related components.

The new units will increase the facility's deep-conversion capacity and expand its ability to process heavy and sour crude oil. With the upgrades, 3 million tons/yr of ultra-low-sulfur automotive diesel will be added to the refinery's production, raising total output of all products combined to about 12 million tons/yr. Project commissioning is scheduled for 2011.

The undertaking is using the latest generation of coker technology. TOTAL is adapting refining operation to meet present and future transportation fuels market. "The refiner must evolve to remain competitive," Mr. Bénézit said. This project increases the refinery's complexity and, according to Mr. Bénézit, project payback should be achieved in one year.

New units. The core project involves constructing the following new units:

- Coker (deep conversion unit)
- Vacuum distillation unit to prepare the coker feed
- Distillate hydrotreater
- Coker naphtha hydrotreater
- Hydrogen purification–PSA
- Sulfur recovery.

In addition, the power supply of the refinery will be modernized by connecting the new entity to the 230-kV network. The upgrade will use about 70,000 cubic yards of concrete—more than the quantity used to construct the Empire State Building. Also, 15,000 tons of steel and 180 miles of piping will be required.

Pace of economic decline forecast to slow in first half of 2009

The US recession deepened dramatically in the fourth quarter of 2008. However, according to one recent industry analysis, the rate of the economic contraction should slow in the first half of 2009, and economic expansion will likely resume in the second half of the year. The Conference Board, a nonprofit business and management organization, says that its forecast of a 5.9% annualized decline in real GDP in Q4 2008 reflects across-the-board weakness from the negative effect of the escalation in the credit crisis on consumer and business activity in the US and abroad.

The worsening labor market, the sharp slide in household net worth, and tighter credit standards resulted in about a 2.5% decline in real consumer spending, despite very steep and early holiday discounting and a rapid decline in the consumer price index.

External demand for US exports also dropped precipitously as the financial crisis spread globally and the economic recession deepened among major trading partners. Companies greatly reduced their inventory levels in Q4 by about $67 billion. "Inventories will continue to be a drag on growth in the first half of 2009, but since more of the inventory correction occurred in Q4 than we previously forecast, they will help limit the contraction of growth in Q1 and Q2," according to the Conference Board.

Slowing slide? Despite the considerable downside risks that exist, the fourth-quarter 2008 could mark the deepest part of the recession. This analysis suggests "a good likelihood" that the US economy will post a modest recovery by the second half of 2009. Financial market conditions are showing some signs of improvement, led by a noticeable recovery in the short-term money markets and a narrowing in investment and noninvestment grade corporate bond yields.

Significant monetary and fiscal policy easing is providing much-needed capital and bolstering confidence, though a high degree of risk aversion keeps financial conditions far from normal. At the same time, concerns about a rising deficit and government debt are mounting and will likely damper future economic growth.

"We look for just a modest recovery in real GDP of around 2.5% in the second half of 2009, as the rebalancing of personal consumption and savings will take significant time," says the Conference Board. As a consequence, a 1.7% decline in GDP growth for 2009 as a whole is forecast, which is just short of the largest contraction of 1.9% posted in 1982.

Nobel Laureate Chu selected to head US Department of Energy

During his recent Senate confirmation hearing for Secretary of the US Department of Energy (DOE), Steve Chu—an acclaimed physicist and Nobel Laureate—said that boosting development of energy-efficient technologies is a critical part of President Obama's plan to revitalize the economy and strengthen energy security.

Dr. Chu, director of Lawrence Berkeley National Laboratory, pledged to implement the new administration's goals of increasing research and development of new energy technologies, developing fuel-efficient vehicles and increasing the energy efficiency of buildings and appliances.

"We are very fortunate to have a nominee of Dr. Chu's high caliber to take on these responsibilities. He will bring to the job the keen scientific mind of a physicist and Nobel Laureate," said US Senator Jeff Bingaman (D-NM), speaking at Dr. Chu's confirmation hearing.

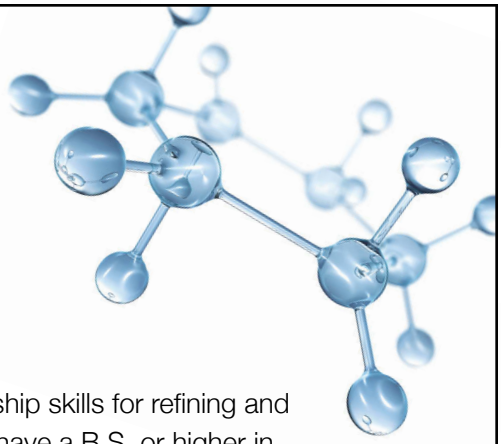
Dr. Chu was a committee member of The American Physical Society that produced the report, *Rising Above the Gathering Storm*.

"The over-arching message of that report is simple: The key to America's prosperity in the 21st century lies in our ability to nurture and grow our nation's intellectual capital, particularly in science and technology. As the largest supporter of the physical sciences in the US, the Department of Energy plays an essential role in the training, development and employment of our current and future corps of scientists and engineers."

In 1997 while at Stanford University, Dr. Chu was one of three scientists to win the Nobel Prize in physics for developing methods of cooling and trapping atoms with lasers—work that he carried out at the former AT&T Bell Laboratories.

Dr. Chu is the first Nobel Laureate to be confirmed as a Cabinet member. He succeeds Samuel W. Bodman, who held the post since January 2005. **HP**

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Regenerable SO_2 scrubbing eases environmental pressures

To manage growing strategic pressures from green fuels and environmental issues, refiners will be required to direct more attention to their refinery total sulfur balance. Non-regenerable sulfur dioxide (SO_2) scrubbing systems will increase costs as expenses for reagents such as sodium hydroxide, lime or limestone increase.

Further, tighter environmental controls will likely limit disposal of gypsum to landfill or to disposal of sodium sulfate into refinery wastewater streams. Regenerable SO_2 scrubbing systems can help ease many of the environmental and market-induced pressures that are associated with greater use of high-sulfur crude oils.

The CANSOLV SO_2 Scrubbing System, operating commercially since 2002, is claimed to be a proven regenerable amine technology that removes SO_2 from various gas streams found in refineries and petrochemical facilities. The system is regenerable—meaning that the chemical absorbent is not consumed within the process. The high costs of consumable absorbents are thus eliminated, and effluents are reduced to a minimum. Furthermore, the high capacity and selectivity of the absorbent reduce capital costs.

This patented technology uses an aqueous amine solution to achieve high-efficiency selective absorption of SO_2 from a variety of gas streams. The scrubbing byproduct is pure water—saturated SO_2 gas is recovered by steam stripping, which is low-quality heat.

The scrubbing systems have been operating in various refining units, including:

- Fluid catalytic cracking unit and fluid coker carbon monoxide boiler SO_2 scrubber
- Claus sulfur recovery unit (SRU)
- Capture-SO_2 from flue gas generated by resid-fired crude unit process heaters and utility boiler systems.

SRU tail-gas scrubbing. To manage higher sulfur loadings and process lower sulfur-content transportation fuels, revamping the refinery will require adding an SRU tail-gas cleanup system. This can also be satisfied by installing the CANSOLV SO_2 scrubber as part of the SRU expansion.

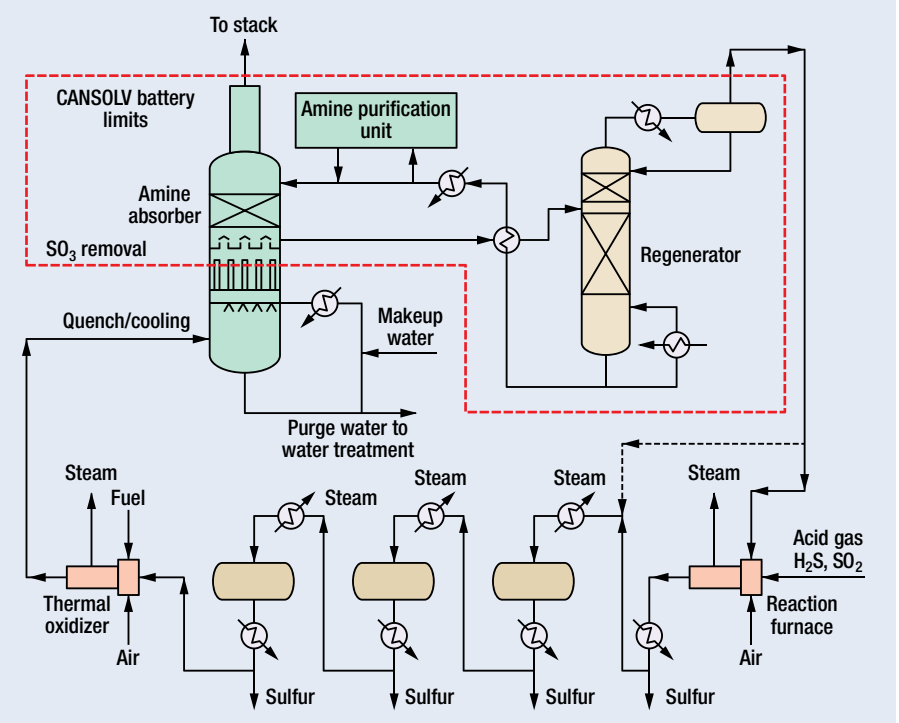


FIG. 1 SRU tail-gas cleanup unit can be integrated into an existing three-stage SRU.

Fig. 1 illustrates how the regenerable amine scrubber can be integrated into an existing three-stage SRU that is designed for 97% conversion efficiency at the end of catalyst run conditions. In this case, operating costs do not include natural gas consumption and steam production in the tail-gas thermal oxidizer.

Extensive flue gas cooling is required to chill the gas to absorber conditions and remove water formed by the Claus reaction. The prescrubbing system must purge 44 gpm, or 7.3 tons of water per ton of SO_2 captured by the tail-gas system. On an SRU basis, this translates to 0.4 tons of water per ton of sulfur directed to the pit.

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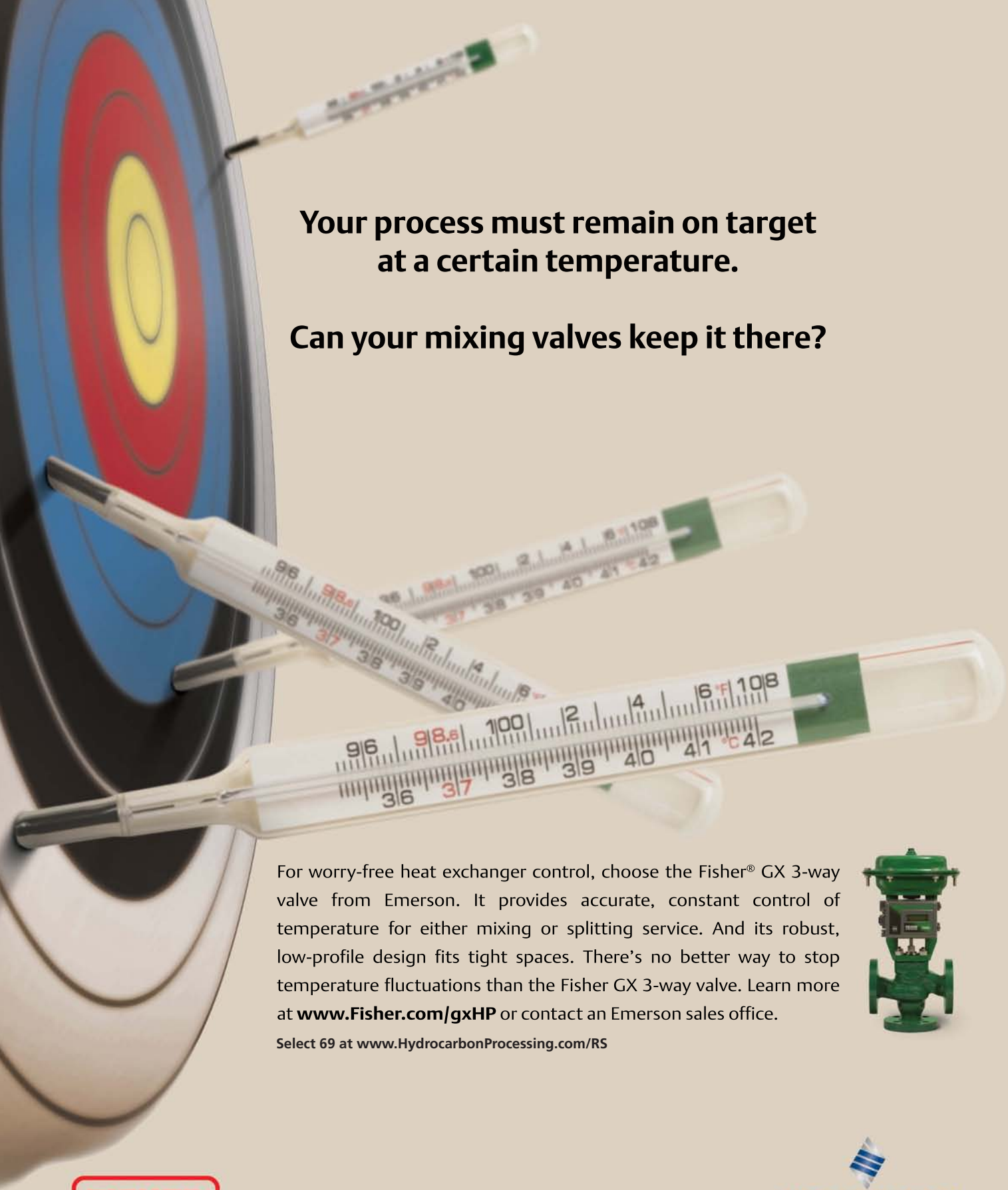
Gas analyzer sets new standard in oxygen measurement

Servomex has introduced the SERVOTOUGH Oxy oxygen gas analyzer. It is claimed to offer an exceptional range of industry-standard options and three unique, groundbreaking functions. The analyzer is expected to set new flexibility, stability and reliability standards from a single, cost-effective unit.

As well as fault and calibration histories, all units offer NAMUR-compliant relay functions, allowing two concentration alarm levels and maintenance-required service in progress, and instrument fault messages to be communicated remotely. A comprehensive Modbus protocol allows remote communication and unit interrogation as standard via RS485, as well as an option for Ethernet connectivity.

Auto-validation and auto-calibration functions allow users complete flexibility for unmanned or remote operation, or to generate maintenance and reliability schedules using trending information. Stainless-steel pipe work, automatic range change,

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- A unique flow sensor has been placed after the measurement outlet, guaranteeing accurate flow alarm settings for all uses including safety applications.
- A novel integrated pressure compensation system not only compensates for barometric pressure but also for back pressure variations from flare stacks, enabling emission compliance targets to be easily met. Both the flow sensor and pressure compensation system technologies report via the instrument's standard communication options, providing all measurement and safety benefits without the need to install additional devices and cost-hungry cabling.

Potential applications for the analyzer include usage in process control, safety critical oxidation such as ethylene and propylene oxide, flare stack analysis, product purity, feedstock cleanup and inerting or blanketing.

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Biodiesel analysis uses radial plasma view

Thermo Fisher Scientific Inc. has incorporated unique capabilities in the iCAP 6000 Series of ICP emission spectrometers to achieve dependable monitoring of elemental contaminants in biodiesel. The dedicated radial plasma view system configuration is claimed to provide enhanced analytical capabilities for important elements such as sulfur and phosphorus. Additionally, the enhanced matrix tolerance torch and swing frequency RT generator easily handle organic matrix samples and ensure improved stability.

Most biodiesel production plants use plant oils as a starting material for production. However, these plants usually have relatively high phosphorous content. This is undesirable in fuels as it can lead to corrosion of mechanical engine components. Sulfur also affects engine wear if present in excess concentrations in the starting materials and causes environmentally harmful sulfur dioxide emissions.

EN 14214 and ASTM D6751 standards have been introduced specifying the requirements for biodiesel and its analysis. These documents require that the concentrations of elemental contaminants in biodiesel be regularly monitored and specify the method for its analysis. The aim is to ensure optimum engine performance and reduce environmental impact.

Traditionally, axial-view ICPs have been the configuration choice for ICP emission spectrometers used to perform biodiesel analyses due to lower detection limits. Owing to the robust nature of its dedicated radial view plasma and the elimination of carbon-based emission interferences associated with the axial view configuration, the new spectrometer's radial view is claimed to be a powerful alternative, considerably increasing analytical sensitivity for important elements such as phosphorus and sulfur.

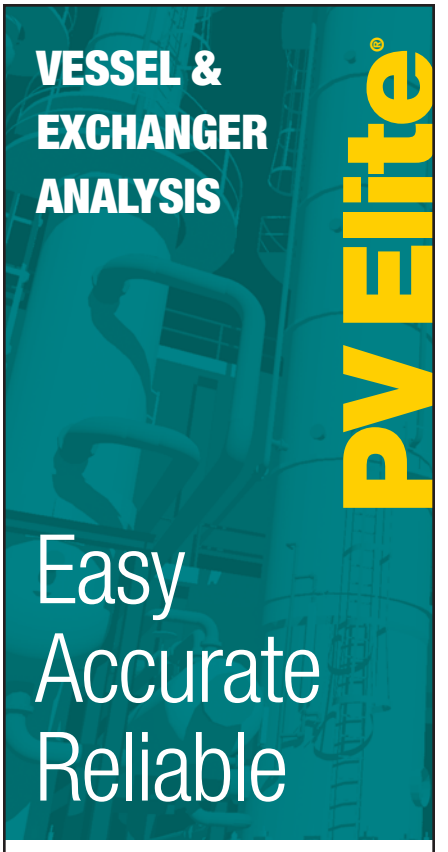
This configuration demonstrates improved detection limits for lower concentrations of samples, being capable of providing accurate, dependable phosphorus, sulfur and potassium analysis. This is a crucial benefit as, according to regulations, detection limits must be 10 times below the regulated concentration levels to provide sufficient margin for ensuring a sensitive measurement.

Other features. Additionally, the iCAP 6000 spectrometers have full wavelength coverage from 166 nm to 847 nm with full frame capability, offering full spectrum trend analysis and contamination identification between batches of biodiesel produced. Their advanced optical design enables improved resolution and detection limits.

The systems are fitted with a fourth-generation CID detector. This provides a wide dynamic range, resistance to saturation and greater detection capability. The new series incorporates fully automated wavelength calibration and offset correction capabilities for excellent long-term stability.

The instrument's distributed purge system offers reduced gas consumption and improved performance for elements such as sulfur and phosphorus that emit light in the ultraviolet spectrum region. The spectrometer's ergonomic design—with a large, wide-opening door—enables easy access to the sample compartment and peristaltic pump. This makes routine maintenance easier and faster.

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BILLY THINNES, NEWS EDITOR

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North America

Total's refinery in Port Arthur, Texas, recently added some equipment as part of an ongoing $2.2 billion upgrade. The upgrade, known as the Deep Conversion Project, includes a 50,000-bpd coker, a desulfurization unit, a vacuum distillation unit and other related units. The new units will add 3 million tpy of ultra-low-sulfur diesel to the refinery's current production. The project should be complete in 2011.

Enerkem Inc.'s plant in Westbury, Quebec, Canada, recently entered a startup phase with the production of its clean-conditioned syngas. Construction on the plant began in October 2007 and the facility was mechanically complete in December 2008. Once the facility begins production, it will produce liquid fuels and green chemicals using renewable, non-food, negative-cost feedstock, like wood from used electricity poles. Production is forecast for 1.3 million gpy of second-generation ethanol.

Praxair, Inc. has a hydrogen supply contract from **Dynamic Fuels, LLC.** Dynamic Fuels will use hydrogen supplied by Praxair to produce renewable fuels from non-food-grade animal fats produced or procured by **Tyson Foods.** Diesel and jet fuels will be produced at Dynamic Fuels' Geismar, Louisiana, production facility by using fats such as beef tallow, pork lard, chicken fat and used greases.

Dynamic Fuels' $138 million plant is currently scheduled to begin production in 2010, with a total capacity of 75 million gallons of fuel per year.

Jacobs Engineering Group Inc. has a contract from a major oil and gas company for the engineering of a thermal facility in northeast Alberta, Canada. Jacobs will perform pre-engineering design specifications (pre-EDS), EDS, detailed engineering and procurement services for the in-situ oil sands central processing facility. Engineering activities began November 2008 and Jacobs is scheduled to complete its scope in February 2011.

CB&I has a contract, valued in excess of $50 million, to design and fabricate a distillate hydrotreating unit for a North American refinery. CB&I's scope of work for the project includes the engineering, procurement and fabrication of the hydrotreating unit, which removes sulfur from diesel by utilizing a catalyst in the presence of hydrogen.

South America

INEOS Technologies has granted two polyethylene technology licenses to **Polimérica S.A.** These plants will form part of Polimérica's cracker and derivatives complex in José, Venezuela. Startup of the complex is planned for 2013.

The first of the two new facilities will be a 430,000-mty gas phase polyethylene plant using INEOS swing gas phase technology to produce linear low density polyethylene (LLDPE) and high density polyethylene (HDPE). The other will be a 400,000-mty slurry polyethylene plant using INEOS slurry technology for the production of HDPE.

Europe

Total Petrochemicals recently started up a revamped styrene unit at its petrochemicals facility in Gonfreville-l'Orcher, France. With capacity expanded by 210,000 metric tpy, the 600,000-metric tpy unit will be one of the largest in Europe. The unit's startup is part of the industrial restructuration project launched by Total Petrochemicals in France in the spring of 2007. Central to this plan, Total Petrochemicals' styrene business in Europe has been rescaled and consolidated at the Gonfreville complex, resulting in the shutdown of the Carling unit in France. This reduced overall styrene production capacity by 120,000 metric tpy.

Project capital expenditure amounted to €320 million, including €20 million to adapt the site infrastructure and improve safety and environmental standards. Due in part to its new reactors, the styrene unit's energy efficiency has increased 30%, thereby reducing carbon emissions from styrene production processes by a similar percentage.

Burckhardt Compression has an order from a refinery in northern Italy to deliver two process gas compressors for a new mild hydrocracker unit. The contract comprises two multiservice makeup process gas compressors that are equipped with a monitoring and diagnostic system and the recycle arrangement in three compression stages. The compressors will be used for the production of ultra-low-sulfur diesel and are driven by 2,500-kW electric motors. They are scheduled to be delivered in July 2009. The plant will start the production of clean diesel at the beginning of 2010.

Foster Wheeler Ltd.'s Global Power Group has been awarded a contract for a heat recovery steam generator (HRSG) by **UTE IBERESE-SOMAGUE**. The boiler will be integrated in a cogeneration plant that **Repsol** is constructing at the Sines refinery in Portugal. Foster Wheeler will design, supply and erect the HRSG, and will also provide startup supervision for the HRSG, which will be coupled to a Siemens SGT-800 combustion turbine, with a total installed ISO rating of 47 MWe (gross megawatt electric). The HRSG will produce high and low-pressure steam for the refinery process. Commercial operation of the HRSG is scheduled for the second quarter of 2010.

TREND ANALYSIS FORECASTING

Hydrocarbon Processing maintains an extensive database of historical HPI project information. Current project activity is published three times a year in the ***HPI Construction Boxscore.*** When a project is completed, it is removed from current listings and retained in a database. The database is a 35-year compilation of projects by type, operating company, licensor, engineering/constructor, location, etc. Many companies use the historical data for trending or sales forecasting.

The historical information is available in comma-delimited or Excel® and can be custom sorted to suit your needs. The cost of the sort depends on the size and complexity of the sort you request and whether a customized program must be written. You can focus on a narrow request such as the history of a particular type of project or you can obtain the entire 35-year Boxscore database, or portions thereof.

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Middle East

Invensys Process Systems (IPS) has signed a multimillion dollar contract with **Qatargas** to complete a major automation upgrade at the Qatar Gas 1 facility in Ras Laffan Industrial City, Qatar. Under the terms of the contract, IPS will upgrade control processors, gateways, local area networks and network security. The upgrade will give Qatargas improved compatibility between different generations of system components at Qatar Gas 1, as well as extend the life cycle of the overall control system there.

Saudi Aramco Mobil Refinery Co., Ltd. (SAMREF) has selected **WorleyParsons** to execute its Clean Fuels Project at Yanbu Al-Sinaiyah, Saudi Arabia. The project encompasses significant modifications to SAMREF's refinery to comply with future mandatory sulfur levels of 10 parts per million in gasoline and diesel. The phased construction project is expected to begin startup in 2013.

WorleyParsons' scope of work includes front-end engineering design (FEED) and full responsibility for engineering, procurement and construction of the facilities. Dependent on finalization of the scope of work details, WorleyParsons' services contract value could be as high as $ 400 million.

Technip has an EPC contract with **Middle East Oil Refinery** (MIDOR), estimated at approximately €43 million, for the expansion of the delayed coking unit of its refinery in Alexandria, Egypt. Engineering, procurement and supply of equipment and materials will be delivered on a lump-sum basis; construction activities will be charged on a reimbursable basis.

The delayed coking unit, based on **ConocoPhillips** technology, will have a production capacity of 30,000 bpd. It is scheduled to be delivered by the third quarter of 2010.

Asia-Pacific

LyondellBasell Industries recently started up its new polypropylene (PP) compounding facility in Nansha, China, with a nominal capacity of 15,000 tpy. The new facility is operated by **Guangzhou Basell Advanced Polyolefins Co.**, and supplies polypropylene composites and alloy materials to the automotive and appliance industries.

Black & Veatch's LNG process contributed to the development of the LNG facility in Erdos, China, which attained full production capacity of 200,000 metric tpy in December 2008. A second facility that Black & Veatch worked on, in Zhuhai City, China, has also begun commercial operation.

Four additional plants are planned in central Sichuan Province, central Shaanxi Province, northwestern Gansu Province and the northwestern Xinjiang Autonomous Region. Upon completion, the six facilities will supply a total of approximately 1.2 million tpy of LNG.

Africa

Shell Global Solutions International BV has a contract with **Oilmoz Lda** to design a refinery. Oilmoz Lda plans to build an $8 billion, 350,000 bpd oil refinery in the Maputo province of Mozambique. Shell Global will start off as technical adviser for the project and will later become technical partner. Once the refinery is completed, it will be the first in Mozambique in over 24 years. The completion date is scheduled for 2014. HP

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After the analysis was complete, KBC presented recommendations to the client, and within four months, the refiner reported that the benefits implemented and achieved amounted to USD$4.3 Million/year. KBC was also able to help the client move from the 3rd quartile to the 2nd quartile of energy efficiency among over 200 other refiners surveyed by KBC around the world.

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Wireless networks improve refinery operation

Smart instruments and secure wireless communications enable enhanced operations and asset management

G. MARTIN, Emerson Process Management, Austin, Texas

Modern wireless technology provides valuable automation options for oil refineries today—improving workforce productivity, safety and plant security. Wireless communications enable access to all assets in the refinery, including instruments, valves, controllers, equipment, cameras for safety and security, and people. Wireless mesh access points use open standards for compatibility and 128-bit encryption for security. Wireless field devices network themselves using a self-organizing mesh that automatically reroutes signals around obstructions.

The low installed cost, reliability, security and ease-of-use of the newest wireless networks are causing increased awareness of their possibilities in refineries, bringing about some innovative applications with excellent results.

Why wireless? A wireless solution eliminates "blind spots" in the plant—operation areas that have been either technically or economically unreachable with wires. While these areas are often not critical, they do play a major role in overall refinery performance and safety.

Smart wireless networks also provide convenient access to diagnostics that already exist in hundreds of plant devices that have no way to deliver them for operations use. Wireless can communicate the information to operators through Web-based portals. And the clipboard walk-arounds, conducted by plant staff because there was simply no other way to get the data back to operations, are replaced by automated solutions.

The low installed cost, reliability, security and ease-of-use of the newest wireless networks are causing increased awareness of their possibilities in refineries, bringing about some innovative applications with excellent results. For example:

- The 225,000 bpd BP Refinery at Cherry Point, WA, installed the first industrial wireless mesh field network in 2006, which continues to operate reliably, eliminating time-consuming operator rounds in the field.
- The same company installed a 45-transmitter wireless monitoring network in a tank farm at a technology center, avoiding the cost of engineering and constructing a wired system to obtain a continuous stream of data on suction and discharge pressures, levels, flow and temperatures.
- At Hunt Refining, Tuscaloosa, AL, three wireless temperature transmitters on a single hot asphalt tank help identify "hot spots" that can lead to roof corrosion which could cause a roof failure costing as much as $200,000.
- At the same location, a wireless device monitors the temperature of cooling water being returned to the local river to assure compliance with environmental regulations.
- Vibration readings on five critical pumps in a hazardous area at a Midwestern refinery are transmitted wirelessly and integrated

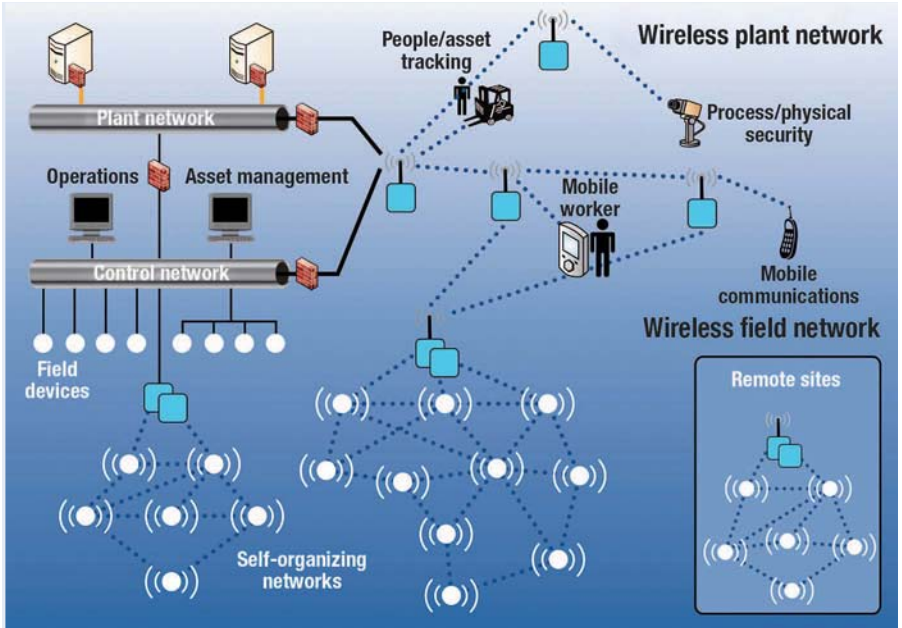


FIG. 1 Wireless in a digital plant.

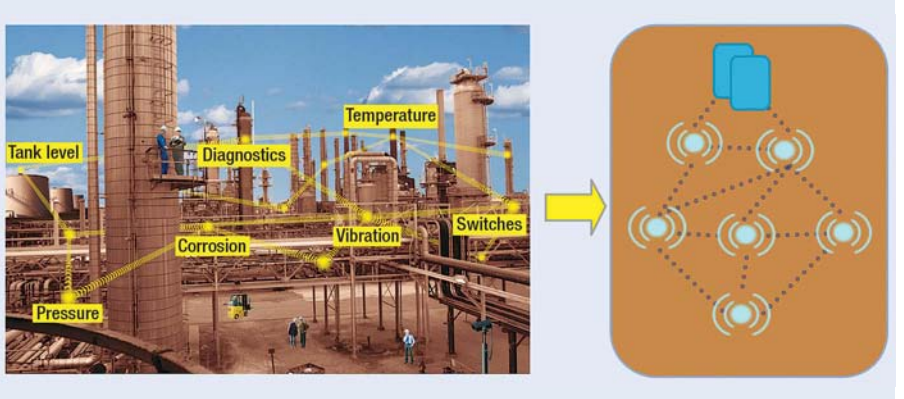


FIG. 2 Self-organizing field network.

with the DCS and plant historian. A serious bearing issue was identified within 24 hours of startup, avoiding a process upset.

Wireless digital architecture. The wireless digital plant (Fig. 1) functions like a conventional wired plant, but with one major difference. Communications between devices are transmitted as radio frequency signals. This makes the wireless digital plant very cost-effective because complex wiring racks including fiber-optic runs are not necessary.

And the wireless technology is scalable. Field or plant network applications are easily added in existing facilities, or to brownfield or greenfield projects. These solutions for process and plant management applications install easily and operate reliably, improving productivity, safety and operational efficiency.

Open-standard solutions. Smart wireless solutions are based on open standards—*Wireless*HART for the field network and IEEE 802.11 a/b/g Wi-Fi for the plant network.

The 802.15.4-based *Wireless*HART standard calls for self-organizing technology that delivers high communications reliability in wireless field networks.

The Class 1 Division 2 wireless access points used in smart wireless plant-level networks are compliant with IEEE 802.11i and Wi-Fi Protected Access 2 (WPA2), which employs hardware-based Advanced Encryption Standard for wireless communications.

Self-organizing networks. At the heart of the smart wireless system is the self-organizing mesh network. Secure and infinitely configurable, the self-organizing network ensures an adaptive, flexible approach to wireless that defies the "canyons of metal" that define most plants.

Unlike many approaches to in-plant wireless that require direct line-of-sight between the instrument and the communications gateway, the smart wireless approach ensures the greatest network integrity by allowing devices to communicate with each other. This means there is no single point of failure; every device serves as a network connector. In the event a temporary obstruction blocks a direct connection, the network automatically reroutes the signal to an adjacent device, ensuring network reliability and data integrity.

Self-organizing mesh networks (Fig. 2) have demonstrated high reliability in the field. They use the IEEE 802.15.4 time-synchronized mesh protocol (TSMP) with added channel hopping. TSMP can be supported by both 900 MHz and 2.4 GHz. Five key components of TSMP that contribute to end-to-end network reliability are:

- Time-synchronized communication
- Frequency hopping
- Automatic node joining and network formation
- Fully-redundant mesh routing
- Secure message transfer.

TSMP networks are robust/tolerant to almost all interference and coexist with other wireless networks. Robust security is designed in. Demonstrated reliability is greater than 99%.

Self-organizing wireless field networks can be easily installed and deliver significant value without the need for investing in a plantwide wireless infrastructure.

Wireless network security. At the wireless field network level, robust security is provided through advanced, standards-based encryption as well as authentication, verification, key management and antijamming techniques.

Smart wireless solutions employ end-to-end 128-bit encryption using the advanced encryption standard (NIST standard FIPS-197). For authentication purposes, each gateway maintains a "white list" of devices allowed to communicate with it, and individual devices accept messages only from a previously identified gateway or from other gateway-validated devices.

Separate "join" and "network" keys can be set to automatically rotate or be changed on demand. Implementing the *Wireless*HART standard adds "session" keys for communication between two network devices so that other devices can't "listen in". These can be rotated as well.

Message integrity codes (MICs) are used to verify messages, both per-hop and end-to-end. Antijamming techniques such as direct sequence spread spectrum (DSSS) with channel hopping plus multipath routing help sidestep noise sources, whether malicious or not. And gateway-to-host security leverages well-known standards such as SSL as well as complete encryption/authentication.

At the wireless plant network level, security is fundamental to the unified wireless network. The standards-based self-defending network solution provides confidence that the plant and business data will remain private and secure. Threat-control capabilities control and contain known and unknown threats, and network admission control helps to enforce organizational



FIG. 3 Several wireless devices are available.

Innovative wireless applications grow at BP

BP is finding more and more ways to use wireless field devices at its Cherry Point refinery in Washington, throughout the tank farm in its R&D facility in Naperville, Illinois, and at other refineries around the world.

At the 225,000 bpd Cherry Point refinery, a 15-transmitter wireless installation in the calciner unit monitors bearing and calciner coke temperatures to help prevent fan and conveyor failure. Fans can cost up to $100,000 to repair but, more importantly, can be down for up to 10 days with associated production losses. This wireless network, believed to be the world's first industrial application of the self-organizing wireless mesh technology in 2006, continues to operate reliably while eliminating operator rounds in the field.

Cherry Point has since expanded the use of wireless to 35 transmitters including tank farm and utility applications, and a smart wireless gateway in the diesel unit has made it ready for wireless motes.

"The principal advantage we see around wireless is the ability to accumulate and analyze a much greater array of data than would otherwise be economically possible," said Michael Ingraham, technical manager for the Cherry Point refinery. "Wireless enables us to get more data more efficiently, more economically than we ever have been able to in the past. We really hope our wireless technology will be a principal tool in maintaining plant availability while expanding our flexibility to meet fuel specs and ever-changing array of feedstock."

Wireless has found a natural home at BP's Naperville R&D facility, a world-class technology center including a model tank farm feeding pilot plants that develop processing options for BP refining worldwide. Following the success of wireless at Cherry Point, BP installed a 45-transmitter wireless network to monitor the Naperville tank farm. Operational for more than one year, this installation has provided strong operational experience and a platform for testing the technology, leading to significant use of wireless at other BP refineries throughout the world.

"The wireless devices allow our operators to be more efficient, collecting data from one central point as opposed to walking around the tank farm and recording all the values," comments a BP representative. "The other advantage of the wireless devices is that they supply data continuously for recording in our historian, allowing us to see what is happening in the tank farm at any time of the day."

The Naperville tank farm network uses wireless transmitters to monitor pump suction and discharge pressures, levels, flow and temperatures. New wireless functions are installed as they become available for refinery-wide applications. The real-world environment in a pilot-scale operation provides hands-on experience for the process engineers and valuable feedback for refinery management. Options for refinery process optimization and sharing of wireless automation technology are thereby shared globally by the Refining Technology team.

"Wireless is an important enabler for 'refinery of the future' technologies," commented Mark Howard, commercial technology manager for BP. "It helps us deploy the sort of instrumentation, sensors and analytical devices that we need for condition monitoring to support predictive maintenance, tracking feedstock through the value chain and a host of other applications. Wireless is a very important vehicle for getting instrumentation into places where wired devices would be too expensive or frankly not very practical.

"Looking ahead, we support the move toward standards such as *Wireless*HART," Howard said. "We like being able to access new wireless transmitters as quickly as we can deploy them, and we're getting very good, robust operation. We look forward to a greater range of instrumentation becoming available."

security policies to allow only trusted end-point devices to access the network.

The wireless access points used in smart wireless plant-level networks are compliant with IEEE 802.11i and Wi-Fi protected access 2 (WPA2) that employ hardware-based advanced encryption standard encryption for wireless communication.

Wireless field networks. A variety of wireless field devices exist, including: pressure, flow, level, temperature, vibration, corrosion, valve position monitor, multi-input temperature, discrete switch, HART upgrade module and wireless device router. Some of these are illustrated in Fig. 3.

Wireless instruments can be widely and remotely distributed throughout a plant, across roads and ponds, or on mobile platforms like railcars, barges, or trucks where traditional wired data collection is not feasible. Only small amounts of bandwidth are used for high-priority bursts of data from each device serving as a transmitter. The self-organizing mesh network continuously monitors signals for signs of degradation and repairs itself as necessary, automatically finding the optimum communication route to the network gateway. If a temporary obstruction blocks a connection, signals are rerouted via adjacent wireless devices, which act as transceivers. In this way, connectivity is maintained while achieving high data transmission reliability.

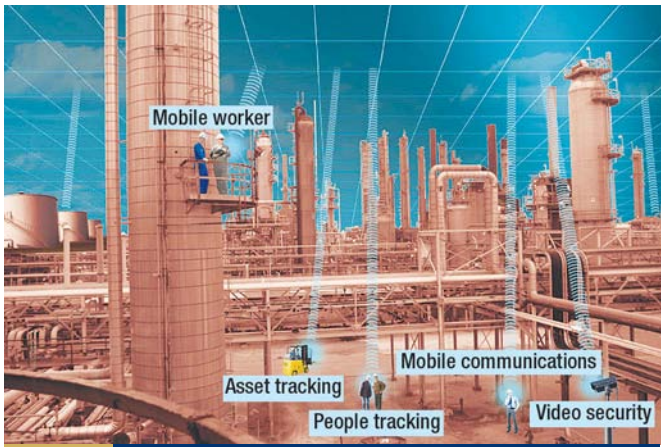


FIG. 4 Wireless plant network.

Wireless plant network. There's a lot more to a plant than what goes on inside the pipes and process vessels. Just as important as the products sold are the people who make them—and the information they use to do their jobs. Not just in offices or control rooms, but out in the field. Applications include video,

voice, mobility and tracking. The wireless plant network is illustrated in Fig. 4.

Wireless technology makes it easier to put those people in touch with the information they need, wherever they are.

- Workers can access desktop applications and perform tasks wherever they are—including viewing and responding to alarms from the field.
- The locations of personnel and physical assets in the plant are tracked at all times—especially useful for safety mustering.
- Messages can be broadcast to specific groups of workers wherever they are.
- Security systems track and ensure authorized plant access.
- Video systems not only patrol the fence line, but keep a cost-effective eye on the process.

At the plant-network level, two types of wireless applications offer significant benefits: workforce productivity and business and plant management.

Workforce productivity. Wireless technology empowers plant workers by giving them instant access to information wherever they are.

Operators can perform many of their duties from the comfort and safety of the control room—but there are still times when they have to go out into the field to collect data, check on equipment or just see firsthand how the plant is running.

Put a ruggedized wireless PC in their hands, and now they can remotely access control and asset-management systems to immediately relate what they see to what's happening in the process—and respond as needed. That includes viewing and acknowledging alarms no matter where the operator is.

Communications improve, too. While many plant workers already use an older wireless technology—walkie-talkies—for short-range communications in the field, combining a plantwide wireless broadband network with Voice over Internet Protocol (VoIP) technology can extend communication reach while also enabling "smart" communications. For example, one can broadcast messages to specific teams based on the IP address of each worker's radio.

Maintenance workers can also benefit. Wireless tools such as handheld communicators let them access maintenance work orders, instructions and other information on the spot, and to immediately track or report inspections, tests and repairs.

Business and plant management. Wireless applications such as personnel and asset tracking, as well as wireless video surveillance for security and safety, have changed the way offices, hospitals, warehouses and retail stores operate. Now they can deliver business and plant-management benefits in process operations, too.

Wireless makes it easy and cost-effective to get better insight into what's happening, especially for safety and security. For example, it's easy and cost-effective to add wireless cameras where it would be too difficult, costly or risky to run wires.

Wireless closed-circuit television cameras and RFID-equipped access badges also enable intelligent security monitoring and control—from restricting access to specific areas based on levels of security, to tracking attempts to violate security protocols, to helping security managers identify potential vulnerabilities and improve systems.

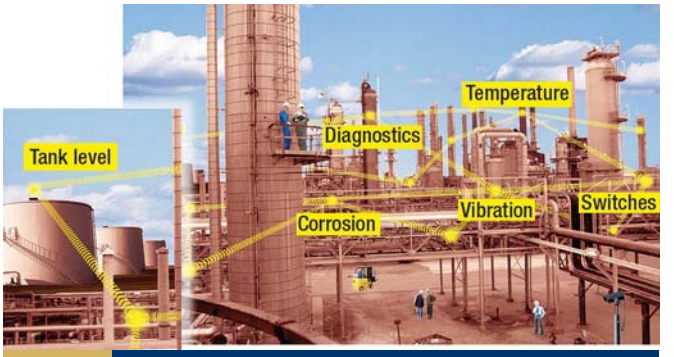


FIG. 5 Grow the wireless network as needed.

Wireless applications also enable one to remotely monitor plant security breaches or onsets of hazardous situations. Wireless monitoring of these situations gives plant security and operations teams time to prepare and dispatch personnel that are suitably equipped for the situation.

And wireless location technologies allow quick access and tracking of inventory and valuable assets—even workers—moving inside and outside the plant. Time spent looking for assets can be dramatically reduced, which can have significant benefits during major turnarounds, emergencies and new construction projects. Being able to quickly locate each worker also offers safety and productivity benefits.

Today's wireless technology enables a top-down or bottom-up approach. Process manufacturers can begin at the plant level and work down or at the field and work up, wherever the highest priority needs are.

Start anywhere and grow the wireless system. Today's wireless technology enables a top-down or bottom-up approach. Process manufacturers can begin at the plant level and work down or at the field and work up, wherever the highest priority needs are. While the reasoning and justification varies widely, a field-level network of measurement devices is often chosen as the first foray into the wireless world. As a result of the flexibility, scalability and ease of use, the process industries already benefit from proven experience over several years and hundreds of wireless installations. This success supports starting now and growing.

Fig. 5 illustrates wireless flexibility and scalability. The small image on the left shows a tank level application, a common starting point for a wireless system because of remote locations and associated costs of implementing a wired solution. Subsequent applications can be added as shown, all being automatically linked via the self-organizing network. **HP**



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OPC UA: an end user's perspective

The updated specification relies on Web services for its data transportation providing significant advantages

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OPC UA (unified architecture) represents the OPC Foundation's most recent set of specifications for process control and automation system interconnectivity. This article explains OPC UA from the perspective of the organization that will benefit from the connectivity—the end user.

The first form of OPC relied on DCOM for its data transportation, which was very powerful and versatile, but posed a problem for those who did not understand how to configure DCOM. Instead of DCOM, OPC UA relies on Web services for its data transportation. OPC UA also uses objects to help with data description. Even though these are major additions and modifications to OPC, OPC UA will be backward compatible with older products through the use of wrappers. All this will ensure that OPC UA will be even better suited to penetrate the entire plant enterprise. Of course, with all the new connectivity that OPC UA offers, the new challenge will be system security.

OPC overview. OPC is an industrial communication standard that enables manufacturers to use data to optimize production, make operation decisions quickly and generate reports (Fig. 1).

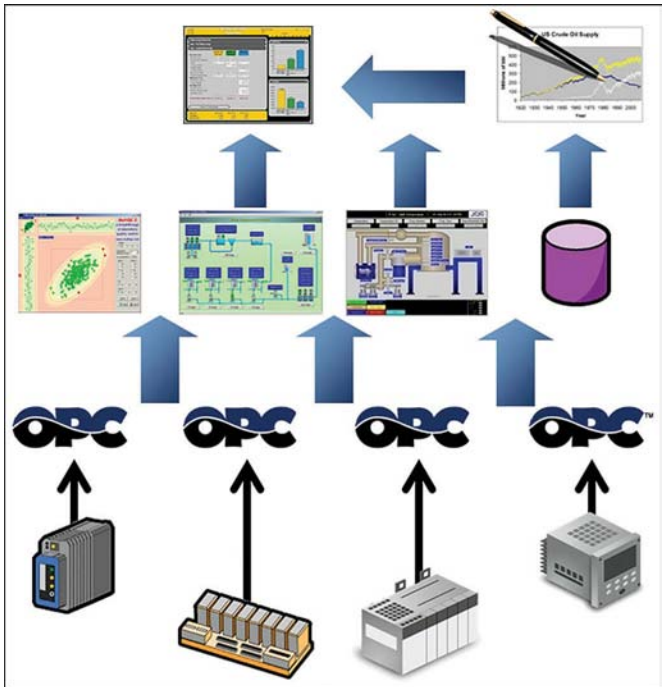


FIG. 1 OPC communication enables applications to interoperate and simplifies system architecture.

OPC enables plants to automate the transfer of data from a control system (PLC, DCS, analyzer, etc.) to an industrial software application (HMI, historian, production system, management system, etc.). OPC is typically found in Level 3 networks and higher. Thus, OPC transfers process control data between the control (Level 2) network and the operations/manufacturing (Level 3) network. It also exchanges data between the operations/manufacturing network and the business (Level 4) network. In essence, OPC is the Modbus of the new century. It is not a replacement for low-level communication standards such as 4-20mA, HART, Profibus, or FOUNDATION fieldbus. Rather, organizations use OPC in high-level communication.

Note: OPC is no longer an acronym. When OPC first released in 1996 it was an acronym for OLE for process control, and was restricted to the Windows operating system. OPC is now available on other operating systems and enjoys significant adoption outside of process control. So, the original name is no longer appropriate and OPC changed from an acronym to a word.

OPC communication started with DCOM. When OPC was first released in 1996, with the OPC Data Access 1.0 (OPC DA 1.0) specification, it used Microsoft's DCOM as the data transportation mechanism (Fig. 2). Data moved between OPC applications on different computers using DCOM. At the time, DCOM was an outstanding choice because it provided a working communication infrastructure complete with all the necessary security services (authentication, authorization and encryption). Thousands of vendors were already using DCOM because it was a relatively versatile application programming interface (API). DCOM was a clear winner at the time, but while it provided a reliable communication backbone for OPC, it did have several challenges.

First, DCOM configuration eludes automation personnel who do not take time to learn it. DCOM is actually very predictable and is not difficult to configure. While there are training classes that explain DCOM configuration in detail, most people do not take the time to learn it and so DCOM's behavior frustrates them. Consequently, automation personnel needlessly experience problems when connecting two computers and configuring firewalls. Nevertheless, knowledgeable users can easily configure DCOM in a matter of minutes.

Second, many programmers assume that network communication will occur without any data loss. This assumption leads them to create products that are highly susceptible to data loss and communication timeouts. As a result, end users might sometimes experience a delay in application responses and complain to

their vendors. However, since the programmers fail to understand DCOM's behavior, they often incorrectly blame DCOM for poor application behavior, which further promotes the false myth that DCOM is unreliable. Again, informed programmers are easily able to compensate for data loss and are able to make DCOM work reliably, and in a way that end users would expect.

The third problem is DCOM does not work through network address translation (NAT). Thus, DCOM does not work in the rare cases where communication must occur between two private networks that are separated by a public network. Such is the case when two plants attempt communication over the Internet. NAT is sometimes used inside industrial facilities, but this is often unnecessary since a firewall would suffice.

The fourth problem is DCOM is proprietary to Microsoft. This makes OPC difficult (to impossible) for vendors to port to nonWindows operating systems. While some vendors are able to embed Windows directly on their own controller (PLC, DCS, analyzer, etc.) hardware, others are unable to do this. Also, companies that use nonWindows operating systems (UNIX/Linux, VMS, etc.) are having a difficult time importing OPC data into their applications.

OPC UA uses Web services. OPC UA uses Web services instead of DCOM for data transportation. This change most end users will notice immediately. Two of the biggest advantages of Web services are ease of communication between networks and independence from specific operating systems. The challenge for the plant will be implementing security to keep the data safe.

Perhaps the biggest technical advantage of Web services is that they enable OPC to communicate over a single port using a protocol that most firewalls will allow to pass by default. This should make it easier for integrators to set up a system for communication between networks. Many firewalls are already configured to let Web traffic pass across port 80. This will make it easier for IT to open the ports necessary to implement OPC communication. Previously, DCOM required multiple ports to establish communication. While this was possible to configure, a significant portion of automation personnel did not take the time to learn how to do it. Nevertheless, opening port 80 opens communication for a plethora of applications (not just those that are needed for operations), so emphasis on security will be required immediately.

In addition, Web services are not bound to any specific operating system. Thus, vendors will have an easier time implementing OPC servers on their automation hardware and nonWindows operating systems. Vendors are already working on PLCs that include an embedded native OPC server that does not require an external computer. However, this implementation might not be as simple as it seems because an automation application (HMI, historian, APC, etc.) typically requires a PC anyway. Nevertheless, it would be possible to have a PLC communicate with a software application using OPC without requiring an intermediate computer that uses Windows.

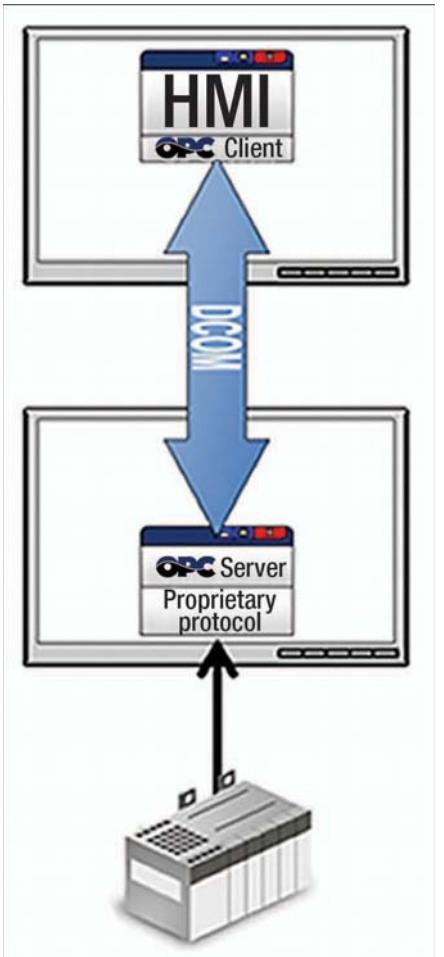


FIG. 2 OPC initially relied on DCOM for data transportation.

OPC UA uses an object-oriented data model. Classic OPC has a fairly simple data model. Each of the OPC specifications handles a different aspect of the data. For example, the OPC DA (data access) specification communicates real-time values, the OPC HDA (historical data access) specification communicates archived values, the OPC A&E (alarms and events) specification communicates various process and system events (such as a temperature that exceeds a prespecified limit), and so on. In addition, classic OPC implements each specification separately; essentially in a different executable. Thus, it is time-consuming to match item names with real-time data and historical data. Even worse, automated applications may not be able to do it at all.

OPC UA provides a unified data model. Thus, when an application uses OPC UA to send a temperature reading, the receiver is able to retrieve the real-time value, any associated historical values, and even alarms and events. All these data are available from pointing at a single OPC item. The OPC server is able to associate all the data together so that the OPC client does not need to redo the association work. For example, in DCOM-based OPC, end users who are interested in a pressure reading would have had to point to the OPC DA server to look at the real-time value. Then they would have to point to an OPC HDA server to trend the pressure over the past shift. If they wanted to take a look at associated events, they would have to point to the OPC A&E server. But with OPC UA, the end user can simply point to a pressure reading, view its real-time value, look at the past shift's trend (historical data) and view all the associated events by connecting to a single OPC UA server.

OPC UA also provides the ability to create more complex objects. For example, one could create a pump that is composed of various temperature, level, pressure, flow and vibration readings. Included would be the history of all values as well as a picture of the pump. One could even associate P&ID schematic diagrams and maintenance orders. This presents a powerful mechanism for integrators from various companies to share data without having to recreate it in their different proprietary software applications.

Improving existing specifications. As OPC evolved over the years, the OPC Foundation provided constant updates and improvements to the specifications. OPC UA continues this tradition. After consulting end users, integrators and vendors, the OPC Foundation decided on various additions to the specifications to handle the most common challenges. OPC UA includes mechanisms to quickly inform

users of broken communication, identify lost data and even provide for redundancy.

OPC UA uses a poll-report-by-exception mechanism. Thus, the OPC client polls the OPC server for changes. The server then responds with any data changes. A failure to respond would immediately tell the OPC client that the communication is no longer active. In addition, updates can come as quickly as the polling itself. However, unlike common protocols that must poll each point individually and consume precious bandwidth, OPC UA enables the OPC server to respond with any data that changed. Thus, a single efficient poll can bring back a large amount of data that include all the changes in the process as well as the health of the OPC server itself. By contrast, before OPC UA, DCOM communication sent all changes to the OPC client by exception. Thus, an OPC client did not have to poll the OPC server periodically. While this was efficient, many programmers overlooked the possibility that no updates would be received when communication breaks. As a result, the OPC client would wait for updates that would never arrive. Various companies overcame these difficulties, but some did not and blamed DCOM instead.

OPC UA also enables an easier implementation of redundancy. OPC UA servers can update a set of clients. By contrast, DCOM-based OPC servers could only update OPC clients that explicitly subscribed to the data. As well, since the OPC client can easily tell when communication with an OPC server fails (as above), the OPC client can now quickly failover to a standby OPC server. In DCOM-based implementations, most vendors relied on third-party OPC redundancy applications that cost them additional funds.

Backward compatibility and tunneling. The OPC Foundation has promised to supply the industry with two simple software applications that will enable people to quickly convert their DCOM-based OPC products to OPC UA. These software applications are called "wrappers" (Fig. 3). Wrappers will ensure that any new OPC UA product will communicate with an existing DCOM-based OPC product. As a result, there is no need to contemplate whether or not one should wait for OPC UA products. It is easy to implement DCOM-based OPC products today and be assured that future OPC UA products will communicate with the old software.

Two wrappers will be available: one for OPC clients and the other for OPC servers. The first wrapper will convert a DCOM-based OPC server to an OPC UA server. Thus, an OPC UA client will be able to connect to the existing DCOM-based OPC server without any changes. The second wrapper will convert a DCOM-based OPC client to an OPC UA client. So an existing DCOM-based OPC client application (such as an HMI) will be able to communicate with an OPC UA server that could be purchased a year from now. Using wrappers, OPC is sure to ease the transition from the old to the new technology.

Wrappers will tunnel OPC to places where DCOM-based OPC can't penetrate on its own. For example, when an OPC client and server are separated by NAT, DCOM will not be able to make the connection. However, by converting the DCOM-based call to OPC UA at the source, and converting it back from OPC UA to DCOM at the destination, the call will transport the required data. Tunneling will likely be the first form of OPC UA implementation as OPC UA products begin to emerge.

Shop floor to top floor: OPC to the enterprise. OPC UA introduces an object model to industrial data, and Web services will enable the OPC applications to transport the data across firewalls, networks and the Internet (Fig. 4). A variety of applications

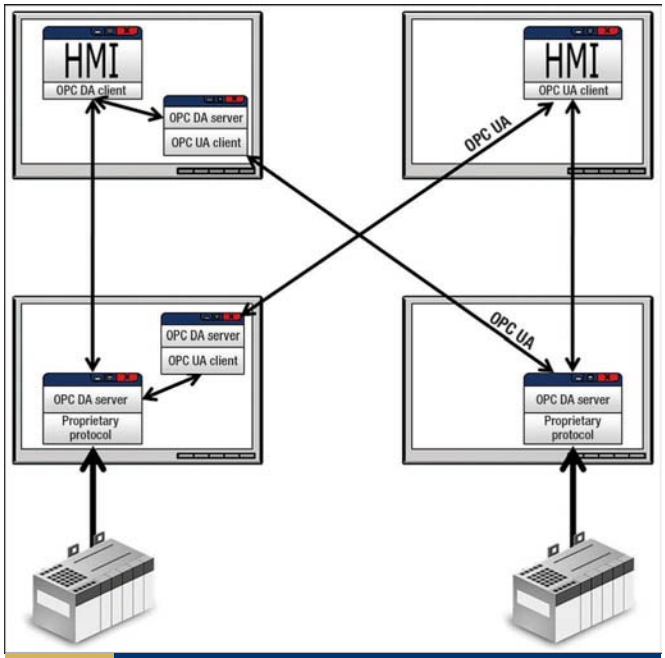


FIG. 3 OPC UA wrappers will enable legacy DCOM-based OPC products to communicate with new OPC UA products.

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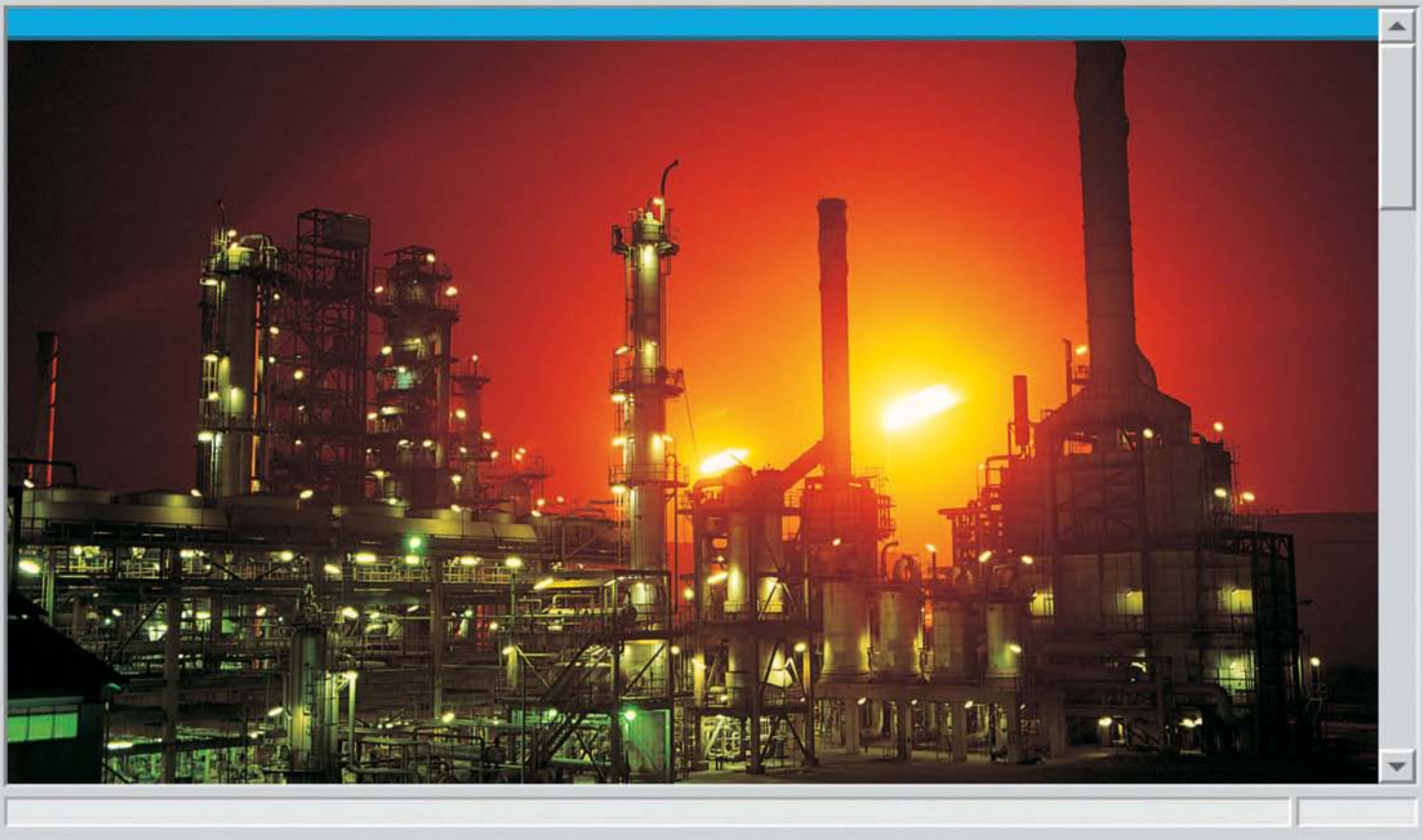
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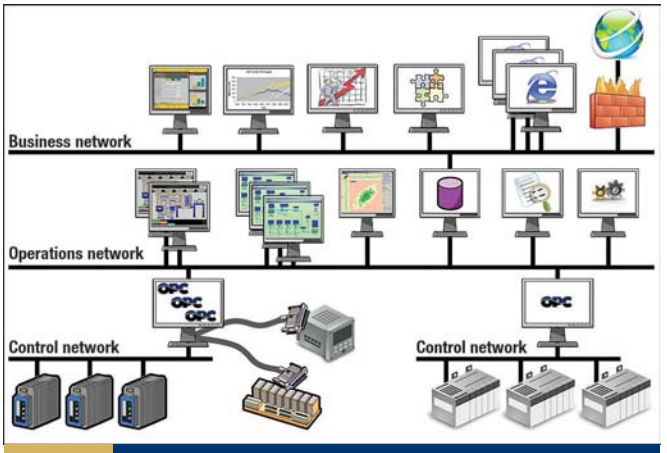


FIG. 4 OPC UA will enable data to move from the shop floor to the top floor.

will be able to supply the enterprise with data. An HMI will be able to pass equipment events to the maintenance system. The historian will be able to pass calculations to various engineering systems. As well, inventory management systems will be easily able to obtain production figures directly from automation equipment.

Plant-floor data will finally find its way to the business local area network (LAN) and enable a variety of applications to benefit from the newly available data. For instance, computer maintenance management systems (CMMSs) or enterprise asset management systems (EAMSs) will be able to obtain equipment condition data so they can implement a conditions-based maintenance (CBM) program. Enterprise resource planning (ERP) applications will be able to obtain inventory information, or even send production orders without any manual intervention.

Security: the new challenge for automation. OPC UA makes it relatively easy for a multitude of applications to connect with each other. So the new challenge for automation personnel will be to secure their systems from unwanted connections. Web services will make it easy to cross firewalls and networks. So, unwanted connections from people and applications will become far more common. However, unlike IT systems, automation systems are responsible for production and safety. Therefore, security will quickly rise to the forefront. Automation personnel will have to learn how to secure their systems in a way that still enables them to provide access to those who need it.

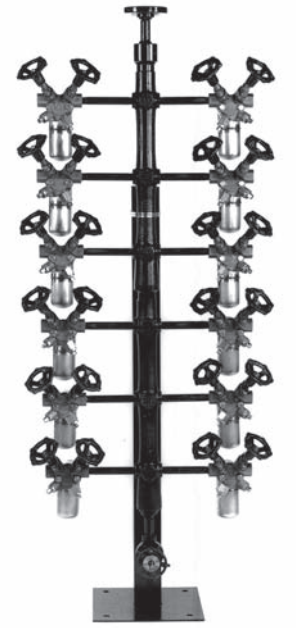
It remains to be seen how vendors will enable their applications with the three pillars of secure connectivity: authentication, authorization and encryption. Various products that are already in the planning stages still do not include the necessary facilities for proper security. These applications use "security by obscurity," which essentially relies on a hacker's inability to understand how a system works to make it behave inappropriately. Both process and attitudes toward security will have to change. **HP**



Randy Kondor is a computer engineer and president of the OPC Training Institute, the world's largest OPC training company. Since 1996, he has been vastly involved within the OPC industry and a strong supporter of the OPC Foundation. Mr. Kondor continues to dedicate himself to spreading the OPC Foundation's message about system interoperability and intervendor cooperation.



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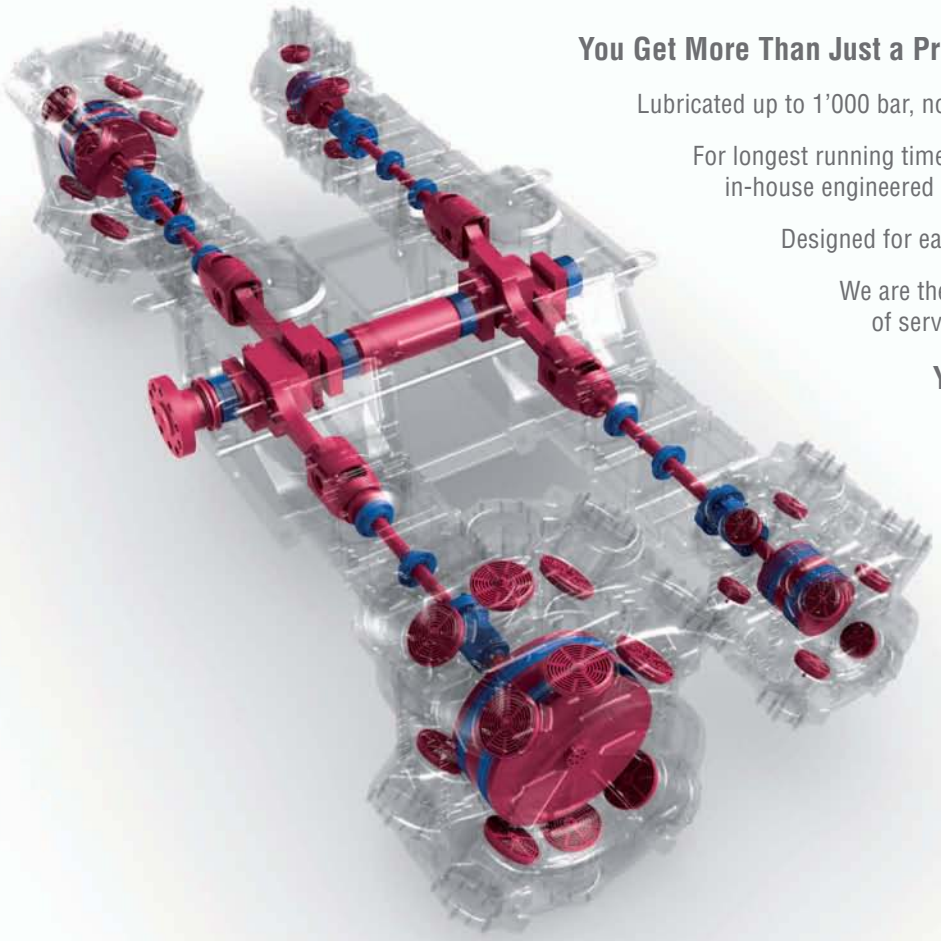
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Soft sensor modeling using artificial neural networks

Here are guidelines for proper construction

V. NANDAKUMAR, Mangalore Refinery & Petrochemicals Ltd., Karnataka, India

With increased competition and rising feedstock cost, pressures are increasing for refinery managers to extract maximum value out of processes. In operations, the online quality monitoring is an important part of process control. Typically, analyzers are provided for this application. However, as parameters increase in complexity from density, moisture content, octane number, sulfur content, etc., the cost and maintenance efforts on analyzers increase exponentially. Moreover, the inherent rigidity in hardwired analyzers makes their extended usage difficult, if not impossible, so soft sensors play a vital role.

Soft sensors have the advantages of easy maintainability, low cost and extensibility to other applications. It's not difficult to design a soft sensor for new parameters and one can be virtually built for every parameter in question. Basic requirements for a soft sensor are the knowledge of fundamental relationships of process variables and the parameter in question. In short, it is a sophisticated correlation model.

Basic requirements for a soft sensor are the knowledge of fundamental relationships of process variables and the parameter in question. In short, it is a sophisticated correlation model.

In petroleum refining, correlations and empirical relations have played an important historical role in plant design and operations. The advent of inexpensive computing power made direct computation models like finite element analysis (FEA) and computational fluid dynamics (CFD) feasible and practical. The skill set requirement for such applications allows for highly trained experts to test. In refineries and production departments, the required skills are different; hence, a CFD or FEA may not be feasible in day-to-day applications. Empirical relations find the best acceptance in quick calculations and the not-so-accurate control algorithms. API data books list many empirical relations between properties of hydrocarbon liquids such as relations between density and boiling point, molecular weight, flash point and initial boiling point relations. These relations place less importance on the underlying theoretical models than the accuracy of the results. It is more like a "black box" approach.

Soft sensor construction can be split into various steps as follows:

- Variable identification
- Data collection
- Programming
- Sensor testing
- Implementation in real time
- Periodic data validation and tuning.

To elucidate the concepts, a real example of a CCR-platforming process unit and the product's research octane number (RON) as required product quality to be monitored was taken.

CCR process brief. The process produces feed for an aromatics complex or a high-octane gasoline blending product and a significant hydrogen as a byproduct. In the unit, hydrotreated naphtha feed is combined with recycle hydrogen gas and heat exchanged against reactor effluent. The combined feed is raised to reaction temperature in the charge heater and sent to the reactor section. Radial-flow reactors are arranged in a vertical stack. The predominant reactions are endothermic, so an inter-heater is used between each reactor to reheat the charge to reaction temperature. The effluent from the last reactor is heat exchanged against combined feed, cooled and split into vapor and liquid products in a separator. The vapor phase is rich in hydrogen gas. A gas portion is compressed and recycled back to the reactors. The net hydrogen-rich gas is compressed and purified in a PSA system. Catalyst flows vertically, by gravity down the reactor stack. Over time, coke builds up on the catalyst at reaction conditions. Partially deactivated catalyst is continually withdrawn from the reactor stack bottom and transferred to the CCR regenerator.

Variable identification. A reformate product is an important component in gasoline blending as well as feed stock for the downstream mixed xylene unit. The key parameter for this product is its RON. Online analyzers are usually provided in the unit. However, most often these analyzers have maintenance problems and require frequent offline calibrations that require laboratory analysis data.

The process technology manual of the licensor suggests that the product RON is a function of the following variables:

- Feed rate (analogously the liquid hourly space velocity (LHSV) or residence time)
- Feed quality—described by naphthenic and aromatic content
- Reactor severity
- Hydrogen partial pressure
- Catalyst activity

However, all of the above cannot and are not directly measured by instrumentation; hence, a soft sensor, though accurate and constructed with those variables, is impractical to use. Therefore, process "proxies" are suggested that are monitored online and easy to configure.

The following variables are substituted:

- Feed quality by reactor total temperature difference which is the weighted sum of each individual reactor delta and reformate product flow
- Hydrogen partial pressure by a total reactor pressure, recycle gas flow, net gas flow
- Catalyst activity can be substituted with a catalyst circulation rate with the coke deposition on a catalyst which in turn was substituted by total air demand and regenerator peak burn temperature. In this particular example, the actual data of catalyst circulation and regenerator variables did not vary; hence, their effect was constant toward RON and was not considered.

Data collection. In the operating unit studied, the daily reformate sample goes to the laboratory at 7 am. Ideally, the RON result is the net effect of that particular instant which is enveloped in the previous three hours of operation due to various hold-ups and residence time in the system. Due to the difficulty in collecting precisely enveloped data from the plant historical database, it was later approximated with the daily average values.

Statistically, a correlation is useful if it is taken with strictly independent variables. To ensure that, from the collected data, paired covariance analysis was conducted and the group was confirmed to be reasonably independent. Since it was possible to have a certain degree of parametric relations between the variables, a judgmental decision was taken.

The following values were collected and examined for any abnormality such as the instrument showing too high or too low values, missing data, etc., and then corrections were made wherever necessary.

Independent variables (input variables):

- Unit feed rate
- Reactor severity
- Reactor total delta temperature
- Reformate rate
- Reactor pressure
- Recycle gas flow, and
- Net gas flow

Dependent variable (output variable):

- Reformate RON as reported by the lab.

Feed-forward artificial neural networks. A neural network is an information processing structure consisting of processing elements (neurons), interconnected with directional signal channels called connections. Each processing element has a single output connection that branches into as many collateral connections as desired. Each carries the same signal—the processing element output signal, which can be any mathematical type desired. Neural networks develop information processing capabilities by learning from examples. Learning techniques can be roughly divided into two categories: supervised and unsupervised learning.

Supervised learning requires an example set where the desired network response is known. The learning process consists in adapting the network in a way that it will produce the correct response for the example set. The resulting network should then be able to generalize (give a good response) when presented with cases not found in the set of examples. Unsupervised learning is an automated process, but details of the process are omitted here.

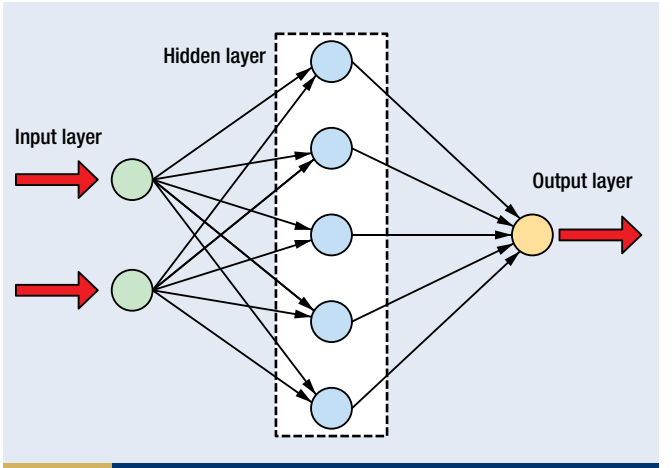


FIG. 1 Standard FFnet.

A popular neural net structure is the feed-forward neural network (FFnet). They are known by another name, multi-layer perceptrons. In a feed-forward neural network, the neurons are usually arranged in layers. A typical layer structure is:

Input → Layer 1 → Layer 2 → Output

Layers 1 and 2 are the inner layers and are labeled as hidden. The connections are always forward, e.g., from Layer 1, every neuron connection is to Layer 2 or to an output layer only. An FFnet has neurons arranged in a distinct layered topology. The input layer is not really neural at all—these units simply serve to introduce the input variable values. The hidden and output layer neurons are each connected to all units in the preceding layer. Although it is possible to define networks that are partially connected to only some units in the preceding layer, for most applications, fully connected networks are used. In a standard FFnet, the connections are strictly to the next layer and all nodes are connected to the next layer nodes. A typical standard FFnet is illustrated in Fig. 1.

Each arrow in the figure symbolizes a parameter in the network. The network is divided into layers. The input layer consists of network inputs and then follows a hidden layer, which consists of any number of neurons, or hidden units placed in parallel. Each neuron performs a weighted summation of the inputs, and then passes a nonlinear activation function, F. The network output is formed by another weighted summation of the outputs of the neurons in the hidden layer.

The network calculations are progressively applied with input layers simply taking the values of input vectors. Each hidden and output layer is calculated by the activation value by taking the weighted sum of the outputs of the units in the preceding layer, and subtracting the threshold value. The activation value is passed through the activation function to produce the neuron output. When the entire network has been calculated, the outputs of the output layer act as the output of the entire network.

A widely used activation function is the sigmoid function given by:

$$F(x) = \frac{1}{1+e^{-x}} \quad (1)$$

The net input to a processing unit, h, is given by:

$$net_h = \sum_i w_{ih} x_i + \theta j \quad (2)$$

where x_is are the outputs from the previous layer, w_{ih} is the weight (connection strength) of the link connecting unit i to unit j, and θ is the bias of unit h, which determines the location of the sigmoid function on the x-axis.

The activation value (output) of unit j is given by:

$$a_h = F(net_h) = \frac{1}{1+e^{-net_h}} \quad (3)$$

The objective of different supervised learning algorithms is the iterative optimization of a so-called error function representing a measure network performance. This error function is defined as the mean square sum of differences between the output unit values of the network and the desired target values, calculated for the whole pattern set. The error for a pattern p is given by:

$$E_p = \sum_{j=1}^{N_O} (d_{pj} - a_{pj})^2 \quad (4)$$

where d_{pj} and a_{pj} are the target and the actual response value of output neuron j corresponding to the pattern p. This factor is improved successively by the learning algorithms and the model is set when the total error is minimum.

The total error is:

$$E = \sum_{p=1}^{P} \frac{1}{2} E_p = \frac{1}{2} \sum_{p=1}^{P} \sum_{j=1}^{N_O} (d_{pj} - a_{pj})^2 \quad (5)$$

where p is the number of the training patterns.

The actual computation process in the FFnet is quite involved and not practical to do manually. The software packages specifically designed for this application are available in both commercial and free open source domains.

Typically, these applications require the user to specify the network topology, input vector and target vector. The inner workings are conveniently shielded from user interface. Of course, the open-source version does permit such changes in the program, but, in a normal course such modifications are not needed.

In the above case, the entire program is scripted in Python, an open source and a highly powerful programming language. The FFnet code was provided by a library module called ffnet. The details of the FFnet structure are:

- Network has feed-forward architecture
- Input units have identity activation function and all other units have sigmoid activation function
- Provided data are automatically normalized, both input and output, with a linear mapping to the range (0.15, 0.85). Each input and output is treated separately (i.e., the linear map is unique for each input and output).
- Function minimized during training is a sum of squared errors of each output for each training pattern.

The module has an added feature that the trained neural net can be exported as a FORTRAN routine that can be compiled to use in other systems.

Model implementation. As mentioned in the data collection section, the input vector has a dimension of 7×1 and the output vector is 1×1.

The FFnet selected has seven input nodes and one output node. Two hidden layers, each having seven nodes, was chosen.

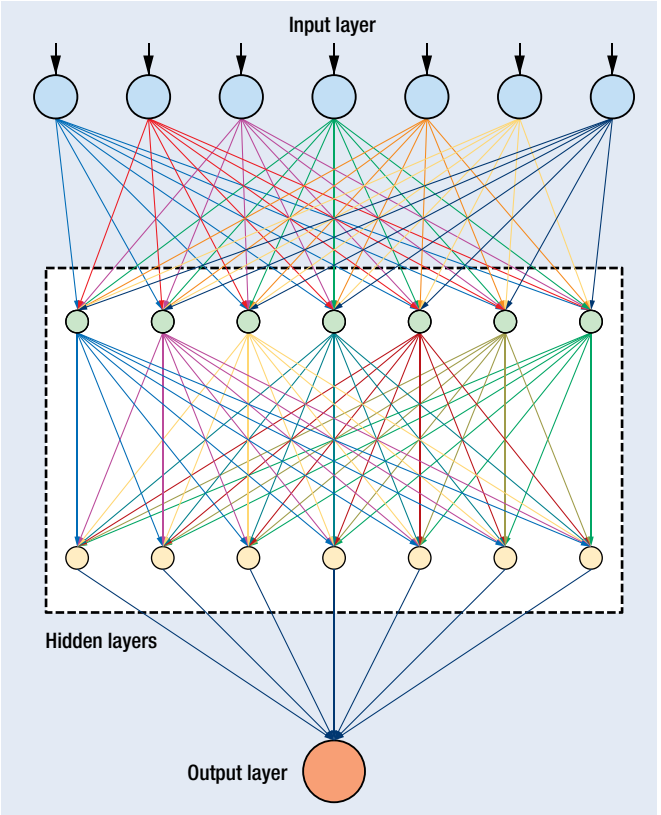


FIG. 2 CCR unit RON model as FFnet {7,[7,7],1}.

This choice was albeit arbitrary, and has medium complexity. In theory, it is a trade-off between accuracy and computation. The selected FFnet is described as FFnet {7, [7, 7], 1}. The square bracket denotes the hidden layers. The network is illustrated in Fig. 2. The program was written in python and the data, which were daily average input and output value vectors for 249 days. The program does a statistical testing to find the neural net regression fit. The data set consists of daily averages with seven parameters and the target RON values for training.

Python code for fitting and training the data for FFnet:[3]

```
# importing the required modules
import win32com.client
from ffnet import mlgraph,ffnet, savenet, exportnet
import pylab as p
# use psyco to speed up
import psyco
psyco.full()
# data is read from the file "ccr1 data new.xls"
xlApp=win32com.client.gencache.EnsureDispatch("Excel.
Application")
xlWb=xlApp.Workbooks.Open("C:\Users\Admin\Documents\
ccr1 data new.xls")
xlSht=xlWb.Worksheets(1)
row_range=range(4,253)
dtemp=[]
wait=[]
feed=[]
reformate=[]
pressure=[]
```

```
netgas=[]
rggas=[]
RON=[]
points=len(row_range)
for i in row_range:
    dtemp.append(float(xlSht.Cells(i,3).Value))
    wait.append(float(xlSht.Cells(i,4).Value))
    feed.append(float(xlSht.Cells(i,5).Value))
    reformate.append(float((xlSht.Cells(i,6).Value)))
    pressure.append(float((xlSht.Cells(i,7).Value)))
    netgas.append(float((xlSht.Cells(i,11).Value)))
    rggas.append(float((xlSht.Cells(i,15).Value)))
    RON.append(float((xlSht.Cells(i,18).Value)))
# input data set includes feed, wait, dtemp, pressure, reformate,
rggas, netgas
data_set=[]
for n in range(points):
    data_set.append([feed[n],wait[n],dtemp[n],pressure[n],
                     reformate[n],\ rggas[n],netgas[n]])
xlApp.ActiveWorkbook.Close(SaveChanges=0)
xlApp.Quit()
# defining ffnet parameters
input = data_set
target= RON
# making a network
conec=mlgraph((7,7,7,1))
net=ffnet(conec)
# using resilient propagation algorithm
```

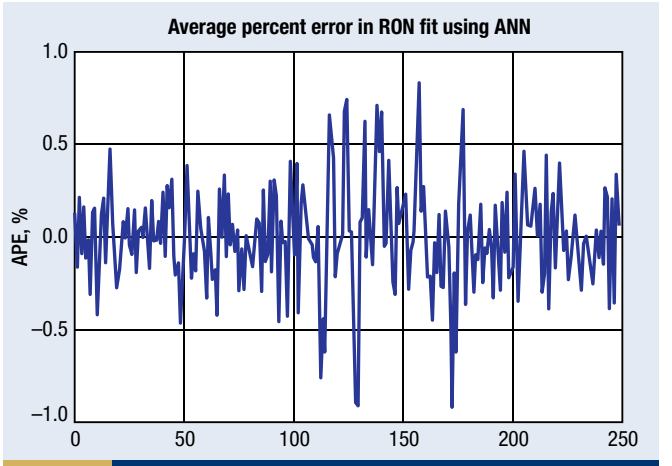
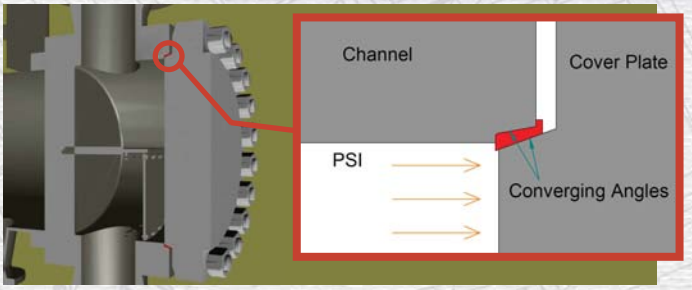


FIG. 3 Result of model fit showing APE.

```
net.train_rprop(input, target, a=1.2, b=0.5,\
mimin=9.9999999999999995e-07, mimax=50.0, xmi=0.10,
maxiter=10000,\ disp=1)
print "TRAINING NETWORK..."
net.train_tnc(input, target, maxfun = 5000, messages=1)
# Test network
print
print "TESTING NETWORK..."
output, regression = net.test(input, target, iprint = 2,\
filename="ccr_yearly_test.txt")
```


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TABLE 1. Model's average percent error

No.	RON Lab data	RON prediction	APE
1	100.9	99.0	–1.9%
2	100.4	100.3	–0.1%
3	100.7	99.0	–1.7%
4	100.1	99.8	–0.3%
5	100.8	97.1	–3.6%
6	101.3	99.2	–2.0%
7	101.3	99.3	–1.9%
8	100.7	99.5	–1.2%
9	100.4	98.6	–1.8%
10	100.4	100.5	0.1%
11	100.5	100.6	0.1%

```
# Exporting network
savenet(net, "ccr_yearly")
# exporting the net as a FORTRAN module to use later
exportnet(net, "ccr_yearly.f")
# Plotting the data
RON_fit=[]
for n in range(points):
    RON_fit.append(net(input[n]))
# Average Percent Error APE
APE=[]
for n in range(points):
    APE.append((RON[n]–RON_fit[n][0])*100/RON[n])
p.plot(range(points),APE,'b')
p.title("Average Percent Error in RON fit using ANN")
p.ylabel("APE %")
p.grid(True)
p.show()
```

The regression result is given below:

```
    Feed-forward neural network:
    Inputs: 7
    Hidden: 14
    Outputs: 1
    Connections and biases: 120
    Testing results for 249 testing cases:
    OUTPUT 1 (node nr 22):
    Regression line parameters:
    Slope              = 0.910627
    Intercept          = 9.021174
    Correlation        = 0.953035
    Tail probability   = 0.000000
    Standard error     = 0.259538
```

The error pattern after training is illustrated in Fig. 3 for the 249 data points.

After fitting and training the FFnet model, it was tested with a different set of data and the accuracy is tabulated and listed in Table 1.

The FORTRAN module exported from the Python program can be compiled with the standard FORTRAN compilers with the standard link file from the FFfnet module (given with the installation of the module), and can be used for any APC implementation.

The above example shows the ease and availability of standard software tools to model software sensors with reasonable accuracy for use in plant operations. The sensors will also help fine-tune the existing APC systems. HP

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AUTHOR'S NOTE

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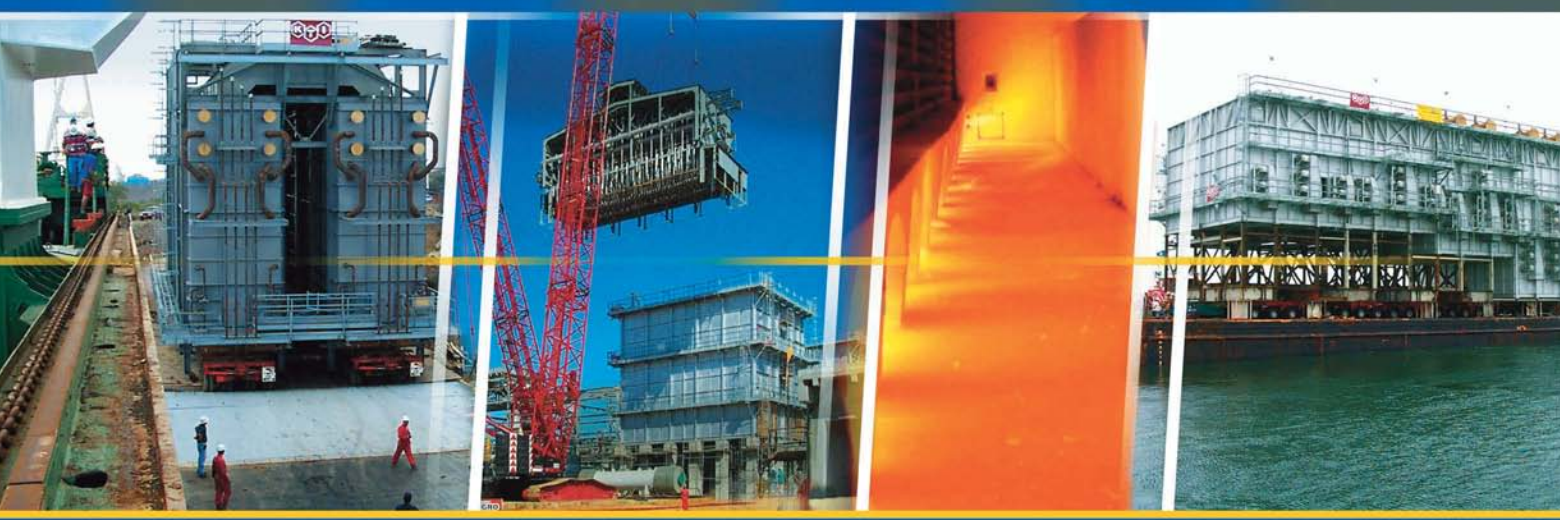


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Hydrogen gas detection

Combining detection systems improves safety

E. NARANJO, General Monitors, Lake Forest, California

Oil refineries are large hydrogen gas producers and consumers. Hydrogen plays a pivotal role in many refining operations, from hydrocracking—heavy gas reduction and gasoils to lower molecular weight components—to gas stream treatment, to catalytic reforming. In catalytic reforming, the gas is also used to prevent carbon from reacting with the catalyst to maintain the production of lighter hydrocarbons while extending the catalyst's life. Not surprisingly, refineries use large volumes of hydrogen that is either produced onsite or purchased from hydrogen production facilities.

Demand for hydrogen is growing. Changes in gasoline and diesel fuel specifications, prompted by environmental legislation, have led to increased hydrogen use to improve gasoline grade. However, higher crude oil prices have enhanced the commercial prospects of heavier crudes, requiring new investments in conversion processes and more extensive hydrotreating and hydrocracking applications.

The scale and growth of hydrogen demand raises the fundamental question about using the gas safely. Due to its chemical properties, hydrogen poses unique challenges in the plant environment. Hydrogen gas is colorless, odorless and undetectable by human senses. Also, hydrogen is not detected by infrared (IR) gas-sensing technology. Since it is lighter than air, it is difficult to detect where accumulations should not occur. Coupled with the challenge of gas detection are the safety risks posed by the gas itself.

A practical approach is offered for the deployment of fire and gas detectors that maximize detection efficiency. The approach is that any one detection technique cannot respond to all hazardous events. Consequently, the risk of detection failure is reduced by deploying devices that have different strengths and limitations.

Improved safety through diversity. There are several hazards associated with hydrogen that include: respiratory ailment, component failure, ignition and burning. Although hazard combinations occur in most instances, the primary hazard with hydrogen is a flammable mixture production that can lead to a fire or an explosion. Hydrogen is easily ignited since the minimum ignition energy at atmospheric pressure is about 0.2 mJ.

In addition to these hazards, hydrogen can produce mechanical failures of containment vessels, piping and other components due to hydrogen embrittlement. Metals and plastics can lose ductility and strength due to long-term exposure to the gas. This leads to crack formation and eventually causes ruptures. A form of hydrogen embrittlement takes place by a chemical reaction. At high temperatures, hydrogen reacts with one or more metal-wall components to form hydrides that will weaken the material lattice structure.

In oil refineries, the first step in fire escalation and detonation is loss of containing the gas. Hydrogen leaks are typically caused by defective seals, valve misalignment, or flange or other equipment failure. Once released, hydrogen diffuses rapidly. If the leak takes place outside, the cloud dispersion is affected by wind speed and direction, and can be influenced by atmospheric turbulence and nearby structures. If the gas is dispersed in a plume, a detonation can occur if the hydrogen and air mixture are within its explosion range and an appropriate ignition source is available. Such flammable mixtures can form at a considerable distance from the leak source.

To address the hazards posed by hydrogen, fire and gas detection system manufacturers work within the construct of protection layers to reduce hazard propagation incidences. Under such a model, each layer acts as a safeguard, preventing the hazard from becoming more severe. Fig. 1 illustrates a hazard propagation sequence for hydrogen gas leaks.

Detection layers encompass different sensing techniques that either improve scenario coverage or increase the likelihood that a specific type of hazard is identified. Such fire and gas detection layers can consist of catalytic sensors, ultrasonic gas leak monitors or fire detectors, which are illustrated in Fig. 2. Ultrasonic gas leak detectors can respond to high-pressure releases of hydrogen, such as those that may occur in hydrocracking reactors or hydrogen separators. Continuous hydrogen monitors, like catalytic detectors, can contribute to detecting small leaks. Leaks may happen when a flange slowly deforms by use or failure of a vessel maintained at or near atmospheric pressure. To further protect a plant against fires, hydrogen-specific flame detectors can supervise entire process areas. Such wide coverage is necessary since a fire may ignite at a considerable distance from the leak source due to hydrogen cloud movement.

When a containment system fails, hydrogen gas escapes at a rate that is proportional to the orifice size and the system's internal pressure. Such leaks can be detected by ultrasonic monitors that sense airborne ultrasound produced by turbulent flow above a pre-defined sound pressure level. Using ultrasound as a proxy for gas concentration is a major technique advantage. Ultrasonic gas leak detectors do not require gas transport to the sensor element to detect gas. They are unaffected by leak orientation, gas plume concentration gradient and wind direction. Such features make



FIG. 1 Hazard sequence for hydrogen dispersal. Layers of protection separate each hazard state.

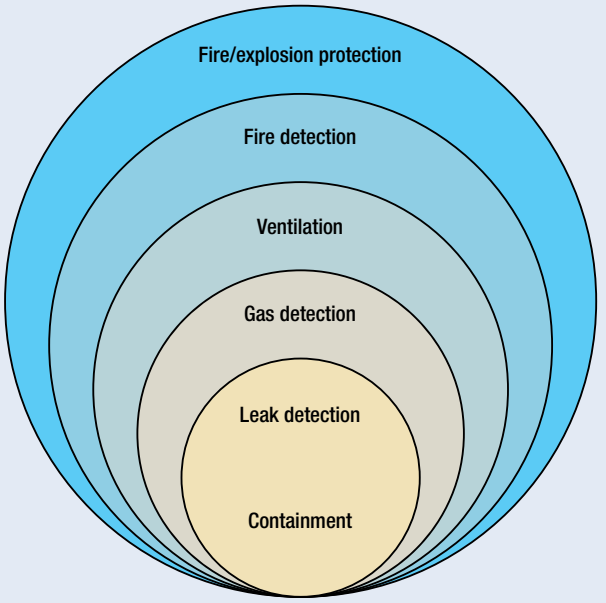


FIG. 2 Protective barrier schematic for a hydrogen accident sequence.



FIG. 3 Sound pressure level as a function of distance for hydrogen leaks. Leak size = 1 mm diameter orifice, differential pressure = 5,515 kPa (800 psi), leak rate = 0.003 kg/s.

ultrasonic gas leak detectors an ideal choice for the supervision of pressurized pipes and vessels in open, well-ventilated areas.

Another instrument advantage is the wide coverage area per device. Depending on the ultrasound background level, a single detector can respond to a small hydrogen leak at about 8 m from the source. As illustrated in Fig. 3, even small leaks can generate sufficient ultrasonic noise to afford detection in most industrial environments, where background noise levels can range from roughly 60 dB to 90 dB. Since the instrument responds to the gas release rather than the gas itself, the alarm quickly activates, often within milliseconds.

A second measure of protection is direct gas detection by means of catalytic-combustible gas detectors. They have a long history and have been used for hydrogen applications for more than 50 years. The sensing devices have a pair of platinum-wire coils embedded in a ceramic bead. The active bead is coated with a catalyst, while the reference bead is encased in glass and is inert. On exposure to hydrogen, the gas begins to burn at the heated catalyst surface per the reaction:

$$2H_2 + 2O_2 \rightarrow 2H_2O + O_2$$

The hydrogen oxidation releases heat causing the wire's electrical resistance to change. The resistance is linear across a wide temperature range (~500°C – 1,000°C) and proportional to concentration. For hydrogen-specific catalytic detection, the reaction temperature and catalyst are tailored to prevent the combustion of hydrocarbons in the substrate. The scheme's simplicity makes catalytic detectors suitable for many applications. Where gas accumulations may occur, catalytic sensors establish hydrogen presence with fair accuracy and repeatability. Hydrogen-specific catalytic detectors also have fast response times (5s–10s) and offer good selectivity. These parameters vary widely among the various manufacturers, but are generally tailored for maximum selectivity and response speed. As pointed out earlier, hydrogen cannot be detected by IR absorption, making catalytic monitors one of the most reliable technologies for hydrogen gas detection.

Along with catalytic and ultrasonic gas leak detectors, hydrogen-specific flame detectors add another barrier against the propagation of hydrogen hazards. The instruments simultaneously monitor IR and ultraviolet (UV) radiation at different wavelengths. Radiation is emitted in the IR by water molecules created by hydrogen combustion. The emission from heated water or steam is monitored in the wavelength span from 2.7 μm to 3.2 μm. An algorithm that processes the modulation of IR radiation allows the detectors to avoid false signals caused by hot objects and solar reflection. The UV detector is typically a photo discharge tube that detects deep UV radiation in the 180 nm to 260 nm wavelength range. Due to atmospheric absorption, solar radiation at these wavelengths does not reach the earth's surface; thus, the UV detector is essentially immune to solar radiation. The combination of IR and UV detection improves false alarm immunity, while producing detectors that can sense even small hydrogen fires at a 15-m range.

Ultrasonic gas leak detection, catalytic gas detection, and hydrogen flame detection have different strengths and vulnerabilities. They respond to different hazard manifestations—the

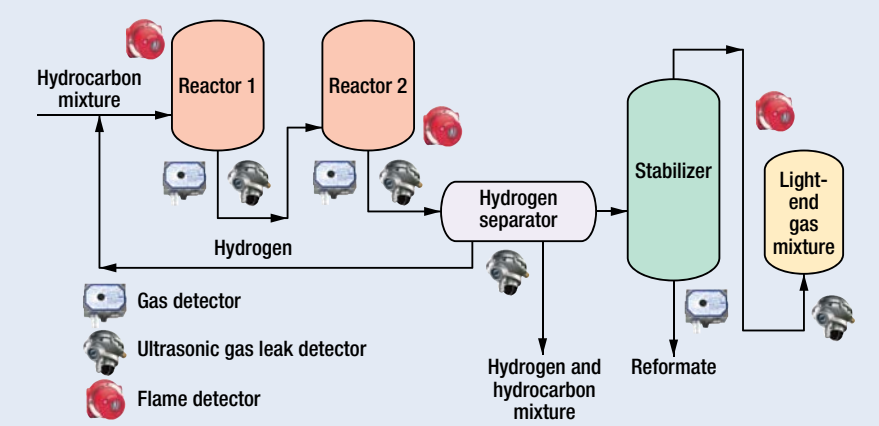


FIG. 4 Dual-stage reforming unit schematic that shows possible gas and flame detector locations.

gas, gas source or fire. Further, each technology operates in a different area of regard, with catalytic detectors as point instruments, and ultrasonic leak detectors and hydrogen flame detectors as area monitors. Due to their unique properties, combining detectors increases the odds that hydrogen gas dispersal or fire is identified early, either before ignition or when an explosion occurs.

An illustration using these technologies can be found in catalytic reforming.[1] In this process, a stream of heavy gasoils is subjected to high temperature (480°C–524°C) and pressure (1,379 kPa–3,447 kPa; 200 psi–500 psi) and passed through a fixed-bed catalyst. Upon reaction, the oils are converted to aromatics that yield much higher octane ratings for gasoline. Due to operating conditions and the continuous production of hydrogen, a rupture in the reactors, separator or unit pipe system can have grave consequences. A detector allocation across a reforming unit is shown in Fig. 4.

The scheme shown in Fig. 4 does not preclude the use of other detection systems. Nor does it eliminate the need for operating procedures, instrumentation and control systems, and adequate training—all necessary for safety. Condition monitoring instruments, like X-ray pipe-testing equipment, play a pivotal role in spotting defects before the pipe network integrity is lost. Likewise, thermal conductivity sensors can ensure detection coverage under oxygen-deficient environments and thus complement catalytic sensors when used above the lower explosive limit. Experience suggests the choice of detection instruments must be carefully weighed to match the types of hazards associated with chemical processes at the refinery, and that each offset the other's vulnerabilities.

Hydrogen production will continue to grow, fueled by environmental legislation and demand for cleaner, higher fuel grades. But rising production must be matched by a comprehensive approach to plant safety. New facilities that use hydrogen should be designed with adequate safeguards from potential hazards; the design of old facilities should also be revisited to ensure that sufficient barriers are available to minimize accidents and control failure. Safety systems that deploy a diversity of detection technologies can counteract possible leak effects, fire and explosions, thus preventing equipment or property damage, personal injury and loss of life.

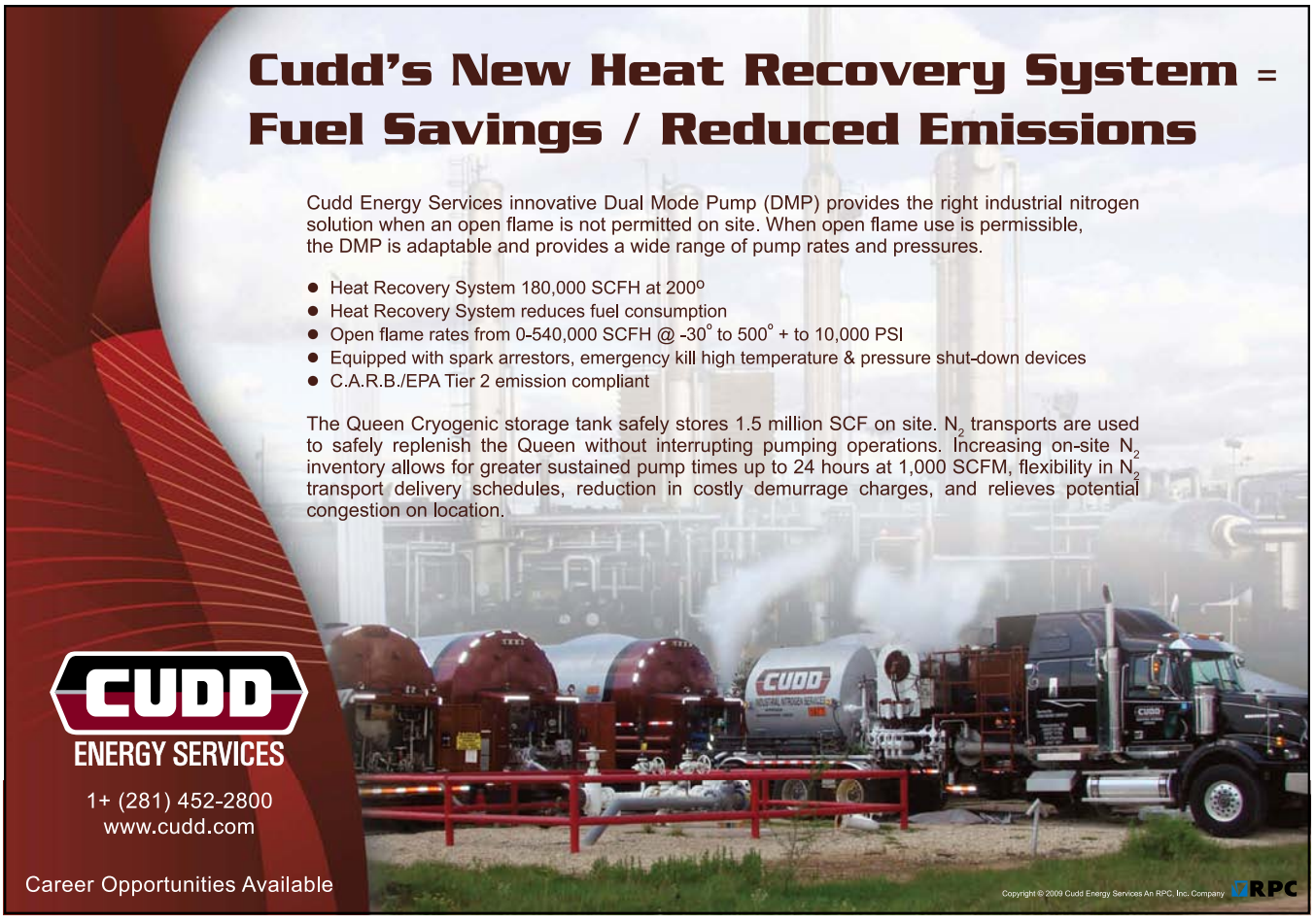
A combination of catalytic and ultrasonic gas leak monitors and fire detectors is particularly effective because they are complementary. The vulnerabilities of one are offset by the other's strengths, so there is less chance of propagating undetected hazards. Such diverse safety systems, combined with a design that prevents leakage and eliminates possible ignition sources, offer a sound approach for managing hydrogen processes. HP

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Edward Naranjo is a product manager for General Monitors, Inc. He has been with GMI for four years and contributes to product innovation and new product development, including gas imaging and ultrasonic technology initiatives. Mr. Naranjo has over 12 years of product development experience in the industrial instrumentation, healthcare and consumer packaged goods industries. He received a BS degree in chemical engineering from the California Institute of Technology and a PhD in the same discipline from the University of California, Santa Barbara. Mr. Naranjo also earned an MBA from the University of Chicago. He is the past chapter president of the Southern California Chapter of the Product Development and Management Association and is a certified new product development professional.



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Fine-tuning demercaptanization process: A case study

Optimizing caustic concentrations and reactor temperatures improved acidic compound removal without installing new equipment

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Liquefied petroleum gas (LPG) is often contaminated with acidic compounds such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), carbonyl sulfide (COS), carbon disulfide (CS_2), and methyl and ethyl mercaptans (thiols). Mercaptans in lighter feeds, such as C_3s, C_4s, LPG and naphtha, are extracted with caustic solution processes, which are also referred to as "sweetening" processes.

Sweetening processes are widely applied to remove acid compounds before transporting LPG for sale purposes. Tighter environmental rules now require reducing the sulfur content of LPG to 30 ppm. In this case study, an investigation is conducted to find a cost-effective method to treat 1.2 wt% (12,000 ppm) sulfur-content LPG streams to less than 30 ppm.

Background. LPG sweetening is a widely applied process using caustic to remove acid compounds from hydrocarbon streams. LPG desulfurization units of Iran's SPGC Phases 4 and 5 were designed and constructed to produce sweetened propane and butane with a sulfur (S) content of less than 80 ppm via caustic extraction. Due to stricter environmental regulations, these units could not meet new 30-ppm S content levels without modification. Although LPG demercaptanization by caustic is widely applied in refineries, the basic information necessary to optimize LPG units was missing. This study was initiated to identify important performance factors for the two existing sweetening/desulfurization units. Thus, optimization requirements and consequent benefits were considered.

TABLE 1. Sulfur impurities of sour propane and butane for design case, SPGC Phases 4 and 5[3]

Feed			Sour propane	Sour butane
Sulfur impurities	H_2S, ppmw	normal	Trace	Trace (<1 ppm)
		design	Trace	Trace
	COS, ppmw	normal	167	Trace (<1 ppm)
		design	118	Trace
	C_3SH, ppmw	normal	645	1,258
		design	957	840
	C_2H_5SH, ppmw	normal	59	11,300
		design	31	8,000
	C_3+ mercaptans, ppmw	normal	Trace	Trace
		design	Trace	Trace

Methods and materials. The propane and butane treatment and drying units of SPGC Phases 4 and 5 are designed to process sour propane and butane in two parallel identical trains; each train processes 50% of the total feed. Design capacity for each train is 26,350 kg/hr and 41,100 kg/hr of sour butane and sour propane cuts, respectively. The unit is designed to handle 40% to 100% of its normal capacity.[1–3]

S content and specifications for main equipment. Propane feed contains methyl mercaptan and COS with small amounts of ethyl mercaptan and only traces of H_2S (less than 1 ppm). The butane feed contains ethyl mercaptan, with small amounts of methyl mercaptan and only traces of H_2S and COS (less than 1 ppm). Table 1 summarizes the design values for S content of the feed. Table 2 lists the current mercaptans content as measured in January 2007. There is a significant decrease in the feed mercaptan amount as compared to the design specifications. According to Table 2 and other plant data collected between 2006 and 2007, the total maximum amounts of mercaptans in butane and propane feed are approximately 2,300 ppmw and 300 ppmw respectively. Specifications of the sweetening unit are listed in Table 3.

Mercaptan extraction. When hydrocarbon and caustic phase are intimately contacted, the mercaptans are absorbed into

TABLE 2. Current amount of mercaptans in sour propane and butane, SPGC Phases 4 and 5

	Total mercaptans in sour propane		Total mercaptans in sour butane	
Date	Train 1	Train 2	Train 1	Train 2
1/1/2007	223.5	183.5	1,397	
2/1/2007				2,306
3/1/2007	295.8	201.5	1,820	
4/1/2007				1,824
5/1/2007	220.6	163.5		
6/1/2007			1,522	
7/1/2007				1,812
8/1/2007	266.7	205.6		
10/1/2007			2,090	

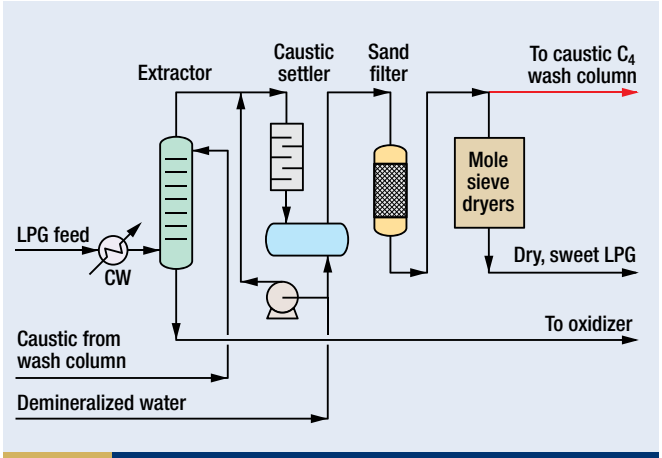


FIG. 1 Simplified process flow diagram of the extraction section.[11]

TABLE 3. Specifications of the main equipment

Equipments	Operating temperature, °C	Operating pressure, barg	
Extraction			**No. of equilibrium stages**
Propane extractor	40	29.5–31.5	15
Propane post-treatment column	70	30	7
Butane extractor	40	11.1–13.3	15
Regeneration			**Dimensions: D×L (m²)**
Oxidizer	50	5.5–6.0	1.4×14.3
DSO separator	50	5.6	2×10
C_4 washing drum	40	15.3	1.6×5

the caustic solution—sodium hydroxide (NaOH). Mercaptan distribution between two phases—water and hydrocarbon—occurs as:

I	II	
RSH	RSH	RS^-
(Oil phase)	(Aqueous phase)	(Aqueous phase)

After extraction of mercaptans by the caustic solution, sodium mercaptides are formed via this reaction equation:

$$RSH + NaOH \rightarrow RSNa + H_2O$$

Fig. 1 is a simplified process flow diagram of the extraction section. According to experimental data represented for normal butyl mercaptans and assuming that variation of K_p and K_E of C_1 to C_3 mercaptans with caustic molarity as well as temperature is similar to that of butyl mercaptan, empirical Eqs. 1 and 2 are represented for K_E and K_p of C_1 to C_4 mercaptans for two liquid phases of isooctane and caustic solution.[4] These equations have shown good agreement with experimental data of C_1 to C_3 mercaptans extraction via caustic:

$$\log K_p = -5.856 \times 10^{-3} \log T + A \quad (1)$$

Where K_p is the partition coefficient and is defined by Eq. 2 when the pH is low enough to prevent acid ionization:

$$K_p = \frac{[RSH]_{aq}}{[RSH]_{oil}} \qquad \text{Since } [RS^-] = 0$$

$$\log K_E = -12.305 \log T + B \quad (2)$$

TABLE 4. Constants A and B for Eqs. 1 and 2[4]

Mercaptan structure	A	B		
		Caustic molarity: 4.25	Caustic molarity: 2.97	Caustic molarity: 1.85
Methyl mercaptan, CH_3SH	0.20235	33.7160	33.6521	33.5074
Ethyl mercaptan, C_2H_5SH	0.05715	33.0043	32.9154	32.7771
Propyl mercaptan, C_3H_7SH	0.02398	32.135	32.117	32.020
Butyl mercaptan, C_4H_9SH	0.01617	31.297	31.28	31.263

Where K_E is extraction coefficient considering acid ionization and is defined as:

$$K_E = \frac{(RS^-)_{aq} + (RSH)_{aq}}{(RSH)_{oil}}$$

Constants A and B are available in Table 4. Constant B in Table 4 depends not only on mercaptan structure but also on caustic molarity. Using experimental, constant B is developed by Eqs. 3 and 4 for C_1 and C_2 mercaptans:[4]

$$B = 0.3504\text{Ln}(M) + 33.267 \quad \text{for methyl mercaptan} \quad (3)$$

$$B = 0.3112\text{Ln}(M) + 32.571 \quad \text{for ethyl mercaptan} \quad (4)$$

As sodium mercaptides form in the caustic solution, the solution's ability to extract mercaptans decreases, due to salting out. The salting out effect is best represented by Eq. 5:[4]

$$\log \frac{S_o}{S_c} = KC \quad (5)$$

So Solubility in water
Sc Solubility in salt solution
C Salt concentration in water
K Salting-out constant

K = 0.075 For ethyl mercaptan
K = 0.181 For n-butyl mercaptan

Caustic regeneration. Rich caustic solution, leaving the extractor, is directed to an oxidizer, and air is injected into this stream. The mixture flows upward through the oxidizer where alkaline is regenerated by conversion of sodium mercaptides to disulfides with CoSPc (sulfonated cobalt phthalocyanine) as catalyst. The separated alkaline solution is recirculated to the extractors. In this process, the catalyst and alkaline solution are regenerated (Eq. 7) and recycled:

$$2RSNa + 0.5O_2 + H_2O \rightarrow RSSR + 2NaOH$$

Fig. 2 is simplified process flow diagram for the caustic regeneration section. Using experimental data represented in the literature, the kinetic equation of mercaptide oxidation in an alkaline medium by molecular oxygen is developed as a function of temperature:[5–7]

$$RSNa = \frac{K_1 K_p [R\bar{S}][Kt][O_2]}{1 + K_p[O_2] + K_r[RSSR]} \times 2.7667 \times 10^{-6} \exp(0.0385 \times T) \quad (6)$$

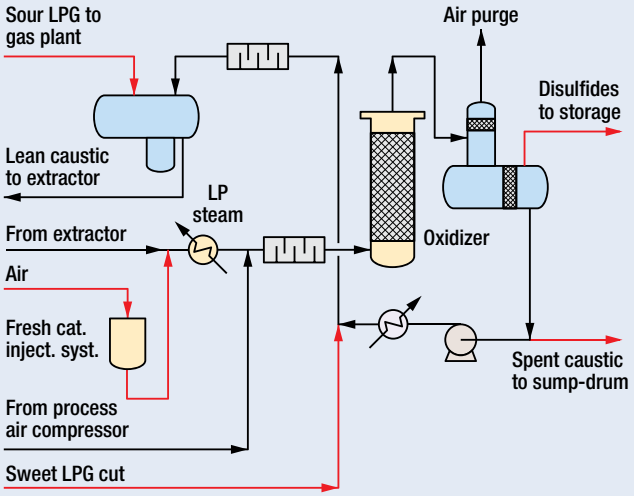


FIG. 2 Advanced process flow diagram of extraction section.[11]

TABLE 5. Minimum required caustic concentration for product purity under specified conditions

Ethyl mercaptan in the butane product, ppmw	Minimum required caustic concentration, wt%
4.5	16
5	15.5
5.5	14.93
10	13.6
20	12.4
30	11.8
80	10.2
Ethyl mercaptan in sour butane, ppmw	2,500
Temperature, °C	40
Mass ratio of caustic solution to butane	0.2061
Caustic flowrate, kg/hr	26,340.1

The constants in Eq. 6 are:

$K_1K_p = 2.07 \times 10^{-2}$ m^3 / [Pa-mole-s]

$K_p = 1.1 \times 10^{-4}$ Pa^{-1}

$K_r = 950$ m^3/mole

The concentration of mercaptide ion [RS$^-$], catalyst [*Kt*] and disulfides [RSSR] are expressed in mole/m^3. The concentration of oxygen [O_2] is specified in Pa. The term [RSSR] reflects the interfacial mass transfer effects and is determined from the experimental data of $[RSH]_{oil}$ vs. time and then calculated by subtracting the $[RSH]_{oil}$ at a particular time from the initial concentration.[6–8]

Molecular structure. According to the experimental data, although increasing the molecular weight of mercaptans has negligible influence on ionization constant, it decreases mercaptan solubility in water and thus K_E.

Caustic concentration and extraction efficiency. Increasing caustic molarity will increase the extraction coefficient. However for C_3^+ mercaptans, this effect increases up to a caustic molarity of 3. After this point, the salting out phenomena occurs. Thus, the partition coefficient (K_p) decreases, and the K_E does not increase greatly due to the caustic molarity. Experiments showed that up to caustic concentration of 2.75 molar mercaptans conversion to mercaptides will rapidly reach to 92%; thereafter, increasing the caustic concentration is not so important.[9]

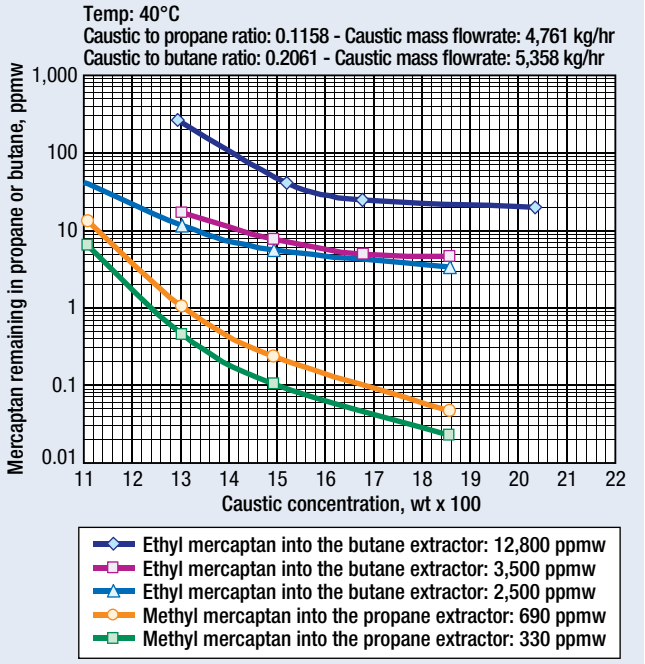


FIG. 3 Simulation results of propane and butane purity vs. caustic concentration in sweetening process.

Simulation results of propane and butane purity vs. caustic concentration are presented in Fig. 3 for design and actual operating conditions. For caustic concentrations greater than 13 wt%, the mercaptan content of the propane products was reduced below 0.5 ppm. Table 5 summarizes the minimum required caustic concentration to reach specific product purity for assumed mercaptan content and conditions. To process present mercaptan content for sour propane and butane, the optimum caustic concentration is 14.93 molar. Thus, the mercaptan impurity will fall to 0.1 ppmw and 5 ppmw in propane and butane products, respectively.

However, for the normal design case in Table 1, Fig. 3 shows that, by applying a caustic concentration of 14.93 wt%, under specified conditions, only 0.3 ppmw and 50 ppmw methyl mercaptan and ethyl mercaptan remains in the treated propane and butane products, respectively.

Temperature and extraction efficiency. Results from experiments treating butyl mercaptan with two liquid phase of 0.5 molar caustic and isooctane at different temperatures shows that the partition coefficient (K_p) is independent of temperature and mercaptan ionization constant decreases with lower temperatures. However, the extraction coefficient is enhanced with decreasing temperatures since the hydrolysis ($K_h=K_w/K_A$) constant likewise decreases:[4]

$$K_w = \frac{[H^+][OH^-]}{[H_2O]} = [H^+][OH^-]$$ Water ionization constant

$$K_A = \frac{[RS^-][H^+]}{[RSH]}$$ Mercaptan ionization constant

$$K_h = K_w / K_A$$ Hydrolysis constant

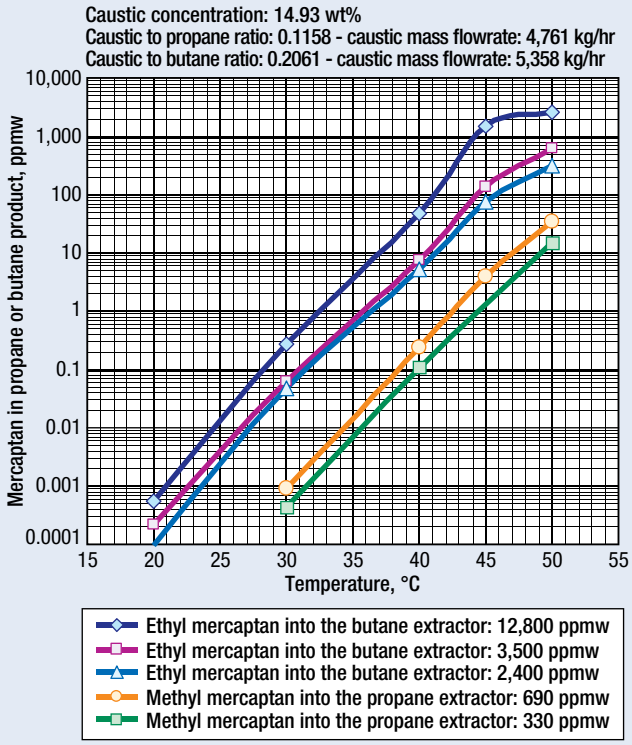


FIG. 4 Purity of the propane and butane products as a function of temperature based on simulation results.

TABLE 6. Maximum practical temperature according to product purity under specified conditions

Ethyl mercaptan in butane product, ppmw	Maximum practical temperature, °C
5	40
10	41.5
30	43
80	45
Ethyl mercaptan in sour butane, ppmw	2,500
Caustic concentration, wt%	14.93
Mass ratio of caustic solution to butane	0.2061
Caustic flowrate, kg/hr	26,340.1

According to the experiments, mercaptan extraction is favored at lower temperatures. Simulation results of propane and butane purities vs. temperature are presented in Fig. 4 for design and actual operating conditions. As expected, reducing process temperature will improve mercaptan extraction. Temperatures lower than 44°C yield a mercaptan content of less than 1 ppmw in the propane product, under the specified conditions in Fig. 4. Maximum practical temperatures for butane products with different specifications are summarized in Table 6.

Data from Table 6 illustrate the significance of temperature control in the butane extractor. Although reducing temperature will enhance extraction efficiency; other processing effects are possible:

- For temperatures lower than 20°C, caustic entrainment problems will occur.
- At lower temperatures, sodium sulfide and carbonate salts will precipitate out of the caustic solution and possibly cause plugging problems.

The upper temperature limit is 45°C, because the mercaptan extraction efficiency begins decreasing. Since temperatures of the sour propane and butane from the NGL fractionation unit are 60°C and 40°C, respectively, the optimum temperature of 40°C for both extractors is recommended to achieve less than 10 ppmw mercaptan concentration in the product under specified conditions.

TABLE 7. Minimum practical caustic flowrate according to product purity, under specified conditions

Methyl mercaptan in the propane product, ppmw	Mass ratio of caustic solution to propane
0.1	0.1158
1	0.1020
5	0.0930
10	0.0890
30	0.0800
Ethyl mercaptan in sour butane, ppmw	330
Temperature, °C	40
Caustic concentration, wt%	14.93
Caustic flowrate, kg/hr	41,113.22

TABLE 8. Minimum practical caustic flowrate according to product purity under specified conditions

Ethyl mercaptan in the butane product, ppmw	Mass ratio of caustic solution to butane
5	0.2060
10	0.1960
20	0.1804
30	0.1708
Ethyl mercaptan in sour butane, ppmw	2,500
Temperature, °C	40
Caustic concentration, wt%	14.93
Caustic flowrate, kg/hr	26,340.1

Caustic flowrate and extraction efficiency. Caustic consumption—kg of 100% NaOH per metric ton of feedstock—for a given treating level is directly related to the initial caustic solution concentration, initial mercaptan concentration in the feedstock and product purity. Experiments with refinery tests on LPG demercaptanization units have confirmed that, if the mercaptan content entering an equilibrium stage, is very high, then NaOH solution saturation with mercaptans is a limiting factor for extraction.[10] Studies have shown that the saturation value, expressed in moles S^{-2} per mole NaOH, does not depend on the initial mercaptan content in the product being treated. This saturation value decreases with increasing initial caustic solution concentration. For a given treating level and NaOH solution concentration, the saturation value is constant.

Considering the saturation capability of caustic solution as a function of caustic concentration, Eqs. 7 and 8 are regression equations that describe the experimental data:[10]

$$Y_2 = 0.350 - 0.00X_1 \quad (7)$$

Y_2 Saturation of the caustic solution for averaging, moles S^{-2}/mole NaOH

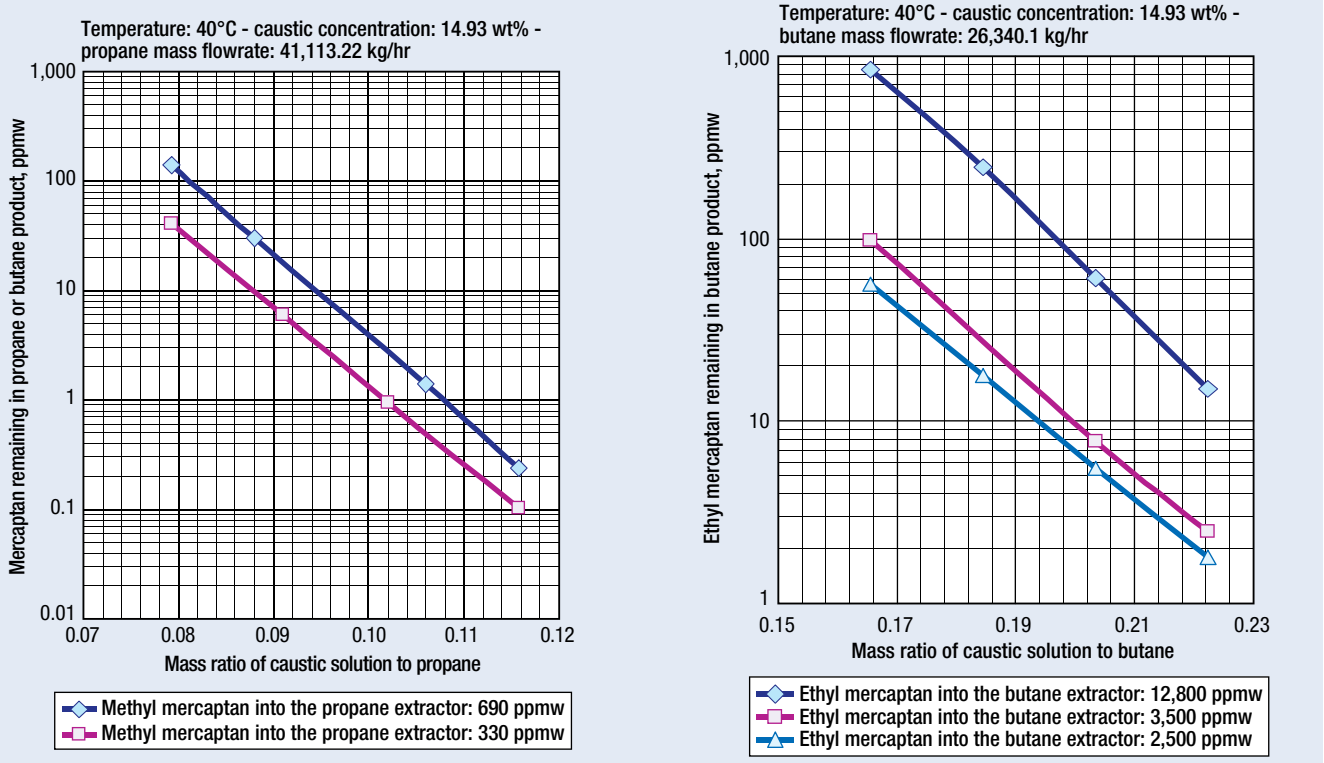


FIG. 5 Purity of the propane and butane products as a function of caustic flowrate based on simulation results.

X_1 NaOH weight fraction in caustic solution × 100

$$Y'_2 = 0.624 - 0.016X_1 \quad (8)$$

$Y'2$ Saturation of the caustic solution for breakthrough, moles S^{-2}/mole NaOH

X_1 NaOH weight fraction in caustic solution × 100

Simulation results shown in Fig. 5 and Tables 7 and 8, represent the required caustic (NaOH) amount based on the impurities levels before and after treatment, under the specified conditions.

Based on these results, 0.102 kg of caustic solution of 14.93 wt% (0.015 kg pure NaOH) per kg of propane and 0.210 kg of caustic solution of 14.93 wt% (0.032 kg pure NaOH) per kg of butane guarantee propane product and butane product with mercaptan impurities of 1 ppmw and 5 ppmw, respectively. **Result:** Higher purity marketable products are now available.

Mercaptan structure and regeneration efficiency. From experimental reaction results for several sodium mercaptides with different structures at similar conditions, it can be found that the more complex the structure of sodium mercaptide the slower the oxidation rate.[2] Tert-butylmercaptide is one of the most difficult mercaptides to be oxidized due to its high steric and inductive effects.[8]

Stability in LPG sweetening. With continuous unit operations, the catalyst will deplete; sweetening efficiency will deteriorate and the alkaline solution must be replaced frequently. This will increase operating costs as well as cost for waste disposal of the alkaline solution.

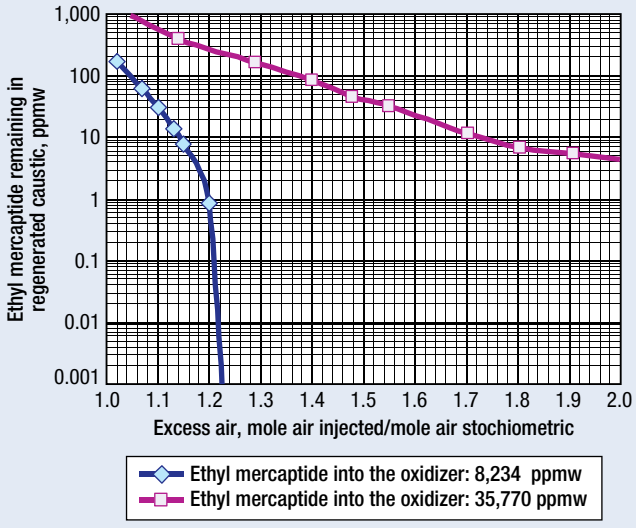
Using operating data, engineers ran simulation models that more accurately respresented the 'sweetening' process for this gas plant.

The colorimetry of the CoSPc—a reliable means for deactivation measurement—shows that the catalyst activity at room temperature is greater than that of higher temperatures. From the literature, adding catalyst to previously prepared caustic solution can provide the highest conversions.[8]

Air injection and caustic regeneration efficiency. The stoichiometric amount of oxygen to oxidize sodium mercaptides is 0.25 mole of oxygen per mole of sodium mercaptide. However, it is necessary to inject excess air into the oxidizer to enhance reaction efficiency. This excess air depends on the sodium mercaptides concentration in the inlet caustic solution.

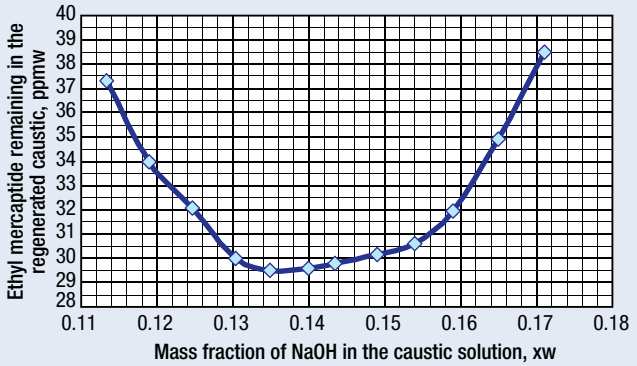
For an initial mercaptide content of 35,770 ppm at the inlet, approximately 200% excess air is needed to reach to 5 ppmw ethyl mercaptide content at the outlet. Considering the actual conditions, 1.16% excess air will yield the same ethyl mercaptide concentration (5 ppmw) in the caustic solution, leaving the reactor if 8,680 ppm of mercaptide is associated with the feed entering the reactor. However, there are some key points:[3]

1) While a low mercaptan concentration is desirable, the caustic solutions should never be completely regenerated via high excessive air rates. In the absence of mercaptans, traces of oxygen can dissolve in the circulating caustic and cause sweetening to



For caustic solution containing 8,234 ppm ethyl mercaptide:
Required Inlet concentration of caustic:12.5 wt% (dealing with not prewashed propane)
Outlet concentration of caustic: 14.93 wt%, oxidizer top to bottom temperature:40°C-50°C
Mass flowrate of caustic solution:13,851.9 kg/hr
For caustic solution containing 35,770 ppm ethyl mercaptide:
Required Inlet concentration of caustic:14.54 wt%
(if propane is prewashed)
Outlet concentration of caustic: 14.93 wt%, oxidizer top to bottom temperature: 40°C-50°C
Mass flowrate of caustic solution: 14,300.3 kg/hr

FIG. 6 Sodium mercaptide in regenerated caustic as a function of excess air based from simulation results.



Inlet caustic containing 8,234 ppm ethyl mercaptide:
Oxidizer temperature from top to bottom:40°C-50°C
Excess air: 110%
Mass flowrate of caustic solution: 13,851.9 kg/hr

FIG. 7 Sodium mercaptide in regenerated caustic vs. caustic concentration based on the simulation results.

occur in the extractor; the disulfides will then return to the LPG phase and increase the product's total sulfur content.

2) Small levels of mercaptides in the caustic (30 ppmw–50 ppmw) keep the catalyst dispersed. Thus, the catalyst does not accumulate at the rich-disulfide caustic interface in the disulfides separator.

Consequently, regenerated caustic must hold 30 ppmw–50 ppmw sodium mercaptide. In Fig. 6, the present unit operates with 8,234-ppmw sodium mercaptide concentration at the inlet of the oxidizer, and 108%–110% excess air is the optimum value. The oxygen level in the air leaving DSO separator must range between 1.5% and 2%.

Caustic concentration and regeneration efficiency. Caustic solution as a reaction medium has an optimum concentration of 1.8–1.9 molar, which supports 75% conversion. While increasing the caustic concentration to 3.8 molar is still practical; the high levels only yield 70% conversion. Consequently, very high caustic concentrations are not beneficial to regenerating NaOH. To explain the regeneration reaction kinetics, there are two points. First, when increasing the concentration of caustic solution, the solubility of CoSPc catalyst will decrease catalyst dispersion in the solution. Second, higher alkaline solutions have greater viscosities, which hinders the transfer of free radical in the radical oxidation reaction of mercaptides.[7,8]

Experimental results suggest an appropriate alkaline concentration of 2.75–4.25mol/dm^3 for the sweetening of LPG. Fig. 7 shows the simulation results over the effect of caustic concentration on the rate of mercaptide oxidation. Rich caustic solution in the oxidizer is mixed with air as oxidant. Thus, variations of caustic molarity by mass fraction of NaOH in solution are not the same as molarity variations of pure caustic solution by its composition, as listed in Table 9.

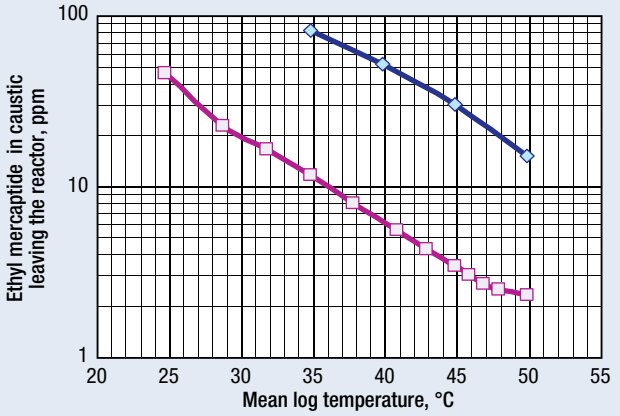
TABLE 9. Variations of caustic molarity by mass fraction of sodium hydroxide in solution

Pure caustic solution		Caustic solution mixed with 110% excess air under conditions of Fig. 7	
Mass fraction of NaOH×100	Molarity of NaOH in the solution	Mass fraction of NaOH×100	Molarity of NaOH in the solution
17.8	5.223	17.1	2.18
14.9	4.288	14.5	1.98
14.1	4.016	–	–
12.9	3.626	–	–
11	3.007	11.3	1.78

Since regenerated caustic is recycled from the oxidizer to the extractors, the concentration of regenerated caustic at the reactor outlet must be the same as the caustic concentration entering the extractor. Caustic concentration at the reactor inlet is specified as a function of the sodium mercaptides concentration to be oxidized to NaOH and the caustic concentration at the inlet of the extractors.

For present plant conditions, 8,200 ppmw of sodium mercaptide is oxidized to NaOH. The optimum caustic concentration to the extractors and, thus, recycling from the oxidizer is 14.93%. Consequently, the caustic concentration from the extractors to the oxidizer must be increased from 12.2 wt% to 14.5 wt% at the oxidizer inlet. Accordingly, 884.41 kg/hr of fresh caustic (solution of 40% wt) makeup is mixed with the rich-caustic solutions from the extractors. Referring to Fig. 7, 30 ppmw of sodium mercaptide will remain in caustic solution, which is a desirable level. **Note:** SPGC Phases 4 and 5 propane is not prewashed; thus, a large volume of fresh caustic is required.

Temperature and efficiency of caustic regeneration. Temperature is one of the most important factors influencing reactions. To oxidize propane mercaptide, the optimum temperature based on oxidizer performance ranges between 40°C–50°C.



Inlet caustic containing 8,234 ppm ethyl mercaptide:
Required inlet concentration of custic: 12.5 wt (if propane is not prewashed
Excess air: 110%
Mass flowrate of caustic solution: 13,851.9 kg/hr

Inlet caustic containing 35,770 ppm ethyl mercaptide:
Inlet concentration of caustic: 14.54 wt% (if propane is prewashed)
Excess air: 200%
Mass flowrate of caustic solution: 14,300.3 kg/hr

FIG. 8 Sodium mercaptide in regenerated caustic as a function of temperature based on the simulation results.

However, the oxidizer temperature should always be kept as low as possible considering catalyst activity while still maintaining the desired degree of mercaptans regeneration. In any event, 55°C would be considered as an absolute maximum temperature because of metallurgical limitations and also the possibility of disulfide oils decomposing into sulfonic acids.

Based on simulation results, Fig. 8 shows the effect of oxidizer temperature on the conversion of sodium mercaptide. The results are presented for two cases—design and actual operating conditions. The extraction of 2,500 ppmw of ethyl mercaptan from butane and 330 ppmw of methyl mercaptans from propane by caustic will yield 8,234 ppmw of sodium mercaptide in the caustic solution at the oxidizer inlet (Fig 8). Since this is an endothermic reaction, if the sodium mercaptide content of the caustic at the reactor inlet is 8,234 ppmw, then the reactor top and bottom optimum temperatures should be approximately 45°C and 50°C, respectively under mentioned conditions in Fig. 8. **Remember:** At least 30 ppm of RSNa must remain in regenerated caustic.

Outlook. According to the results, caustic concentration of 14.93 wt% and temperatures of 40°C are optimum values for extractors. The required amount of caustic to extract mercaptans can be selected according to the purity of the product, as shown in Tables 7 and 8. When considering caustic regeneration conditions, amount of air injection to the oxidizer is a key factor affecting the sweetening process efficiency. Approximately 30 ppm–50 ppm of sodium mercaptide must be included in the circulating caustic. Fig. 6 shows the required air amount for specified conditions. The optimum log mean temperature of the oxidizer is 40°C to 45°C depending on the impurities concentration. The optimum caustic concentration of 1.9 molar after mixing with air is the optimum value within the oxidizer, which can be adjusted by fresh caustic makeup. However, the required concentration of recycling caustic to the extractor as well as the amount of sodium mercaptide impurities in the rich caustic are limiting factors for the unit and should be considered when defining the required concentration of the inlet caustic to the oxidizer.

High-purity propane and butane products were obtained in SPGC Phases 4 and 5 when operating variables were adjusted. LPG with mercaptan content less than 10 ppm is sold at $ 3/ton to $4/ton—more than present LPG prices. Consequently, optimizing this unit resulted in a total net income increase of $2.9–$3.9 million/yr. This task is achieved without new equipment installed or equipment modifications. The results were possible by only fine-tuning operational process parameters with some extra caustic consumption reduction. **HP**

NOMENCLATURE

K_p	Partition coefficient
K_E	Extraction coefficient
S_o	Solubility in water
S_c	Solubility in salt solution
C	Salt concentration in water
K	Salting-out constant
r_{RSNa}	Reaction kinetic of sodium mercaptide oxidation
K_W	Water ionization constant
K_A	Mercaptan ionization constant
K_h	Hydrolysis constant
Y_2	Saturation of the caustic solution for averaging (moles S^{-2}/mole NaOH)
Y'_2	Saturation of the caustic solution for breakthrough (mole S^{-2}/mole NaOH)
X_1	NaOH weight fraction in caustic solution×100
T	Temperature
x_w	Weight fraction

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What are the opportunities to construct liquefaction facilities at the Arctic Circle?

Building and operating natural gas plants in the high latitudes pose numerous challenges

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Locating natural gas liquefaction installations around the Arctic Ocean for export markets poses many challenges. This region is hostile with many changing environmental obstacles. As shown in Fig. 1, many hurdles must be addressed when constructing and operating a liquefied natural gas (LNG) facility. Yet, the potential oil and gas resources located at the Arctic region draw global interest. Several formidable obstacles must be addressed in conquering this region to develop these new energy resources.

Arctic Ocean and its margins. The Arctic Ocean is a vast, remote and inhospitable region. A substantial portion of its continental shelf lies off the north coast of Russia, which is where most of the human settlements proximate to the Arctic Ocean are located (Fig. 2). The North Pole is surrounded by the Arctic Ocean. Five countries surround the Arctic Ocean: Russia, the US (via Alaska), Canada, Norway and Denmark (via Greenland). Currently, these nations' claims to sovereignty over the Arctic continental shelf are limited to a 200-nautical mile (nm)—approximately 370-km—economic zone bordering their coasts. Under international law, no country can claim sovereignty to the areas surrounding the North Pole. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) provides a country with a 10-year period to make claims to extend its 200-nm zone. Due to this, Norway (ratified UNCLOS in 1996), Russia (ratified UNCLOS in 1997), Canada (ratified UNCLOS in 2003) and Denmark (ratified UNCLOS in 2004) have launched claims under the convention that certain Arctic sectors should belong to their territories.[1] The US has signed, but not yet ratified this treaty. Because of the potential mineral resources possibly existing

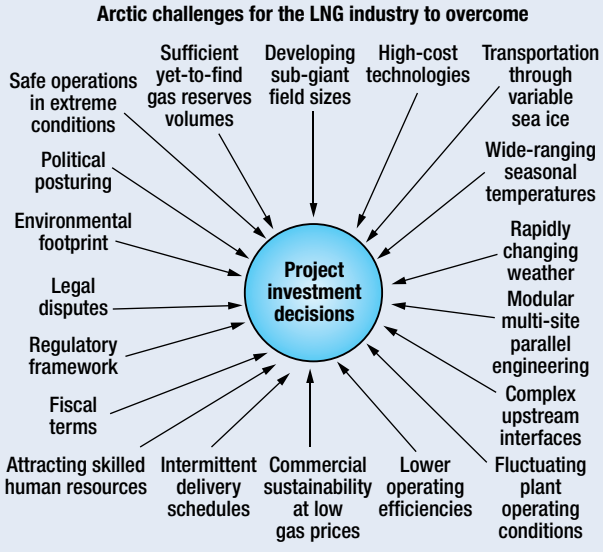


FIG. 1 Challenges of exploiting Arctic Ocean natural gas resources with LNG supply chains.

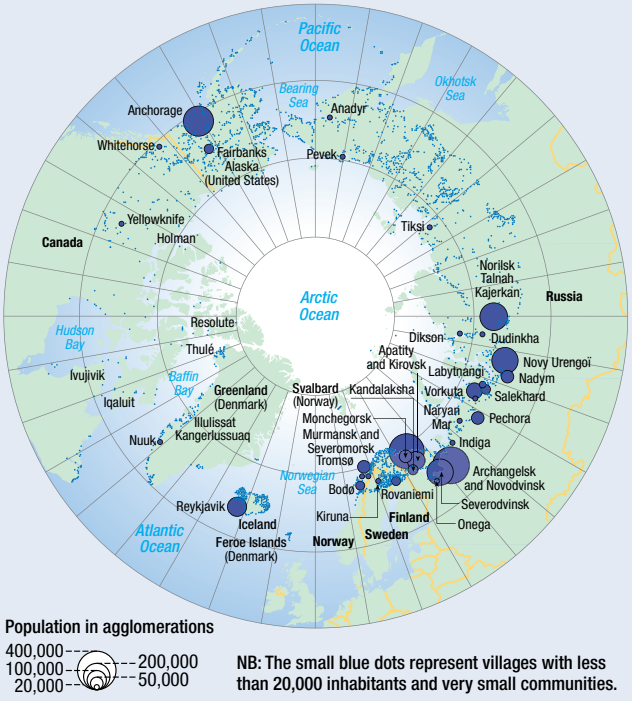


FIG. 2 The Arctic Ocean and its surrounding settlements. Source: UNEP/GRID-Arendal Maps and Graphics Library, 2005.[9]

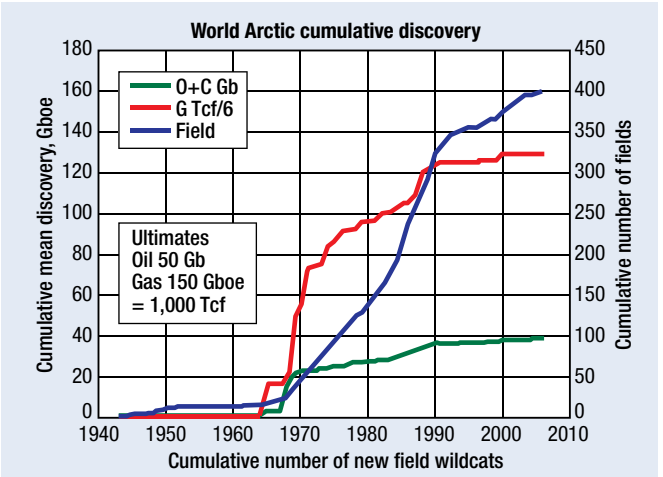


FIG. 3 World Arctic cumulative discovery of oil and gas resources through to the end of 2006.[3]

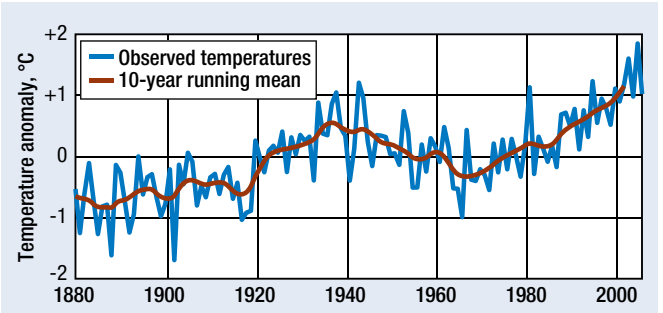


FIG. 4 Trends in Arctic temperature, 1880–2006. Source: CRUTEM3v dataset, Climate Research Unit, University of East Anglia.[10]

in the deeper waters of this region and the ability to control strategic shipping routes, there is significant competition and political maneuvering by these nations to optimize the size of their claims. It is therefore unlikely that clearly defined and internationally agreed borders covering the entire Arctic Ocean region will be available in the near future. Some resource development could be delayed due to potential international disputes over such borders.

How much petroleum exists in the Arctic? There is much uncertainty concerning the volumes of oil and gas that exist and can be commercially recovered from Arctic regions. Some speculate that between one quarter and one third of all remaining oil and gas reserves to be found worldwide could possibly be located in the Arctic regions. A study by Wood Mackenzie reported a more conservative view that 233 billion barrels of oil equivalent (boe) of oil and natural gas combined has already been discovered in Arctic basins.[2] It is estimated that some 166 billion boe remain undiscovered (yet-to-find). That report identified the South Kara-Yamal basin and the East Barents Sea in Russia, along with Greenland's Kronprins Christian basin to have yet-to-find resources greater than 10 billion boe. However, only the South Kara-Yamal basin and the East Barents Sea were considered to offer yet-to-find potential in pool sizes of over 1 billion boe.

An even more conservative view is expressed by the IHS database (February 2007) for existing Arctic fields and New Field Wildcats (NFW) for Russia, Europe (Norway and Svalbard) and North America (US and Canada) north of 66°33'39".[3] Fig. 3

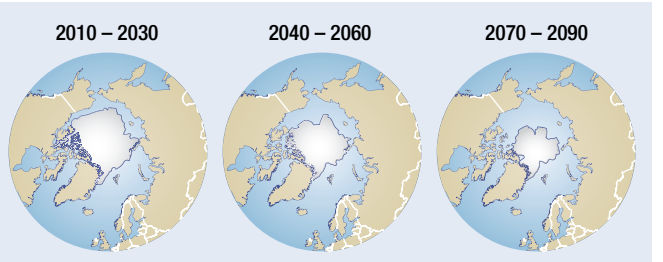


FIG. 5 Forecast impacts of warming Arctic: Arctic Climate Impact Assessment. Source: Cambridge, UK: Cambridge University Press.[11]

shows extrapolated discovery trends of the second report, which used mathematical models to estimate ultimate recoverable petroleum reserves of 50 billion barrels of oil and 1,000 trillion cubic feet (Tcf) of natural gas for a combined 217 billion boe. Although this study excludes Greenland, it does highlight that most land sections of the Arctic are already well explored and can be used reliably to estimate yet-to-find resources.

With much exploration to be undertaken, it is no surprise that yet-to-find estimates vary widely. However, there is a consensus among analysts that approximately three-quarters of the reserves in the Arctic Ocean sedimentary basins are natural gas. The major oil and gas companies are attracted by the potential of finding other giant fields such as the Shtokman in the Barents Sea.

For the global gas consumers and long-term sustainability of natural gas as a major global energy source, a more significant challenge is advanced technologies that can cost-effectively develop the numerous smaller-sized gas fields of the Arctic Region. These methods, in addition, could be applied to the few giant gas fields that remain undiscovered and could be developed using existing technologies and resource approaches. In this case, the technological focus should be on *how to commercially develop and transport* a large portion of these gas resources to global markets, not just on how to develop a few giant fields.

Changing Arctic climate opens new frontier. Although some debate remains over the causes of higher global temperatures, the evidence and consequences of climate change are nowhere more evident than in the Arctic Ocean and its margins. The consequences of a rising Arctic temperature trend (Fig. 4) according to scientific models are likely to be quite rapid and cause substantial contraction of sea ice (Fig. 5). The continental margins of the Arctic Ocean are also likely to see environmental changes due to higher mean annual temperatures before the end of the century (Fig. 6).

Contemporary conditions around the Arctic Ocean continental shelf vary substantially. For instance, whereas the Barents Sea remains ice-free even in winter (due to the influence from the Gulf Stream), the Chukchi Sea is ice-locked in winter. Changing marine currents could have significant consequences for local ice conditions, and these are more difficult to predict. Accordingly, there is much uncertainty over which regions will become navigable in winter by shipping, including LNG carriers. The Arctic Ocean will, under all climatic scenarios, remain a challenging nautical environment to navigate and this will require special ship designs. In terms of oil and gas operations, extreme cold and limited winter daylight pose both operational and human endurance challenges.

The longer-term global consequences of such dramatic changes in the Arctic Ocean (e.g., rising sea levels and less predictable weather patterns) are more difficult to forecast and may have significant overall

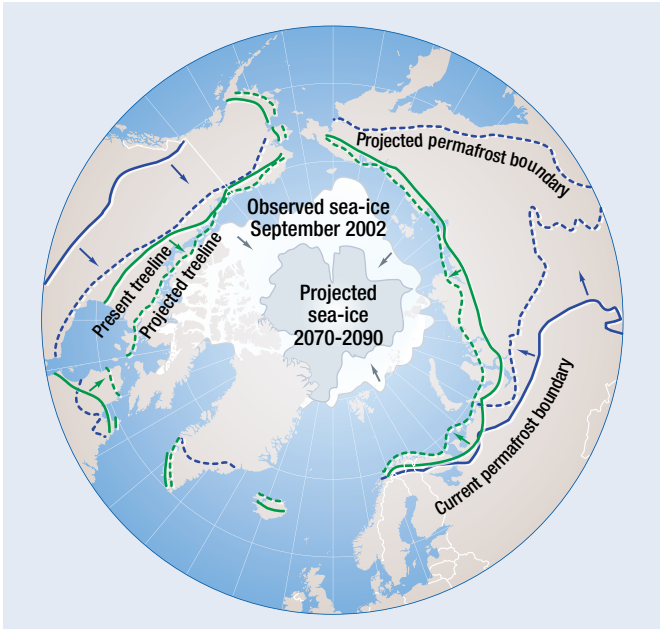


FIG. 6 Impacts of a warming Arctic. Source: Arctic Climate Impact Assessment (ACIA), 2004, and UNEP/GRID-Arendal Maps and Graphics Library.[9,12]

negative sustainability consequences. However, the medium-term implications of such scenarios are: a greater number of Arctic sea ports will be ice free during the winter; a greater area of the Arctic Ocean will be navigable for shipping; and easier access to oil and gas resources beneath the Arctic continental shelf. It is likely that countries and corporations will make efforts to exploit such opportunities.

The potential of access to additional petroleum resources and the opening of a new exploration and development frontier are stimulating many in the petroleum industry. The energy industry is becoming excited about these opportunities and is seriously considering the technological challenges associated with exploiting Arctic resources. One of the first indications of institutional cooperation is the agreement reached in April 2008 between the American Bureau of Shipping and the Russian Maritime Register of Shipping to jointly develop classification rules for Arctic LNG carriers.[4] This agreement came in the wake of the Shtokman Development Co. preparing plans for the giant Shtokman gas field (>100 Tcf of reserves) in the Barents Sea. Russia, following Norway's Snøhvit LNG project (onstream September 2007), is known to be planning substantial gas liquefaction facilities along its northern coast to enable worldwide exports of its gas resources. Among the Russian oil industry's plans under consideration is an LNG plant in Teriberka on the Barents Sea coast, along with a plant in the Yamal Peninsula. Russian state-owned gas monopoly Gazprom and its subsidiary Sevmorneftegaz expect that 25 new LNG tankers will be required in connection with the Shtokman project. No surprise that the LNG shipping industry is showing interest.

Liquefaction at high latitudes. Cold average annual temperatures are actually beneficial for operating efficiencies and energy consumption by cryogenic facilities, regardless of the technology applied. For example, cold ambient temperatures enhance gas-turbine power outputs. In the Arctic region, it is not, therefore, the average annual temperature, which is low (close to 0°C, the point at which fresh water freezes), that poses the challenge to gas liquefaction. Rather, it isthe seasonal temperature and weather variations



FIG. 7 Arctic LNG shuttle Höegh LNG. The photo is used with permission from Höegh LNG.

that are largely the challenges for LNG facilities and operating equipment. Winterization technologies are required to restrict icing at the air and gas inlets and initial chilling plants, but these units can require frequent adjustments as weather conditions vary widely leading to inefficiencies.[5] The propane refrigerant cycle provides the initial chilling in the most commonly licensed liquefaction processes and is responsible for taking temperatures down to the –35°C to –40°C. The cycle is also used to liquefy and separate substantial volumes of gas liquids from the feed gas. To improve initial cooling cycle efficiencies under Arctic conditions may require replacing propane as a refrigerant with a lower boiling point gas (e.g., ethane or ethylene) or a multi-component mixed refrigerant.

The ability of liquefaction plants to benefit from theoretical higher efficiencies at cold temperatures depends upon the design temperatures for these Arctic plants and their design operating strategies. If the average annual temperature is used as a fixed-design temperature, losses due to higher than average temperatures (assuming a rate of 1.8%/°C) significantly outweigh gains attributable to more efficient condenser performance at lower than average temperatures, as plant capacities are varied to achieve annual production quotas.[6] Conversely, fixing the design throughput capacity and raising design temperatures (above average ambient conditions) to achieve that capacity can lead to higher total efficiency, but at higher capital costs.[5]

If liquefaction plants are to be operated at varying throughput capacities dependent on changing ambient temperatures, then the feed gas and LNG shipping logistics must be adjusted to cope with such variations. This may not always be possible. For instance, colder weather conditions may lead to shipping delays at a time when the plant is capable of maximum output. The liquefaction plant operators will have to balance the economic benefits of larger-capacity train installations, optimum design configuration from an operating perspective, and the challenges of constructing and operating the plant at remote sites under adverse and variable weather conditions.

Limited winter daylight hours, more costly human resources and difficult construction logistics also have to be acknowledged as major contributions to greater capital and operating costs and extended project schedules. The very large cost overruns vs. the originally sanctioned budgets experienced by the StatoilHydro-operated Snøhvit LNG plant, and the Shell-operated Sakhalin LNG plant during their construction phases, and the significant and costly teething problems experienced by the former testify that installing liquefaction plants at high latitudes has substantial associated cost penalties.

Modular and offsite construction of major components offer a partial solution to some of these problems. But careful upfront planning, extensive front-end engineering and design evaluations and parallel engineering, procurement and construction methodologies would be necessary to effectively execute such projects. Multi-site operations themselves pose challenges due to resource procurement, integrated planning, control, regulatory and fiscal complexity.

Operations and maintenance issues. Winterization of gas processing and liquefaction plants is necessary to prevent fluid freezing, liquid drop-out, and wax and hydrate formation. Elements of gas-processing plants, pre-cooling refrigeration cycles and air-cooling systems are most likely to experience such problems. Systems that facilitate rapid responses to short-term changes in weather conditions are required. Rotating equipment such as pumps, power generators, and refrigerant gas turbine and compressor units will require heated and ventilated buildings to house them. Plant layouts should facilitate easy access to equipment by maintenance staff so that both routine maintenance and emergency responses can be conducted in a safe and timely manner. In fact, plant and equipment access under extreme weather conditions need careful consideration. Compressors, pumps, valves, air coolers, wellheads, etc., require sheltered containment that facilitates easy access and enables both staff and equipment to withstand extreme conditions.

Arctic LNG shipping. The first ice-class LNG vessels are about to enter service for the Sakhalin-II project in eastern Russia. Five new LNG ships will service the liquefaction terminal at Prigorodnoye in Aniva Bay. Three were built in Japan with the Moss-type independent tank and hulls designed to Finnish-Swedish ice-class 1B standard; two ships were built in South Korea, each with different membrane tank designs. All five ships have their propeller and line shafting built to the Russian Maritime Register of Shipping ice-class LU2 standard and membrane containment ships also have their ice-strengthened hulls built to that standard.[7] The performance of these vessels will provide an indication of the standards required for a more extensive Arctic LNG carrier fleet to withstand sea ice seasons of 100 days and more.

As LNG supply chains develop, it is not just at the liquefaction terminals where sea ice will be encountered. Plans to build regasification terminals along the St. Lawrence River in Canada suggest that the ships may have to operate in ice at both ends of their routes. The power installed and the ice class of the vessels apply to the more challenging Arctic routes, such as to the Western Arctic coastline of Russia. They will need to be higher unless dedicated ice-breaker vessels are commissioned to assist these vessels. With winterization features, such as low-temperature-proof materials to the deck equipment on the vessels and on loading and unloading facilities, the ships will have to withstand severe wave conditions and persistent cold environments. Carriers using membrane-containment designs will need reinforced tank supports to avoid cargo-sloshing damage. Indeed, membrane designs will need to prove their reliability under such challenging conditions before operators will order them for Arctic service. LNG ships built for dedicated service to the Snøhvit LNG facility in Northern Norway (ice-free all year) are all of the Moss-type design.

The challenges associated with first-year ice navigation and those with multi-year ice navigation are very different. Multi-year ice is prevalent in the Kara Sea and for year-round navigation with icebreaker assistance. Typical hull-structure design values over ice-sheet thicknesses vary from 120 cm to 170 cm in the summer and autumn seasons and 170-cm to 320-cm thickness (with hummocks) in the winter and spring seasons.[7] Movement in such winter conditions requires very powerful engines (85 MW to 120 MW), narrower beams and strong propulsion equipment to push ice-breaking hulls that are moving slowly (2 nm/hr).[8] Although the highest ice-classed LNG vessels do need to have ice-breaker assistance at times, the vessels and support services will not only be expensive, but the periodic slow speeds along the most challenging parts of their routes will require more tankers to transport similar contract quantities than for ice-free supply chains. Shuttle-tanker methodologies may make sense in some cases, i.e., ice-classed tankers to move cargoes past the ice edge either to trans-shipment ports or for ship-to-ship transfer may make commercial sense in some cases. The reality is that each port and shipping route will probably pose its own challenges and require tailored vessel design solutions (Fig. 7).

Exploiting NG reserves using LNG technologies in high latitudes is commercially viable today at some locations. However, in more extreme Arctic conditions, new technologies and plant configurations must be developed for field development, liquefaction and shipping segments of the supply chain. These solutions will be more costly to develop, construct, install and operate than for lower-latitude routes. The LNG industry has the optimism and track record for innovation to justify that acceptable technological solutions can be found. Questions, however, remain over the magnitude of gas reserves yet-to-be discovered and the long-term sustainability of such high-cost supply chains of natural gas. **HP**

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In-line laboratory and real-time quality management

An in-depth look at NIR spectroscopy

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Process plants have traditionally relied on laboratory-quality determinations and a limited number of in-line measurements to control feed qualities, intermediate streams and commercial products. Driven by a very demanding economic environment, this situation has changed dramatically with progress in reliable, accurate and affordable process spectrometers, advances in spectral information processing techniques (chemometrics) and availability of fast real-time computers.

Spectroscopic methods have found applications in many sectors, including agricultural and environmental sciences, food and beverage, the pharmaceutical industry, electronics, oil and gas, petrochemicals, etc. Refer to Workman's article for a more comprehensive review of applied spectroscopy in the infrared domain.[1] Applications in the process plants essentially relate to oil refining, chemicals and petrochemicals, and impact the economics and operation organization.

Since spectroscopy allows for a deep knowledge of chemical entities, the methods have enabled a number of advanced process control (APC) and real-time optimization (RTO) applications that could not be achieved with traditional analytical methods for cost and process dynamic reasons.

Process plant spectroscopic methods. Most process plant laboratories are using several spectroscopic methods, including ultraviolet (UV), visible (VIS), near-infrared (NIR), fluorescence X, etc. There has been much debate on the compared merits of each method and Chung's article gives a more detailed description.[2] It appears that nuclear magnetic resonance (NMR) and mass spectrometry, although both are powerful and sensitive methods, are difficult to implement and maintain online in an industrial environment due to the high-level skills required.

Raman spectroscopy has specific merits and has been used successfully in BTX (benzene, toluene and xylene) plants. Some advantages of Raman spectroscopy are:

- Fine analysis of chemical mixtures, including isomers
- No requirement to remove water from sample
- True simultaneous detectors, no beam splitter required
- Frequency ranges close to visible, allowing the use of inexpensive long optical fibers (up to 350 m).

With NIR and MIR spectroscopy, experience has shown that vibrational spectroscopy in the NIR and the mid-infrared (MIR) domain was the most appropriate technique for online quality determinations, for the following reasons:

- Nondestructive methods
- Very fast answers, about 10 to 200 times faster than ASTM methods for some quality determinations, such as octane, cetane, detailed hydrocarbon analysis or crude true boiling point (TBP)
- Fiber optic use provides a safety advantage in oil refineries and the possibility for fast multiplexing on several process streams
- Easily maintained.

MIR offers the most sensitive spectra in the 2,500–20,000-nm domain with a "fingerprint" region between 5,000–15,000-nm where functional absorption bands can be related to organic functional groups and be used for quantitative analysis of an individual component. This is the case for cetane booster additives used in gasoil blending. However, the strong absorption requires extremely costly fiber optics and very short optical paths, making MIR spectroscopy economically difficult to justify for in-line use.

NIR has become the favored spectroscopic method in the oil industry due to its robustness, high photometric and wavelength accuracy, and short response time compared to the traditional ASTM methods.[3] Operating at shorter wavelengths, the energy level is higher and provides better signal/noise ratio than MIR. However, NIR spectra are made of broad absorption bands that require extensive mathematical processing to extract meaningful quality information.

NIR principles. NIR spectroscopy operates in the 780–2,500-nm (12,800–4,000 cm^{-1}) electromagnetic spectrum regions, consult Workman's article for a basic introduction to NIR.[4] Any molecule having C-H, C-S, C-N or O-H bonds can be analyzed by NIR. First, second and third overtones are to be found in the 800–2,000-nm domain while combinations give absorption bands in the 2,000–2,500-nm domain. Low intensity and broad overlaps require very low signal/noise factors from accurate spectrometers.

NIR spectrometer use for industrial applications. The complex analysis of NIR spectra became feasible when fast computers were made available along with powerful chemometrics software, efficient detectors and affordable fiber optics. NIR is the most versatile spectroscopic method with at least 15,000 papers published on the technology fundamentals and applications.

Chemometrics. Useful information extracted from NIR spectra is performed by mathematical processing, generally using statistical techniques. The most commonly used method is partial least squares (PLS) and its derivatives combined with principal

components analysis (PCA). Although widely available, it has severe limitations for complex applications such as blending. Some severe limitations are:

- Lack of explanation in outlier cases
- Limited prediction capability for global quality determinations, particularly cold properties of gasoil
- Necessity to calibrate one separate model for each quality determination.

PLS models may require spectral range optimization to be effective[5] and avoid artifacts from over fitting. Furthermore, they are difficult to transfer from one spectrometer to another. They are widely supported by several software technologies and affordable. Also, they can be efficient on simple applications such as octane on a reformate or alkylate stream and used for fast product identification.[6]

A more advanced method makes use of topology-based data mining from a spectra reference library. It is proven highly effective on very complex NIR applications. The specific advantages of this method are:

- Uses the whole spectrum of information, including the combinations domain (this depends on the optical fiber type used)
- Provides a sample classification by chemical species, a useful feature with outliers (unrecognized spectra), that gives a physical explanation
- Allows computation of blending indices for non-linear properties, used in linear programming (LP) models and creates virtual blends for the spectral database densification, as shown in Figs. 1 and 2.
- Predicts responses to some additives
- Cumulates spectral information over time, improving predictions and only requires a single model for all properties of a given process stream.

Besides the ability to provide the required precision and accuracy for quality determinations, the main criterion for the chemometrics selection method allows refinery laboratory staff to maintain NIR models independently on the long-term.[7]

Oil and gas production. NIR has only recently been used to monitor crude production from various gathering centers to predict composition at receiving terminals. Given untreated crude conditions, i.e., sand, sediments and water, the sampling system is the most critical application. There are on-going projects to use NIR to determine condensate qualities on gas fields with an objective to deliver a constant commercial product at the loading facilities.

Refinery process units. NIR applications for quality petroleum product determinations were initiated in the US during World War II. With the contribution of such pioneers as the BP Lavera Research center, these online applications now cover major refinery processes such as:

- Atmospheric distillation unit: crude mix true boiling point (TBP), side stream qualities (naphtha to heavy gasoil)
- Vacuum distillation unit: vacuum gasoil
- Vacuum residue hydrodesulfurization: gasoil, naphtha
- Naphtha hydrotreater
- Hydrodesulfurization gasoil, wild naphtha
- Reformer: feed and reformate
- Gasoline hydrogenation: gasoline
- Isomerization: isomerate
- Alkylation: alkylate
- Aromatics units: feed and BTX extract
- FCC unit: feed, light gasoline, heavy gasoline, light cycle oil, heavy cycle oil
- Hydrocracker unit: gasoline, jet fuel and middle distillates
- Lube oil units: intermediate streams.

More recently, NIR has been used on crude distillation units to predict the crude mix TBP (12 distillation points ASTM D2892) in real-time to minimize transient operations during crude swings.[8,9] This application is most useful to increase throughput in European refineries processing a large crude slate with frequent swings, sometimes once a day.

Blending. Early NIR applications were quite simple, measuring the reformate octane number, but were quickly extended to include very complex gasoline and middle distillates blending. This blending operation is critical as it is the last processing step before selling the commercial product. It also requires accurate quality determinations for specifications that include the quality certificate for commercial transactions. Tables 1 and 2 provide a quality specifications list that is routinely predicted by NIR for gasoline and gasoil optimal blending with repeatability and reproducibility equal to or better than ASTM.

An NIR-based blending application is performed with increased efficiency compared to traditional methods.[10,11] However, a number of quality determinations illustrated in Tables 3 and 4 may be required on commercial quality certificates but are not achievable by NIR or not yet proven.

It should be noted that:

- Water in samples can be noticed by NIR but is a nuisance

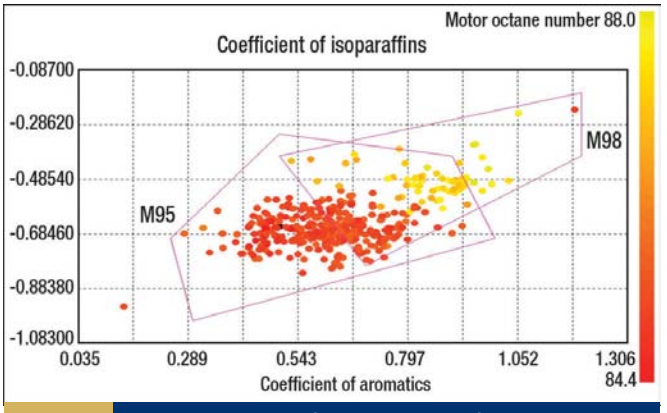


FIG. 1 Spectral database before primary densification.

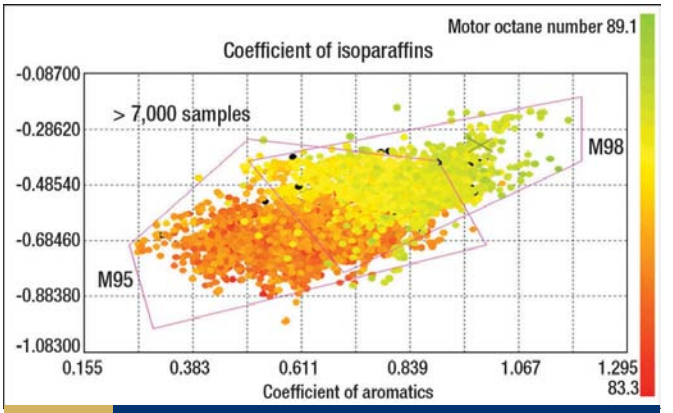


FIG. 2 Spectral database after MC primary densification.

TABLE 1. Gasoline quality determinations by NIR

Quality determination	Unit	ASTM methods	Specification	Note
Research octane number		D2699	Min	
Motor octane number		D2700	Min	
Density	Kg/liter	D1298	Range	1
Temperature 10% distilled	°C	D86	Max	
Temperature 50% distilled	°C	D86	Range	
Temperature 90% distilled	°C	D86	Range	
Temperature FBP	°C	D86	Max	
Reid vapor pressure @ 100°F	Psi	D323 B, D5482	Max	2
Benzene content	% Vol.	D6293, D5134	Max	3
Total aromatics content	% Vol.	D4420, D1319, D6293	Max	
Olefins contents	% Vol.	D1319, D6293	Max	3

Note 1: ASTM D4052 repeatability cannot be achieved by NIR.
Note 2: If no C3 variations.
Note 3: If C > 0.5 % mol.

TABLE 2. Gasoil quality determinations by NIR

Quality determination	Unit	ASTM methods	Specification	Note
Cetane number		D613	Min	
Cetane index		D4737	Min	
Flash point (PMCC)	°C	D93	Min	
CFPP	°C	D6371	Max	
Pour point	°C	D6749, D2500	Max	
Cloud point	°C	D5773, D2500	Max	
Density @ 15°C	Kg/ liter	D1298	Range	1
Temperature 90% distilled	°C	D86	Report	
Temperature 95% distilled	°C	D86	Max	
FBP	°C	D86	Report	
Kinematic viscosity @ 100°F	cSt	D445	Range	4
Conradson Carbon Residue	% Weight	D4530, D189	Max	
Aromatics content	% mass	D5186, D2429, D5292	Max	
Polycyclic aromatics (PAH)	% Weight	D5186, D2429, D5292	Max	

Note 1: ASTM D4052 repeatability cannot be achieved by NIR.
Note 4: Without ASTM repeatability.

for spectra quality

- Gums and oxidation stability are presently indicated by NIR
- The traditional copper corrosion and doctor test are not critical with low sulfur gasoline.

Petrochemical plants. Spectroscopic methods have been used on BTX units and ethylene plants.[12,13] Liquid feeds to steam crackers are excellent candidates for NIR-based high frequency analysis to predict PINA by carbon atom and cracking yields to manipulate in real-time the cracking furnace severity and adapt to the cold section operating conditions. As for crude TBP determination, this

TABLE 3. Some required gasoline quality determinations

Quality determination	Unit	ASTM methods	Specification
Water content	mg/kg	D1744, D1364	Max
Washed gums content	mg/100 ml	D381	Max
Potential gums	mg/100 ml	D873	Max
Oxidation stability	minutes	D525	Min
Copper corrosion		D130	
Doctor test		D4952	
Mercaptan sulfur unit	mass %	D3227	
Color		D1500	

TABLE 4. Some required gasoil quality determinations

Quality determination	Unit	ASTM methods	Specification
Water and sediments content	% Vol	D1796	Max
Water content	% Vol	D2709	Max
Ashes	% Weight	D482	Range
Lubricity at 60°C	Micron	ISO 12156-1	Max
Total acidity	mg KOH/g	D974	Max
Conductivity	pS/m	D2624	Min
Copper strip		D130	
Total contamination	mg/kg	D2276	Max

* Total acidity and lubricity are likely to be predicted by NIR.

detailed hydrocarbon analysis is performed at NIR spectra acquisition speed and processing, i.e. about once a minute, 200 times faster than gas chromotography-based methods. Pyrolysis gasoline partial hydrogenation is optimized using real-time dienes measurement content. NIR has also been used to determine the ethylene content in flakes or propylene/ethylene copolymer pellets.[14]

Laboratory methods. Because NIR is a secondary method, it relies on proper quality determinations on the laboratory spectrometer with traditional instruments. Prior to any NIR project, it is recommended to certify the laboratory to ensure that best practices are used. Particular care must be given to regular instrument calibration, sampling procedures and sample conditioning (water content, for instance), and spectrometer cell temperature control.

Spectrometers. The advantages of Fourier transform infrared spectrometers (FTIR) have been recognized by process plants, in particular repeatability, robustness (no moving parts) and stability. They offer a very high signal/noise ratio.

FTIR spectrometers performances are brilliant, typically:

- Maximum spectral resolution better than 2 nm
- Wavelength accuracy: better than 0.3 nm
- Wavelength repeatability: 0.01 nm
- Cell path length: 500 ± 15 µm
- Absorbance repeatability: 5.10^{-4}
- Baseline stability better than 1.10^{-3}.

Calibration transfers between laboratory and process spectrometers are easily achieved, provided precautions have been taken on identical cell reference temperature and optical path.

Sampling systems. Extractive sampling systems are generally preferred to in-situ probes for complex applications as they allow a strict temperature cell control. In-situ probes are essentially used

in the chemical industry on simple streams that are not subject to temperature variations and are free of water and solids. Sample conditioning, such as filtering or water removal is generally required on oil refinery process streams. Sampling systems can become quite complex, as shown in Fig. 3, and be a weak NIR system component from a reliability view point. Together with the shelters, they are a major CAPEX item, considering sample extraction, fast loops and sample recovery system. Sampling systems must also include the reference control and wash chemicals, generally high-purity toluene and n-Hexane.

Fiber optics. Process spectrometers are frequently multiplexed on several detectors using fiber optics. Silica-grade fibers used for telecommunications cannot be used in the combinations domain because of their high absorption and must be replaced by more expensive zirconium fluoride grades.

Limitations on sensitivity. Since NIR is not a sensitive method, it is necessary to use standard ASTM analyzers for the following quality determinations:

- Densimeter to obtain ASTM 4052 repeatability
- Gas chromtography or other methods for low concentrations (less than 0.5%), e. g., very low benzene or olefins content
- Sulfurimeter for very low sulfur content
- Reid vapor pressure (RVP) analyzer if C3 concentration in the C4 gasoline blending component is subject to significant variations.

Repeatability and reproducibility. Repeatability is important for advanced process control strategies, as when saturating constraints. Reproducibility is the main performance indicator when measuring commercial product quality that might be re-tested by a third party. In both cases, performance guarantees must not only be agreed upon prior to NIR project signatures on both repeatability and reproducibility but also on the acceptable outlier ratio, measuring the NIR model robustness. The NIR model robustness is the most difficult issue—any condition that impacts the chemical species must be taken into account to avoid outliers.

TABLE 5. NIR vs ASTM reproducibility results

Quality determination	ASTM method	NIR reproducibility	ASTM reproducibility
Cetane number	D613	1.9	4.0
Cloud point	D2500	2.7	4.0
CFPP	D6371	2.5	3.5
IBP	D86	7.7	8.5
E 95	D86	5.5	8.5
E 250	D86	2.3	6.2
E 350	D86	1.5	3.2
E 360	D86	1.4	1.5
FBP	D86	4.2	10.5
Flash point	D93	3.6	5.0
Viscosity	ISO 3104	0.06	0.05
Poly aromatics	IP391	0.2	1.8
Aromatics	IP391	0.3	4.4
Specific gravity	D4052	1	0.5



FIG. 3 Sampling system.

As a consequence, the spectral database population and densification is the most critical NIR project step, as it must cover such events as:

- Crude swings
- New crude imports
- Process unit operating modes
- New intermediate stream imports
- Blend recipe variations
- Additive changes
- Partial process unit shutdowns
- Catalyst activity changes
- Seasonal product specifications.

There is a significant initial workload for the refinery laboratory to achieve the required database density, but when the models are properly calibrated and maintained, NIR can provide superior results, for example on gasoil blending as illustrated in Table 5.

System integration. To capture all its benefits, NIR applications require a strong integration with many other sub-systems and they are:

- Distributed control system
- Laboratory information management system
- Advanced process control
- Real-time optimization
- Instrumentation maintenance
- Analyzer data validation system.

Plant acceptance. Since it impacts the responsibility matrix between laboratory and maintenance, implementing NIR in a plant is not straightforward.

The main acceptance criterion is conformance with primary standards, essentially ASTM and ISO. This must be observed over a time period, typically six months, to make sure the reproducibility is not affected by operating conditions and seasonal change of transportation fuel specifications. NIR models should never be accepted on the basis of calibration statistics that ignore the practical operation range.[15] Another fundamental prerequisite to success is to find an NIR champion within the laboratory staff to not only be the focal point but also to implement the necessary changes to the work processes.

Maintenance burden. Maintaining FTIR spectrometers is very easy compared to traditional ASTM analyzers. Designed originally for space missions, the hardware is extremely robust. Unfortunately, sampling systems still require attention as they are likely to plug and/or leak. The most critical task is the NIR models maintenance burden. The plant laboratory must be able to absorb the workload of expanding the spectral database and taking care of outliers. Lacking model support is the first NIR project failure cause, followed by indefinite re-modeling (generally due to inadequate chemometrics) and poor reliability of sampling systems.[16] OPEX under-estimation related to NIR models maintenance is the shortest route to project failure.

NIR advanced applications. The following are some applications that can bring additional benefits.

Blend indices. NIR spectra contain the non-linearity information for such properties as RVP, flash point, distillation points, octane, cetane, cold properties and viscosity. Therefore, they are used to predict the blend indices to be used in LP models, to correct blending recipes, taking into account heels and to feed-forward real-time optimal control—all very useful for in-line certification.

In-line certification. When logistics are tight, there is a strong interest for loading products directly from the blender header to a sea tanker without the need to fill a refinery tank, isolate, sample, analyze and then release. This in-line certification process requires accurate, fast and reliable online quality determinations, exactly what NIR is providing. The majority of new grassroot refineries being built in the Middle East and Asia are planning to use this efficient procedure.

Additives management. Many additives are used in the oil refining industry, in gasoil blending, and may include:

- Cetane booster
- Cloud-point depressants
- Flow improver (MDFI)
- Drag reducing agent
- Lubricity improver
- Anti-static
- Oxydation stability
- Wax anti settling
- Corrosion inhibitor
- Bactericide
- Anti-foam.

Presently, NIR provides cetane-booster and cold-property additive responses.

Using combined NIR and MIR offers a large potential for optimized additive dosage, a significant operating cost savings.

Heavy process streams. Early work on quality determinations of heavy streams by NIR started with FCC feeds on a laboratory FTIR spectrometer equipped with a heated cell. Refineries have also tested NIR use to predict the bitumen penetration quality.[17] More recently, new techniques based on automatic solvent dilution have been implemented on a laboratory spectrometer at line to provide quality heavy feed determinations, such as vacuum residues.[18] Quality determinations for FCC feeds typically include: density, Conradson carbon residue, sulfur, total acid number, basic nitrogen, distillation curve, detailed aromatics analysis and viscosity. Compared to traditional laboratory analysis, NIR has a significant advantage by updating at high frequency the quality determinations that are required by APC and RTO. There is ongoing developmental work to predict bitumen quality determinations.



Additional quality determinations. Research is underway to extend the range and quality determination accuracy, such as gasoil viscosity, presently on the borderline of ASTM reproducibility. Potential gums and oxidation stability should be accessible by NIR, at least for indication. Gasoil lubricity is becoming a constraint with very low sulfur gasoil and could benefit from NIR in-line determination with additives. Fuel oil and bitumen blending could be optimized using NIR.

Lube-oil characterization on laboratory spectrometers has proven feasible and could be extended for on-line use in APC strategies, in particular, the following units:

- Hydrofinishing unit: % PCA, Conradson carbon, Pour Point, viscosity index (VI), viscosity
- Dewaxing unit: oil content and slack wax viscosity
- Furfural unit: % PCA, viscosity and % S extract, % PCA, VI of raffinate
- Deoiling unit: wax oil content.

In-line laboratory. New refineries are becoming very complex in terms of process unit numbers, sometimes over 50. In addition, the crude slate can be extremely wide in European refineries. The new export refineries in the Middle East and India will produce a very wide range of commercial grades, including up to 15 different grades of gasoil. Quality determination numbers requested by process unit and blending operations are growing significantly. Table 6 illustrates quality determinations on a laboratory FTIR spectrometer for commercial products of an export refinery in the Middle East.

This is an incentive to systematically use in-line NIR spectrometers to obtain high-frequency quality determinations at acceptable CAPEX and OPEX.

One spectrometer can analyze several streams:

- Streams can be multiplexed optically on multi-channel FTIR spectrometers whenever a high frequency of data acquisition is required, e.g., an APC application with high dynamics.
- Liquid multiplexing by the sampling system can be used when the stream qualities are not critical.
- In practice, a mix of two types of multiplexing is implemented on one spectrometer, providing quality determinations on as many as 16 streams with frequencies between less than 1 minute and 15 minutes.

Each stream has between 5 and 10 quality determinations, so one spectrometer can deliver between 80 and 160 quality determinations. If four or five FTIR spectrometers (depending on plant topology) are strategically placed in a refinery, between 300 and 600 quality determinations are available online, justifying the label "online laboratory."

In a recent front end engineering design (FEED) for a grassroot refinery in the Middle East, NIR systems were designed to be used on the 30 streams, as shown in Table 7.

NIR spectrometers have been used so far on liquid streams. More recently, NIR tunable diode laser analyzers are being applied for quality determinations, including traces on gas streams.[19] The primary applications in gas processing or liquified natural gas plants are for moisture analysis, H_2S, CO_2, NH_3 or HCl but TDL could be used in refinery gas plants, extending the online laboratory range with very fast and sensitive quality determinations.



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TABLE 6. FTIR spectrometer quality determinations for commercial products

Product	Grades	Determinations	Specifications
Mogas	4	28	7
Jet kero	8	88	11
Condensate	1	6	6
Gasoil	16	116	11
Naphtha	6	54	9
Total	**35**	**292**	

TABLE 7. NIR for a grassroot refinery

Category	Streams	Determinations	Comment
Mogas pool	7	78	
Middle distillates pool	6	84	
Process units	13	127	
Heavy streams	4	28	At line
Total	**30**	**317**	

Extended use of spectroscopic methods in process plants has been made feasible by the availability of robust and affordable hardware and powerful mathematical processing of spectral information. New applications are being developed in all sectors of the oil and gas industry, allowing real-time quality control from feeds receipts to products liftings. The concept of "in-line laboratory" is becoming a reality. **HP**

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Auxiliary pumps and support systems for process machinery

Proper system design and operation are critical to plant uptime and reliability

J. R. BRENNAN, Colfax Corp., Monroe, North Carolina

Much has been written on the subjects of process pumps, pipeline pumps and similar mainstream hydrocarbon processing machinery. Such equipment is obviously critical to ongoing operations, but little has been produced covering auxiliary support pumps.

Most rotating machinery within refineries, petrochemical complexes and chemical processing plants requires forced lubrication, and many process-gas centrifugal compressors and turboexpanders also require forced-oil systems to seal process gas within the machine. Control-oil systems are also common, supplying an oil flow proportional to machine speed. Proper system design and operation of these auxiliary pumps is critical to plant uptime and reliability, considering 24 months between turnarounds and 24-hr-per-day operation are normal.

Rotating machinery large enough to require forced lubrication will normally have both main and standby lube-oil pumps. These can be used for prelubrication before starting the machine, continuous lubrication while the machine is running (even if a lube pump, driver or power supply goes down) and lubrication during coast-down, which can take several minutes or more for very large machine sets. These oil systems are frequently designed by the machinery manufacturer, and many are constructed in accordance with American Petroleum Institute (API) Standard 614: *Lubrication, Shaft-Sealing and Oil-Control Systems and Auxiliaries.*

Probably the simplest systems are found on gear-speed reducers (or increasers) and large centrifugal pumps. The main oil pump is frequently machine-driven, whereas the standby pump is most commonly electric-motor-driven.

The standby pump is started before the machine. Once the machine is up to normal running speed range, the standby pump is shut down and remains in standby mode. Should the lube-oil header pressure fall below some setpoint, a pressure switch will cause the standby pump to start. Fig. 1 shows a simplified schematic of this type of lube system.

The standby pump may be of the external, horizontal type or of the vertical, in-tank arrangement. Normally, all external pumps are steel cased to minimize risk of a lube pump case fracture during a fire, which might allow lube oil to escape in large volumes that could fuel an otherwise small fire.

Fig. 2 shows 1,100-hp twin-screw pipeline pumps. Their timing gears and antifriction bearing system are force-cooled and lubricated using a small-flow gear pump driven from the outboard end of one of the pipeline pump's rotors. An oil reservoir, filter and air-to-oil heat exchanger complete the system.

In this case there is no standby pump since the pumping station has full standby twin-screw pump capacity. Note that driving the auxiliary pump from the machine it serves is the most reliable method to ensure that power is available to the lube pump. As long as the machine rotates, the pump supplies cooling flow. The site location for these machines, Venezuela, could not readily provide cooling water for the lube system; thus the radiator/fan arrangement of the heat exchanger.

Large rotating equipment trains may need cooling oil flowrates in excess of 1,000 gpm, usually at pressures of about 75 to 150 psi. Such systems invariably have main and standby auxiliary pumps. Frequently the main pump is steam-turbine-driven, if steam is available on site, and the standby pump would normally be driven by a conventional AC electric motor.

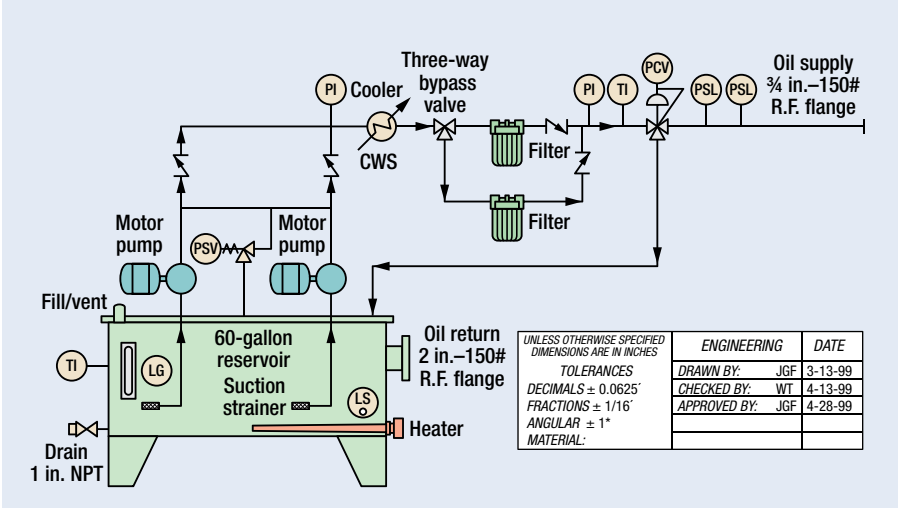


FIG. 1 Simplified lube-oil system schematic.



FIG. 2 1,100 hp-twin-screw pipeline pumps with integral lube-oil pump.

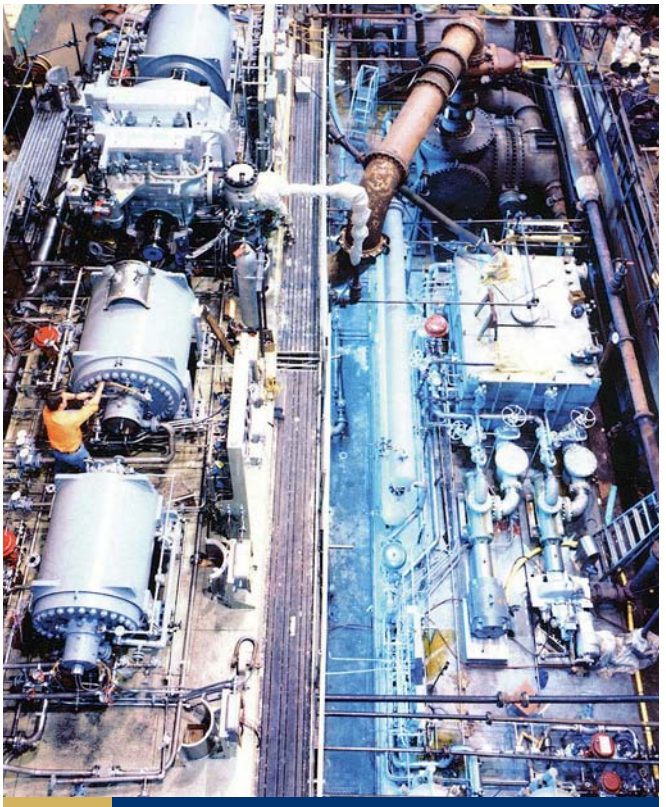


FIG. 3 Turbine/compressor train on test with lube-oil console (right).



FIG. 4 Small three-screw lube-oil pump for smaller flow requirements.

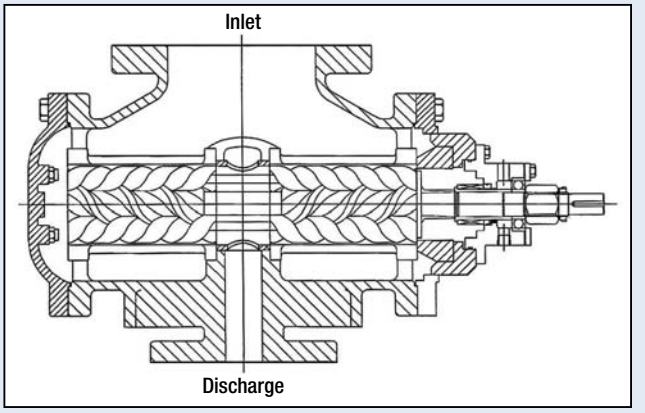


FIG. 5 Section view of a large-flow double-suction lube-oil pump.

If two AC motors are used for main and standby service, they should be wired to different power sources so the failure of one source does not compromise the machinery train. In some cases, a third "coast-down" pump may be desired, frequently driven by a DC motor supplied with power from a trickle-charged battery bank.

Fig. 3 is an overhead photograph of a steam-turbine/hydrogen-booster compressor train on test. The lube-oil console is to the right. A pair of double-suction three-screw pumps is at the lower right, one a motor drive, the other a steam-turbine drive. Each pump provides about 530 gpm to all the bearings in this four-machine train. The installation is at an oil refinery in Jurong, Singapore.

For cost and efficiency, auxiliary pumps should be sized to operate at two- or four-pole motor speeds (1,500 to 3,600 rpm), if possible. This results in less costly pumps and drivers as well as better pump and driver operating efficiencies. Positive-displacement rotary pumps are usually preferred over centrifugal pumps for these auxiliary services since they are self priming, do not become air bound, have very predictable performance and are simple to control.

Fig. 4 is a small three-screw pump typical for lubricating smaller rotating machinery. Each wrap of the screw set forms a chamber, relatively independent of adjacent chambers. Pressure rise across the pump is effectively staged and causes very low internal unit loading.

Fig. 5 is a section view of a pump similar to those shown in Fig. 3. Flow is split equally at the pump inlet and delivered to the pump outlet in a smooth, continuous manner.

Because of the opposed flow pattern in these pumps, internal axial hydraulic forces due to differential pressure are canceled. Radial forces are reacted in the hydrodynamic oil films surrounding the pumping screws. These features, together with the pres-

sure-staging effects of the pumping chambers, result in very long operating life for this kind of pump.

Most centrifugal process compressors and turboexpanders use labyrinth or mechanical shaft seals to contain the process gas, and these seals frequently are supplied with cooled lube oil at a pressure just slightly higher than the gas pressure at the seal. Depending on the service involved, the seal-oil pressure can range to 4,000 psi or higher.

Again, three-screw pumps are typically used for this demanding 24x7 service. They are frequently boosted from the lube pump system, sharing the same oil system. Since the pressure demand on many of these pumps is much higher than lube pumps, they will normally have many wraps or stages (up to 12) to effectively resist internal slip through running clearances and maintain internal loading at low levels for prolonged operating life.

By far, the most vulnerable time for auxiliary pumps is their initial startup. The culprit is almost always hard, solid contaminant in the oil system. Because rotary, positive-displacement pumps are close-clearance devices, they do not generally survive well in the presence of pipe scale, weld bead, metal filings, machining chips and other debris typical of a new installation.

While the served machinery oil flow is usually filtered to the 10-micron range before it reaches critical bearing clearances, the flow to the pump inlet may go through a strainer that stops particle sizes around 150 microns or even larger. It is, therefore, important that new installations be thoroughly flushed using separate flushing pumps. Flushing pumps should be large-clearance centrifugal pumps that can supply system flows higher than the lube pumps so the high velocities produced encourage debris to be moved to the filters. Once the system is verified clean, the rotary pumps are ready for use.

Auxiliary pumps are small but important parts of process industry reliability. Provide them the environment that they need and they will provide many years of trouble-free service.

Another system problem more common than it should be is excessive lube-oil aeration. Almost all lube-oil systems gravity drain the lube oil returning to the oil reservoir, which aerates the oil during its passage through the machinery served. If the reservoir is not properly baffled, this aerated flow will travel directly to the auxiliary pump inlet where pressure will be lowered more and the air content by volume expanded. When that occurs, pump operation can become noisy, erratic and result in system shutdowns. Severe cases can cause pump damage or destruction.

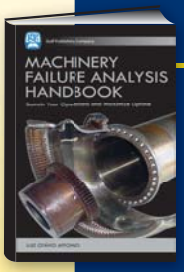
To reduce aeration, all oil return lines need to terminate below the minimum oil level in the reservoir. Baffles need to be arranged within the reservoir to maximize the time that the oil is allowed to release entrained air before entering the pump again. A 10-minute retention time is a fairly standard reservoir sizing criteria (minimum reservoir volume equals 10 times the pump flowrate). Improper or no baffling will defeat the retention time by allowing return oil to "short circuit" directly back to the pump.

Some rotating machinery will drain lube oil to the machine sump or, in some cases, the crankcase of a large reciprocating machine. This oil needs to be pumped, rather than gravity-drained, to the main oil reservoir. Positive-displacement scavenge pumps (machine- or motor-driven) are used for this service and are sized to displace about twice the main oil pump's rated flow. These pumps deliver about 50% air and 50% oil at very low pressure (usually 10 to 15 psig), ensuring that lube oil does not accumulate in the machine sump.

Rotary positive-displacement pumps can also be used as hydraulic power recovery motors (HPRMs). Processes that reduce liquid pressure by throttling are prime candidates for dropping pressure across an HPRM which, in turn, can power a partial-capacity feed pump or a plant air compressor. Otherwise wasted energy (throttling) is recovered at efficiencies up to 75%. Given today's energy costs, HPRMs are well worth their expense.

Auxiliary pumps are small but important parts of process industry reliability. Provide them the environment that they need and they will provide many years of trouble-free service. **HP**

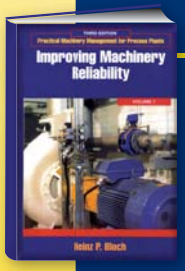
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Consider practical conditions for vacuum unit modeling

A good simulation model is a tool that reveals critical operating conditions and can be applied to daily operations

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Simulation tools are frequently applied to identify critical operating conditions. Modeling operating parameters will help ensure better unit reliability. Some operating parameters cannot be measured directly. In such cases, the parameters are calculated via a model. In a revamp case, simulation models are tools used to determine project goals. Too often, revamp projects failed due to incorrect simulations. The author discusses tips to improve simulation methods when revamping crude vacuum units.

Vacuum units. Many different types of vacuum towers are used in refineries.[1] The typical and most common refinery vacuum unit is shown in Fig. 1. In this vacuum unit, the feed (atmospheric residue—long residue) is separated into two vacuum gasoil products—light vacuum gasoil (LVGO) and heavy vacuum gasoil (HVGO). Typically, VGOs are sent to catalytic units for further processing (conversion).

The refinery's main objective is to increase VGOs yield to improve plant profitability. Higher yields mean higher true boiling point (TBP) cutpoints. At the same pressure, increasing the TBP cutpoint allows higher heater outlet and flash-zone temperatures.

For catalytic processes using VGOs, there are some limitations regarding metal content, microcarbon residue (MCR) and/or asphaltenes of the feed. In this processing operation, increasing the TBP cutpoint can be done while minimizing the metal content of the LVGO and HVGO. Process and equipment designs that minimize the distillation tail will reduce metals.[2] Minimizing HVGO metals will dramatically increase catalyst life.[3] This problem could become critical, especially for HVGO.

Vacuum unit critical operating conditions. The most common important problem of vacuum units is coke formation in fired heater and wash sections. This is a matter that has been discussed in many articles. Wash-bed coking continues to be a common problem affecting vacuum unit run length.[4] In several cases, vacuum heater and column wash sections coked in less than one year.[5]

Wash zones continue to coke causing poor HVGO product quality, low HVGO yield and unscheduled outages to replace packing.[6] Nearly every vacuum column operating above a 730°F–740°F (388°C–393°C) flash-zone temperature has coked the wash section packing in less than a four-year run.[2] An inadequate wash-zone liquid rate is one of the primary causes for coking.[7] The bottom of the wash section is kept wetted by flash-zone entrainment. The top of the packing is wetted by the wash oil flowrate.[8]

Preventing coke formation requires sufficient wash-oil flow to keep the middle of the packed bed wet; otherwise, high-residence-time stagnation zones are created.[4] Coke forms in the middle because it is the only part of the bed that is not wetted.[4] Coking in the middle of the wash zone has been discussed in the literature.[7–9] Wash-zone efficiency has a large effect on the HVGO quality. Small changes in the 95 vol% EP distillation tail have a large impact on GO product metals.[2] Increasing wash-section efficiency can reduce the GO product 95 vol% EP distillation tail and metals.[2]

Coking in the heater outlet is a common problem.[5] Coke forms inside the radiant section tubes of the vacuum heater, because the oil film flowing along the inside of the tube exceeds the temperature and residence time needed to initiate thermal cracking.[5] So, controlling the oil-film temperature and residence time is essential to minimizing coke formation.[5]

Vacuum unit design. Vacuum unit design can influence VGO yield, product quality and run length.[2] When designing

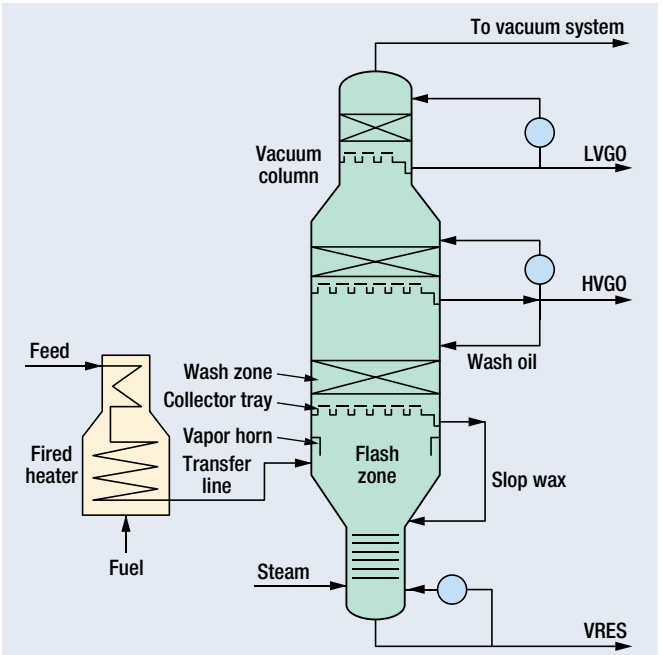


FIG. 1 Flow diagram of a typical crude vacuum unit.

a vacuum unit, special attention should be paid to these critical points. Vacuum unit product yields and critical operating conditions must be accurately predicted.[4] Features of the system are the heater outlet, transfer line, flash zone, collector tray below the wash section and wash-section column internals.[4] Other parts of the vacuum column are straightforward and well understood.[4]

Often, the design of the wash section is considered a trivial item; yet, process and equipment design issues surrounding the wash section are complex.[7] Wash-zone packing coking is caused by poor feed characterization, process modeling and equipment design.[7] Wash-zone design and operation are not trivial issues.[7] Predicting total VGO yield, operating temperature at the heater outlet and flash zone and wash-oil flowrate needed to prevent coking are critical design parameters.[4] Transfer-line, flash-zone and wash-section designs influence the coking rate in the wash-section internals.[10]

Vapor and liquid feed enter the column at velocities as high as 380–400 ft/sec.[4,6,8] The vapor phase contains small droplets of VRES that have been generated in the transfer line. The droplet size is too small to allow settling in the transfer line because the velocity is too high.[4,6,8] Hence, the flash zone and wash sections need to remove the entrainment.[6] The flash-zone vapor horn and flash zone help remove larger droplets and distribute the rising vapor across the column cross-section.[6] By uniformly distributing vapor, the high-velocity areas are minimized, allowing the packing to remove essentially all of the small droplet residue.[6]

In the vacuum unit, the transfer-line critical flow expansion, flash zone vapor horn and wash-section internals determine the amount of entrainment.[2] The quantity of entrainment on a unit varies according to the flash-zone design, flash-zone height, transfer-line velocity, etc.[9] Poorly designed transfer lines with high pressure drop critical flow expansions at the column inlet nozzle generate fine mists that are difficult to remove.[2] Yet, the entrainment can be almost eliminated through prudent transfer-line and column internal designs.[2]

While entrainment from the flash zone contains high metals, concarbon and asphaltenes, the amount of entrainment should be minimized as much as possible. Transfer-line, flash-zone and wash-section designs influence the HVGO concarbon, metals and asphaltenes content through their impact on Vacuum residual (VRES) entrainment.[10] The wash zone removes entrained residue from the flash-zone vapor and provides some fractionation of the HVGO product.[7,8] So, in the vacuum column design, flash-zone vapor entrainment and its effect on the wash zone should be considered, and the HVGO quality has to be calculated. Depending on the design, flash-zone vapor entrainment can enter the wash bed. Since the wash-section internals remove entrained VRES from the flash zone, liquid on the collector tray below the wash bed consists of true over-flash plus removed entrainment from the flash zone.[4] This liquid is always referred to as slop wax.

Vacuum unit model. According to the mentioned criteria, the critical sections of the vacuum unit are the fired heater, transfer line, flash zone and wash section. Modeling other components of the unit are not complex and can be simply made and/or predicted. When building a model to estimate critical operating parameters, some simulation exercises are needed. *But the problem is: Can we believe the simulation results?*

The only way to ensure that the model is representative of the vacuum unit is to verify it against measured plant data.[4] Estimating the pressure profile accurately throughout the heater and transfer line is important, because the heater-outlet and transfer-line pressures are used in the process model.[4]

Estimating the heater-outlet and transfer-line pressure profiles accurately requires a model that is capable of rigorous tube-by-tube heat transfer and accurate two-phase flow calculations.[4] Calculated phase regimes in the transfer line are either stratified or stratified wavy.[8,10] Stratified phases cause the liquid and vapor to have poor mass and energy exchange across the interface.[4,8] Thus, liquid and vapor contact is poor.[8] Since the transfer line consists of large-diameter piping, the liquid and vapor separate in the horizontal section of the transfer line, vapor flows along the top of the pipe and liquid flows across the bottom.[4,8] Transfer-line vapor becomes superheated due to pressure reduction as the two phases approach the flash zone.[4] Phase separation causes superheated vapor to flow through the top of the pipe and colder liquid to flow on the bottom.[10] Thus, the vapor and liquid entering the flash zone are not in equilibrium.[4,8]

Assuming that the liquid and vapor entering a vacuum-column flash zone are in equilibrium is a critical mistake.[4] Transfer-line phase separation increases the amount of wash-oil flow needed to prevent coking, because the wash oil vaporizes more of the wash liquid.[4] In reality, accounting for transfer-line phase separation raises the wash-oil flowrate by 200% to 300% over conventional modeling practices that assume liquid and vapor leaving the transfer line are in equilibrium.[8]

Often, the vacuum unit is modeled assuming that the liquid and vapor in the flash zone are in equilibrium.[7] Assuming that the flash zone is in equilibrium, this position will cause the calculated wash-oil rate to be too low.[10] The vapor/liquid equilibrium may exist at the heater tube outlet, but it does not exist in the flash zone.[7]

A practical approach to modeling transfer lines and vacuum columns that better predicts yields and other critical operating parameters requires that the model to be segmented into a number of operations before the vapor enters the column wash section.[4] Using multiple unit operations allows estimating the non-equilibrium nature of the system.[4,2]

Evaluating different vacuum unit models. As mentioned earlier, the sections that are important and critical that require to be accurately simulated are heater outlet, transfer line, flash zone and wash zone. Other parts of the vacuum column are straightforward and well understood. While the entire unit will be simulated, we will only use these listed sections to analyze and evaluate different models. To evaluate different cases, simulation models were made according to these rules:

- Two theoretical stages were applied for the wash bed.
- The heater outlet temperature was set for a TBP cut point of

TABLE 1. Simulation results of an ideal model (equilibrium in the transfer line and no entrainment to the wash zone)

Wash-oil rate, m^3/hr	Minimum wash zone liquid flow, m^3/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
165	25	Bottom of wash zone	564	584	20	533

1,000°F (538°C) on the HVGO cut. The heater outlet was within the normal range for such a TBP cutpoint.

- All slop wax was sent to the top of the stripping section.
- Flash-zone pressure, transfer-line pressure drop and, consequently, heater-outlet pressure were fixed for all cases.
- The amount of entrainment from the flash zone is the same in all cases.
- The tower top pressure and temperature for all cases are the same.
- The same amount of stripping steam was used for all cases.
- The same number of theoretical stages was assumed on the stripping section.
- A minimum wetting rate of 0.15 gpm/ft^2 for the wash zone was set on all cases.

At the first step, an ideal model is considered and simulated. In this ideal model, we will assume that the liquid and vapor phase entering the tower flash zone are in equilibrium and that no phase separation occurs in the transfer line. Also, complete phase separation in the flash zone is considered (no entrainment). Table 1 lists the simulation results.

Another case is an equilibrium transfer line (TL) with a non-ideal flash zone (FZ) (considering an estimated amount of entrainment). But the problem is how the entrainment could be entered into the simulation model. To answer this question, it is necessary to go through the process of what is happening in the vacuum-tower flash zone. The vapor and liquid phases from the transfer line enter the flash zone. Due to high velocity, a considerable portion of the liquid is dispersed into the vapor phase as large and small droplets. As mentioned earlier, the large droplets are removed by the flash-zone vapor horn and the flash zone. The wash zone removes small entrainment droplets from the flash-zone vapor. Accordingly, the entrainment is the small droplets that are coming up with the flash-zone vapor.

In the wash section, the small droplets are removed from the vapor phase. The removed droplets with the wash oil (over flash), as a liquid phase, come down to the collector tray below the wash zone. De-entrainment could happen in the middle of the wash section. Thus, the entrained droplets could come up to the middle of the wash-zone packing. In fact, from the bottom to the middle of the wash-zone packing, the vapor phase from the flash zone is in contact with the remaining wash oil, and the separated droplets that are now coming down as a liquid phase to the collector tray below the wash section. If the wash section is simulated by this viewpoint, the result should be proved with the reality of the vacuum tower.

The simulation result of the tower, considering that the liquid entrainment comes up to the middle of the wash section, shows that minimum wash-zone liquid flow happens just in the middle of the wash zone. As mentioned before, coke is always formed in the middle of the wash zone. While the middle of the wash section is prone to coking, it means that minimum liquid flow is occurring. Thus, simulation results that include entrainment in the middle of the wash section are in complete agreement with the actual performance of the crude vacuum-tower wash section.

So, an estimated amount of entrainment should be considered in the simulation model. Table 2 shows the simulation results for this case.

When compared against the ideal model, except for the minimum wash-zone liquid flow, no considerable changes have occurred. In the equilibrium TL, entrainment from the flash zone has little effect on tower operating conditions and product specifications for HVGO and VRES. The minimum wash-zone liquid for the ideal flash zone (no entrainment) is 25 m^3/hr. This is true over flash. For the non-ideal flash zone (entrainment with the flash-zone vapor outlet), the minimum wash-zone liquid is 48 m^3/hr, which is not a true over flash. The entrained liquid droplets from the FZ contain coke particles.

When the droplets contact the wash-zone packing, coke particles transfer onto the packing surface. Liquid flow in the bottom of the wash section is sufficient to remove the coke particles, and the coke is transferred with the liquid. But, in the middle of the wash section, conditions are different. Here, liquid flow is minimal. If this flow is not sufficient, coke particles are not washed away. In such cases, the coke particles accumulate in the middle of the wash section. By this view, the minimum wash liquid flow should be calculated based on the required liquid flow to remove and to

TABLE 2. Simulation results of equilibrium TL with entrainment to the wash zone

Wash-oil rate, m^3/hr	Minimum wash zone liquid flow, m^3/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
167	48	Middle of wash zone	565	586	21	533

TABLE 3. Simulation results of non-equilibrium TL with no entrainment to the wash zone

Wash-oil rate, m^3/hr	Minimum wash zone liquid flow, m^3/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
144	9	Bottom of wash zone	577	598	21	523

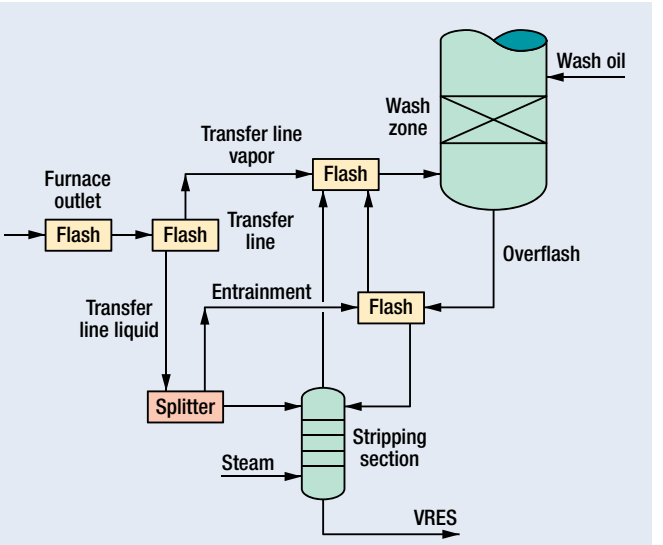


FIG. 2 Multiple unit operation for a non-equilibrium transfer line model.

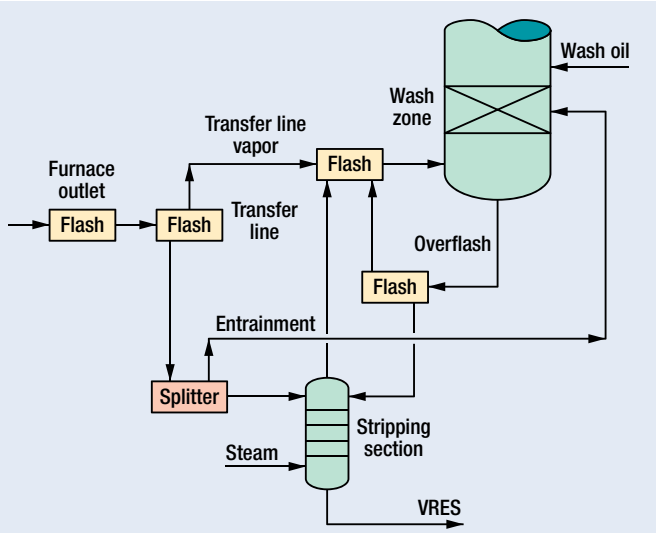


FIG. 3 Multiple unit operation for a non-equilibrium transfer line with entrainment to the wash zone (modified model).

TABLE 4. Simulation results of non-equilibrium TL with entrainment to the wash zone (modified model)

Wash-oil rate, m³/hr	Minimum wash zone liquid flow, m³/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
164	42	Middle of wash zone	568	591	23	529

transport coke particles from the wash-bed packing surface and layers. This required liquid flow would be much higher than the minimum liquid flow to prevent the wash bed from drying out.

It is obvious that, the higher the FZ temperature, higher coke particles will be produced. Actually, when the coke particle content of the entrained liquid droplet is increasing, the required liquid for washing, removing and transporting the coke within the wash-zone packing should be sufficient. If the liquid flow is not sufficient, then the coke particles can accumulate. Consequently, the wash bed will coke up soon. For these conditions, nearly every vacuum column operating above a 730°F–740°F (388°C–393°C) flash-zone temperature has lost wash-section packing due to coke in less than a four-year run.[2]

A model has been proposed to address this non-equilibrium system.[2,4] Fig. 2 shows a schematic of this model. In this model, vacuum unit operations consist of a simple exchanger (fired heater), with the outlet temperature determined by the HVGO cutpoint target. The heater outlet pressure depends on the transfer-line pressure drop and whether parts of this line operate at critical two-phase velocity.

The transfer line is modeled as an adiabatic flash, with the pressure set at the same pressure as the first large horizontal section of the transfer line. Liquid and vapor from the transfer-line flash are separated into two streams. The transfer-line liquid stream is split into an estimated flash-zone entrainment and flash-zone liquid feed.

The column flash zone is modeled as a simple flash if it does not have a stripping section or as a distillation column if it has

TABLE 5. Simulation results of non-equilibrium TL, non-ideal flash zone and no entrainment to the wash zone

Wash-oil rate, m³/hr	Minimum wash zone liquid flow, m³/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
137	9	Bottom of wash zone	577	599	22	521

TABLE 6. Simulation results of non-equilibrium TL, non-ideal flash zone with entrainment to the wash zone

Wash-oil rate, m³/hr	Minimum wash zone liquid flow, m³/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
155	41	Middle of wash zone	569	591	22	527

a stripping section. The wash and pumparound sections of the vacuum column are modeled using a standard distillation column model. The bottom-product stream from the distillation column is the true overflash. Entrainment and overflash feed an adiabatic flash, with the operating pressure set at the pressure of the collector tray located above the flash zone. Vapor feed to the wash section consists of transfer line vapor, collector tray vapor and flash-zone vapor.

In this model, the maximum phase separation in the transfer line has been considered. And, consequently, super-heated vapor enters the column. As seen in Fig. 2, entrainment was allowed, but no contact between removed entrainment liquid and vapor from the flash zone has been considered. Based on this proposed configuration, a simulation model was prepared and run. Table 3 summarizes the results from this simulation.

From Table 3, the results show, using this arrangement and with the same heater outlet, the wash-oil rate and minimum wash-zone liquid flowrate were largely decreased. Also, the HVGO 95% and EP increased. Conversely, a large drop in the VRES 5% occurred.

There are some discrepancies between the proposed arrangement and the real FZ (Fig. 1) configuration:

1. By the recommended model, no contact between the liquid stream, which is produced from de-entrainment action of the wash zone, and vapor from the flash zone was considered.
2. Conversely, by using this model, the minimum wash-section liquid flow occurs in the bottom of the wash zone. In fact, this model could not predict coking of the middle of the wash-zone packing.
3. The transfer-line vapor and liquid with the stripper-section vapor outlet (strippout), are already in contact with each other in the real flash zone. As mentioned before, the vacuum tower flash zone is not an ideal stage. So, the heat and mass transfer at this stage could not be done up to a theoretical stage (vapor and liquid outlet in equilibrium). But, in the proposed model, they meet each other at the theoretical stages.

To correct the proposed model for discrepancies Nos. 1 and 2, modifications on the liquid entrainment could be considered.

The modified proposed model is shown in Fig. 3. Table 4 shows simulation results for the modified model. This simulation shows that, for the modified model, the minimum wash-section liquid flow occurs in the middle of the wash zone.

Contrary to the equilibrium TL model, the effects of entrainment on the operating conditions and HVGO specifications are considerable and are important for non-equilibrium TL models. As seen, the entrainment to the middle of the wash section in the model causes the wash-oil rate, and minimum wash-zone liquid flow increased from 144 m^3/hr to 164 m^3/hr and from 9 m^3/hr to 42 m^3/hr, respectively. The results also contain a considerable reduction in HVGO 95% and EP while the VRES 5% increased.

All of the data express improvement in fractionation. In fact, any contact of the superheated vapor from the flash zone with the liquid from the de-entrainment action of the wash zone causes gains in fractionation. This is true because superheating of the vapor phase in the transfer line occurs due to phase separation, which causes poor mass and energy exchange; thus, any contact between the vapor and liquid can lead to equilibrium. The maximal separation and fractionation are done when the transfer line vapor and liquid are in equilibrium. In this case, there is non-equilibrium TL, which produces super-heated vapor at the column inlet.

Unlike the expectation, the existing entrainment is useful in heat and mass transfer point because it approaches the conditions (systems) to the equilibrium. But plugging of the wash-zone packing is very harmful and has caused unscheduled unit shutdown repeatedly and/or periodically. Entrainment from the flash zone can plug off the wash-section packing because it contains coke particles.

By modifying, two discrepancies were solved. Yet, there is one more item to be resolved. This point is the non-ideal flash-zone stage. A model is presented in Fig. 4 to solve this problem. In this model, the phase separation and, consequently, super heating of vapor in the transfer line is considered. The vacuum tower is modeled according to the standard simulation route.

But, to compensate for non-idealities of the flash zone, a non-equilibrium stage is determined. A model was developed to simulate this case. The simulation was adapted to have the same amount of overflash to meet the specified minimum wetting rates. Table 5 lists the simulation results for this case. The simulation results show some interesting points. In comparison to a similar model (the proposed model in Fig. 2), the lower wash-oil rate was calculated as 144 m^3/hr as compared to 137 m^3/hr or the equivalent to 5.1%. The changes in the HVGO specifications and VRES specs are not too much.

In this model, entrainment from the FZ to the wash section could be considered. In this case, a model will be made as shown

TABLE 7. Simulation results for the case that all non-idealities have summarized to the FZ stage without entrainment to the wash section

Wash-oil rate, m^3/hr	Minimum wash zone liquid flow, m^3/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
137	9	Bottom of wash zone	577	599	22	521

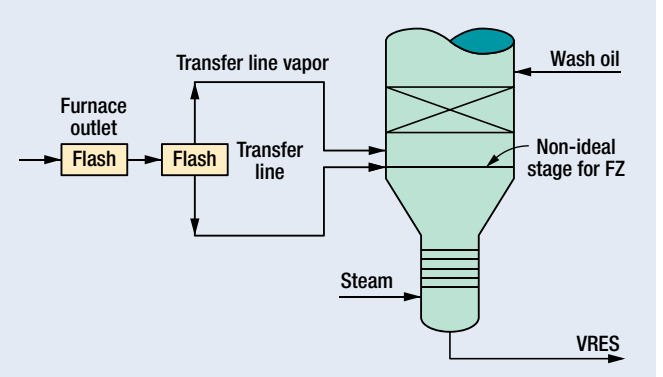


FIG. 4 Flow diagram of a non-equilibrium transfer line, non-ideal stage for the flash zone and no entrainment to the wash zone.

TABLE 8. Simulation results for the case that all non-idealities have summarized to the FZ stage with entrainment to the wash section

Wash-oil rate, m^3/hr	Minimum wash zone liquid flow, m^3/hr	Place of wash zone minimum liquid rate	HVGO 95%, °C	HVGO EP, °C	HVGO distillation tail—95%-EP, °C	VRES 5%, °C
155	41	Middle of wash zone	569	591	22	527

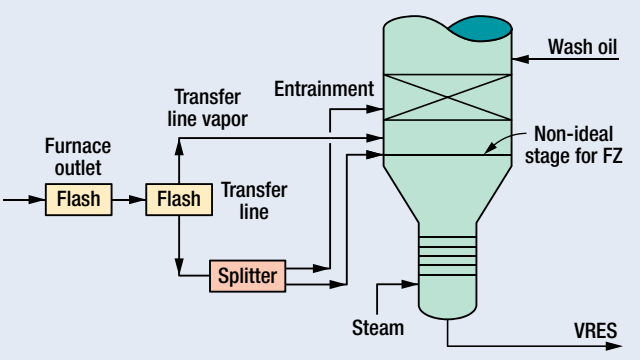


FIG. 5 Flow diagram of a non-equilibrium transfer line, non-ideal stage for the flash zone with entrainment to the wash zone.

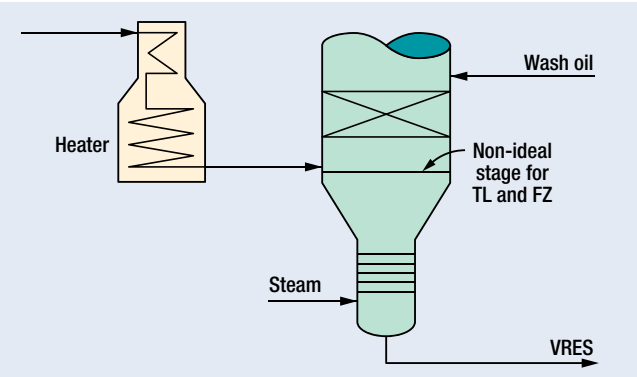


FIG. 6 Summarized conditions for a non-equilibrium transfer line and a non-ideal flash zone in the non-ideal stage for the flash zone with no entrainment to the wash zone.

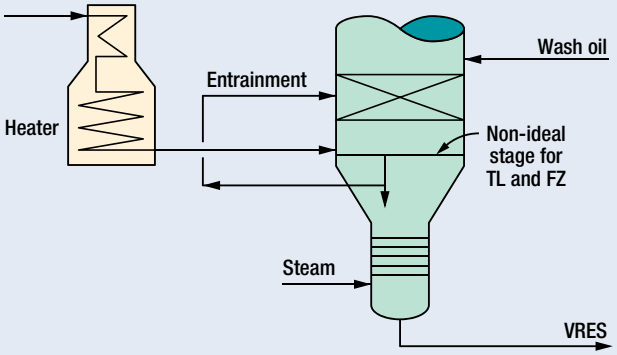


FIG. 7 Summarized conditions for a non-equilibrium transfer line and a non-ideal stage for the flash zone with entrainment to the wash zone.

in Fig. 5. This model has all of the non-idealities for the transfer line and flash zone. The flash zone non-idealities consist of non-ideality in phase separation, and heat and mass transfer. It seems that the model (Fig. 5) could manage the realities found in crude vacuum towers.

Simulation results of this model are listed in Table 6. Again a noticeable change in the minimum wash-zone liquid flow occurred—137 m^3/hr compared to 155 m^3/hr or equivalent to 13.1%. Also, decreases in HVGO 95% EP and increases in VRES 5% are considerable. Likewise, in the previous case, entrainment to the middle of the wash section can compensate for many non-idealities in the TL and FZ and help the unit approach equilibrium to improve fractionation. This is obvious in simulation results, as shown in Table 6.

The question now is: Is it possible to summarize all non-idealities of the TL and FZ in mass and heat transfer to the assumed non-ideal stage for the FZ? To answer this question, the model from Fig. 6 is considered. This model was simulated, and the results listed in Table 7. This simulation was done to have the same amount of overflash. The results are exactly similar to the case when phase separation is considered for the transfer line.

For this case also, if entrainment from the FZ to the wash section is considered, a model as shown in Fig. 7 should be used; Table 8 lists simulation results for this case. The values from Table 8 are exactly similar to a case in which the non-idealities were addressed in the TL separately.

What should technology do? As seen, considering the entrainment from the flash zone to the middle of the wash section, it corresponds with actual experiences from the crude vacuum unit in many refineries. Furthermore, phase separation in the TL and, consequently, creating superheated vapor at the tower inlet has been discussed. According to the presented study, entrainment from the FZ is not totally undesirable. In the non-equilibrium TL, the liquid and vapor phases do not have sufficient mass and energy exchange. In this case, the de-entrainment action of the wash section provides another opportunity for more mass and heat exchange between the liquid and vapor phases from the TL to approach equilibrium. Therefore, it is an improvement because, in equilibrium, maximum mass and heat transfer occur. Alternately, entrainment can plug the wash section due to coke particles caused by cracking.

Plugging the wash section causes low quality and yield of VGOs; all reduce plant profitability. Plugging of the wash section is one of the worst events in a vacuum unit and requires unit shutdown to replace packing. So, although entrainment may push the system to higher yields or quality (in mass and energy exchange points of view), it can plug the wash section of the tower.

According to the presented study, under equilibrium for the TL, no change will occur if entrainment is considered. When the equilibrium TL provides vapor and liquid phase in the equilibrium state and maximum mass and energy exchanges have occurred, no more mass and heat transfer can be expected. So, while the desirable effect of entrainment could be achieved by *equilibrium transfer line*, it is offered to eliminate the entrainment. New technology should address these goals:

- Provide equilibrium transfer line
- Provide a suitable flash-zone arrangement and vapor horn to eliminate entrainment from the flash-zone vapor outlet as much as possible.

Currently, there are many designs for flash-zone arrangements and vapor horns to eliminate entrainment. In some, the center inlet is recommended; in others, a tangential type is offered. In addition, the flash zones are available in different designs to remove entrainment from the flash-zone vapor outlet. Some designs are found in the open literature while the others are patented. Again, if the flash-zone arrangement is designed to remove entrainment without any attempt to maintain equilibrium in the transfer line, then the quality and/or yield of the VGOs will drop.

Options. When simulating crude vacuum units, some non-idealities must be considered. When developing a model based on these non-idealities, these non-idealities must be identified and understood. The next step is to incorporate these non-idealities into the simulation model. While there are many options and alternatives to develop simulation models, in some cases, a simple model may be offered instead of sophisticated ones. As shown here, by a simple non-idealities assumption, a model was developed that is completely consistent to the real performance of the tower. **HP**

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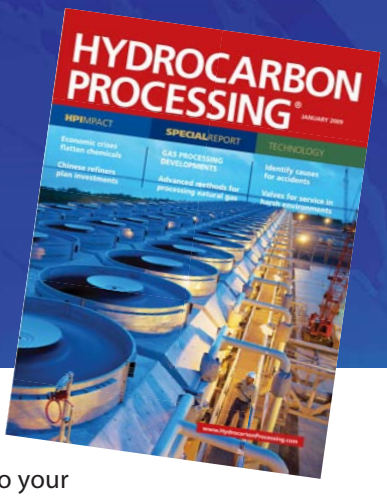
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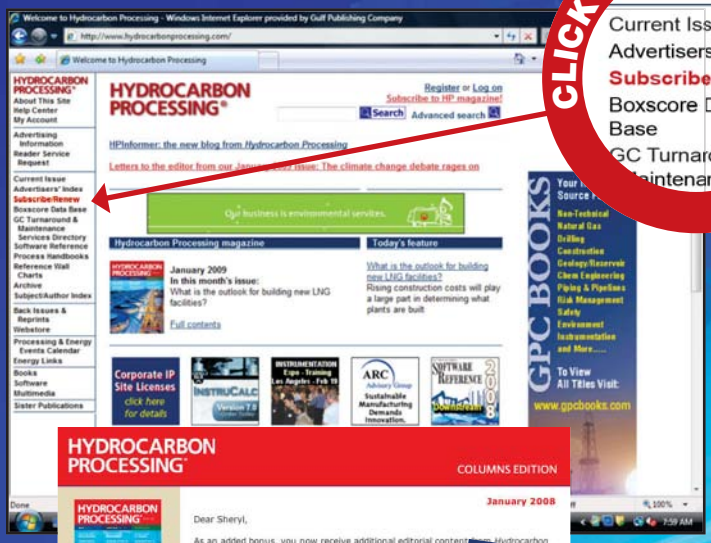
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From dynamic 'mysterious' control to dynamic 'manageable' control

Instructional design strategies and delivery methods for bridging the DMC chasm

S. M. RANADE and **E. TORRES**, RWD Technologies LLC, Houston, Texas

Dynamic matrix control (DMC) is a type of model-based process control (MPC) that uses an explicit plant model derived from plant tests. It has been over 25 years since information about the first industrial applications of DMC appeared in the open literature. Since then, hundreds of papers and many books have been published on the topic of MPC or model predictive control (MPC).

Every new edition of all process control books typically has a chapter devoted to MPC. DMC experts and some plant process control engineers and operators involved in the entire implementation cycle of a DMC project seem to be comfortable with the technology. However, typical responses we get from board operators (who run the units) include:

- DMC probably makes money for the unit, but we are not sure how.
- After a recent thunderstorm, the controller went crazy!
- Sometimes I expect it to increase the flow, yet it seems to raise the pressure. I am not sure why.

> **"Initially, the operators need to know the what and, to some extent, the why. Understanding the how will then happen with time."**
>
> ***—Ricardo Lecompte P., operations supervisor, Ecopetrol, Cartagena, Colombia***

The gap. With such a long history and ubiquitous presence in process plants, one would have expected a higher level of knowledge and acceptance of dynamic matrix controllers among operators and process engineers. This does not seem to be the case. Possible reasons for this gap include:

- The technology is complex. This was recognized and discussed by Cutler, et al., in the early 80s.[1] Even today, some "die-hard" purists sense a high degree of risk in attempting to try to get everyone on board. Their advice is to let the experts handle the problems.
- In a typical DMC project, 80% or more of the investment goes into the initial model identification, tuning and commissioning part of the project. The assumption is that if designed and tuned correctly the controller should run relatively maintenance-free for a long time. While this is a reasonable assumption, it does not mitigate the anxiety among the operators who run the units.
- Recognizing the maturity of the core technology, MPC software vendors have shifted their emphasis from knowledge transfer to enhancements such as using state-space modeling, better estimation of tuning parameters, newer techniques to deal with integrating systems, integration with neural networks, etc. These areas of research are clearly needed to maintain their competitive edge but have not helped address the discomfort of newcomers to the technology.
- Traditional DMC courses have focused on training the site specialists and process control engineers on how to use the software but not on the operators who run the unit. The courses in the past have focused more on product features than on learners' needs.
- Since its inception over 25 years ago, a new generation of operators and engineers has started working at the sites where the technology was implemented. At many sites, the specialists are gone and knowledge about DMC implementations has been orphaned.

Proposed solution. Michael Buckland and Doris Florian in their paper on intelligent information systems identified four courses of actions when the complexity of a task strains or exceeds one's expertise: education, advice, simplification and delegation.[2] MPC software vendors are actively engaged in investigating ways to improve user interfaces.[3] Many universities have created process control labs to improve their students' familiarity with the technology.[4] We decided to approach the problem from a training perspective.

Different perspective. Instead of comparing monitoring a dynamic matrix controller to performing a brain surgery which made sense more than 25 years ago when Dr. Cutler and other pioneers[5] in the field were applying it in plants with limited computing power and high perceived risks, we began by asking a different question: "What if running a DMC application was more like driving a computer-controlled car?"

For operating and maintaining such a vehicle, one does not have to be an expert on the design and tuning of the computer or the engine. Yet, having a foundational understanding of how the computer and car work together would clearly be beneficial to everyone involved. This different perspective seemed to resonate well with users and lead to developing a DMC course.

Target audience, objectives. Using the terminology introduced by Guy Boy,[6] we selected two goals for the course: increase user knowledge to improve cognitive stability and use simplification to reduce perceived complexity. The most important step in instructional design is to ask: "Who will take this course?" We selected the board operators and new plant engineers as our initial target audience and set the following objectives for the course:

On course completion, the students will be able to:

1. Communicate more precisely about DMC
2. Show a measurable improvement in their ability to monitor their unit with DMC on it
3. Show an improvement in their ability to diagnose a problem in their DMC-controlled unit.

With a known learner-profile and defined objectives, we broke down the content into units and selected a sequence and delivery methods. Two instructional design strategies and two instructional delivery methods got high ratings during the initial test runs of the course. The two instructional design strategies are:

- Simplify content to match learner needs
- Equip students with alternate schemas to validate new knowledge.

The two instructional delivery methods are:

- Use humor and metaphors
- Use dynamic interactive motion graphics elements.

These strategies and methods can be easily extended to improve the training effectiveness for other DMC-like advanced technologies and are the main focus of the rest of this article.

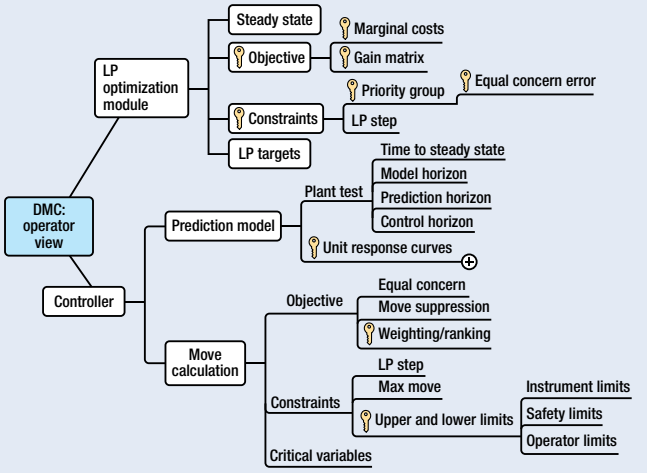


FIG. 1 Example of key DMC concepts from the literature.[8–13]

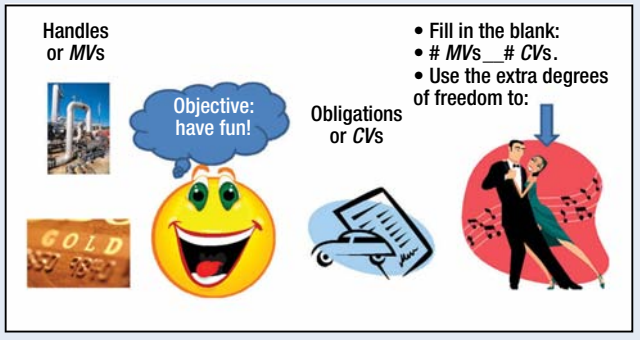


FIG. 2 Representation of the fictional Beauford's life in his early 20s.

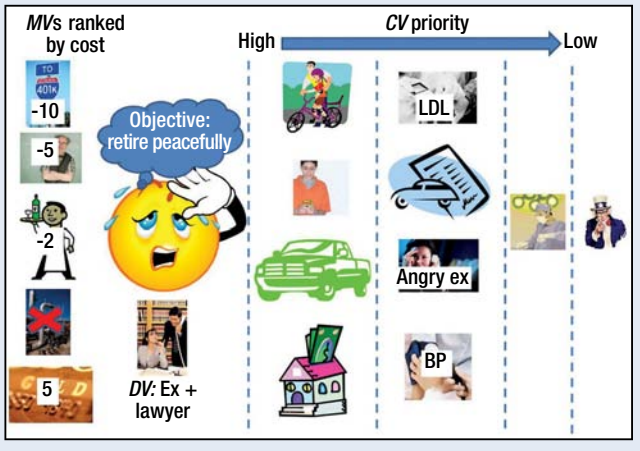


FIG. 3 Representation of the fictional Beauford's life in his early 50s.

Simplify content. A literature review reveals that most articles on MPC are written for application developers and include details such as model horizon, control horizon, prediction horizon, move suppression factors, coincidence points, etc., that are of minimal interest to operators and new process engineers trying to learn the technology. However, simplification is a double-edged sword as illustrated by the well-known maxim called Ockham's razor.[7] Cognizant of the requirement that any simplified representation of DMC should not preclude future in-depth understanding of the application, we created a "simplified" overview derived from numerous textbooks and papers[8–13] and shown in Appendix A: How DMC works. The common terms used in association with DMC applications are defined in Appendix B: Glossary. Fig. 1 is an example of a system representation appropriate for our situation. The main concepts that must be understood by the learner are marked with the "key" icon.

Use humor and metaphors. The operators we interviewed felt challenged by the language and terminology used in connection with DMC applications. As reported by Benedict Carey in *The New York Times*, researchers have found that the human brain has a natural affinity for narrative construction.[14] Also, emotional memory has been recognized as the most effective pathway to long-term retention.[15]

Author Marc Prensky coined the phrase "digital natives" to represent the new generation of high school and college graduates.[16] According to Prensky, this new generation prefers games to "serious" work. So, instead of simply listing the DMC vocabulary, we decided to leverage the power of stories, metaphors and humor. We created a story called "The life of Beauford—A DMC interpretation." Figs. 2 and 3 illustrate snapshots of Beauford's life in his early 20s and in his mid-50s.

For example, to illustrate the concept of equal concern error, we stated that one phone call from his ex-wife's lawyer, a 5-mpg drop in his car's mileage, a 10-point drop in his son's grade and a $500 drop in his bank account were all viewed by Beauford

■ **"Humor and use of interactive models in this course helped me overcome an internal barrier to learning."**

—Maria Helena Calvachi, sr. process engineer, Ecopetrol, Barranca, Colombia

as deviations worthy of equal concern. The learners who saw Beauford's story were able to quickly grasp and recall in their own words concepts such objective function, manipulated variable (*MV*), controlled variable (*CV*), disturbance variable (*DV*) and even specific terms such as *CV* ranks, equal concern error and dynamic equal concern error.

Use dynamic interactive motion graphics. Digital natives, who will soon be joining the process industry, grew up playing video games and learn by interacting with the content. DMC has the right level of complexity to explore the use of "motion graphics" in training. The availability of simulation software,[17] animation programs and other graphics tools has also made it easier to incorporate motion graphics in teaching. Here's an example that illustrates the role and importance of animation.

Consider the problem of optimizing the number of light- and heavy-duty engines[18] manufactured by an aircraft manufacturer using facilities in Abilene (A), Texas; Birmingham (B), Alabama; and Calgary (C), Canada. The light engine is made with parts produced in plants A and B. The heavy-duty engine is made with parts produced in plants B and C. As shown in Table 1, there are constraints on the availability of the three facilities. The objective is to find the mix of light- and heavy-duty engines that will maximize the weekly profits.

Traditionally, linear programming (LP) courses use static parametric graphs such as the one shown in Fig. 4 for introducing the concepts like constraints, feasible region, etc., and to demonstrate that the maximum value of the objective function always occurs at a vertex of the graph. Since operator adaptation to DMC requires a shift from sensor-motoric mode to a cognitive mode,[6] we supplemented the traditional approach with an interactive approach to allow the learners to experience the "what if scenarios:" What if the plant availability of the Birmingham plant decreased by an hour per week? What if the profitability of each heavy-duty engine decreased by $100,000?

In the initial tests, the students were quickly able to discover and explain that their changing of the plant availability had an immediate impact on the size and shape of the feasible region for optimization and that although they changed the conditions the optimum still occurred at a vertex of the graph. You may try this yourself by going to: http://elearning.rwd.com/dmc.

This "interaction" approach to be ideal for introducing "time-dependent" concepts such as dead time and inverse response and to enable learners to experience how narrowing down the range of reflux or steam rates in a distillation column would constrict the movement of a dynamic matrix controller.

Equip students with alternate schemas. Many years ago, when I was a graduate student, I had calculated a heat transfer coefficient for a heat exchanger. I shared the result with my advisor, Dr. Prengle. He did a quick "back of the envelope" calculation and told me that I might have missed a decimal point. He was correct.

For true learning to occur, the learner has to process, cross-check and validate new knowledge by some alternate means. Some of this knowledge validation happened, as in the case of the late Dr. Prengle, through years of experience. When faced with a new technical problem, my natural instinct is to use the language of mathematics to analyze the situation. Operators and engineers

TABLE 1. Data for LP example

Plant	Prod. time per light engine	Prod. time per heavy-duty engine	Max. time available per week
Abilene	1	0	4
Birmingham	0	2	12
Calgary	3	2	18
Profit per engine	$300,000	$500,000	

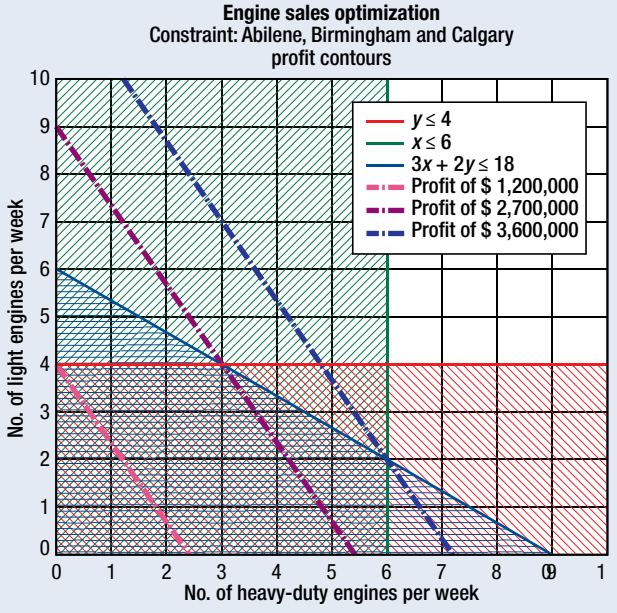


FIG. 4 Parametric plot to illustrate LP concepts.

Parameter	Change		Change	DMC response
Operator-entered limits	↕	→	↕	Feasible region
CV upper limit = *CV* lower limit		→	↓	Feasible region; *CV* at setpoint
No. *MV*s = no. of *CV*s		→		Unique solution
No. *MV*s relative to no. *CV*s	>	→	↑	Scope for economic optimization
No. *MV*s relative to no. *CV*s	<	→		Give up on some *CV* limits by priority
ECE for *CV* limit (tolerance)	↑	→	↓	Importance of that limit
LP cost	⊕	→	↓	Use of that *MV* (resource)
No. *MV*s constrained	↑	→	↓	Feasible region; give up on some *CV*s.
No. of available *MV*s	=	→	=	Number of *CV*s @ limits

FIG. 5 New DMC tool: parameter relationship diagram and description.

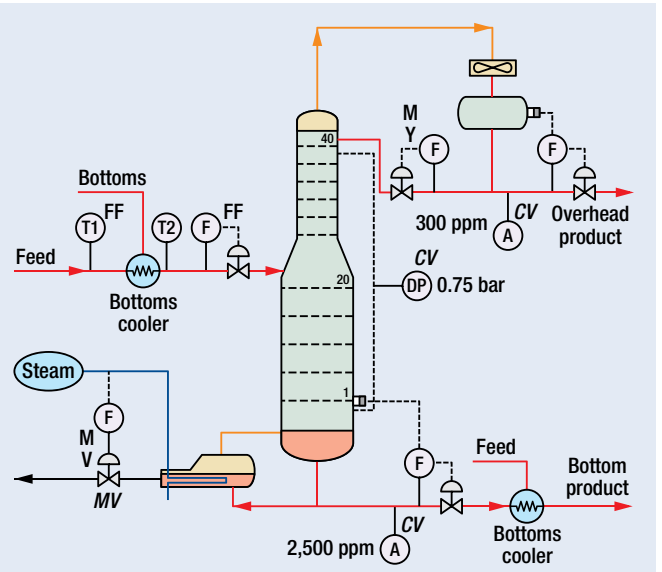


FIG. 6 A distillation tower example originally presented by Hokanson, D.A. and J. G. Gerstle.[13]

new to DMC do not have the benefit of vast experience or other internal reference or a mechanism to crosscheck and validate the actions of DMC.

To move their learning about DMC from Bloom's recall level to analysis level, they need some "back of the envelope" type tools. Of course, if one could easily do "quick" calculations to get the same answer as that found by DMC, one would not need DMC. The true benefits of technologies like DMC are in their power to find "non-intuitive" but optimum solutions. One approach that might accelerate this "knowledge internalization" process is to provide "learner-appropriate" tools that would enable students to make at least qualitative sense of the actions taken by the controller. Such an approach would move the student from simply the "know what" to the "know why" state of learning.

Our understanding of the learning styles and preferred information processing methods of operators and new plant engineers matches closely with the empirical theory of intelligence developed by Elliott Jacques.[19] Recognizing that most new board operators are comfortable with a "symbolic verbal" (vs. abstract conceptual) style of learning and have experience in declarative, cumulative and serial methods of information processing, we developed two "cognitive" tools and a recipe-type "what if analysis strategy" that uses the two tools. One of these tools—parameter relationship diagram and description—for DMC is illustrated in Fig. 5. An example of the application of the two tools and the "what if analysis strategy" to a refinery distillation column (Fig. 6) is presented in Table 2.

These instructional design strategies and delivery methods increase user knowledge and decrease the perceived complexity of DMC. The techniques can be easily extended to designing and delivering training for other DMC-like mature complex applications. **HP**

ACKNOWLEDGMENT

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TABLE 2. What if analysis strategy example

Unit (Fig. 6) objectives:
1. Meet overhead product specs.
2. Meet bottom product specs.
3. Minimize energy consumption.

		For the unit		
	CVs →	ppm heavies in OVHD	ΔP as proxy for flooding	ppm lights in bottoms
LP costs	*MVs*			
10	Steam flow SP	↑	↑	↓
5	Reflux flow SP	↓	↑	↑
	DVs			
	Feed rate FI	↑	↑	↑
	CV priorities			
	Group	2	1	2
	Upper limit	High	High	Medium
	Lower limit	Low	Low	Low

Question: What if the flooding constraint becomes active?

Analysis:
- Under normal operating conditions, the DMC controller has 2 *CVs* and 2 *MVs*
- From Fig. 5, No. *MVs* = No. *CVs* → Unique solution. Also, No. of available *MVs* = No. of *CVs* at constraint. i.e., the product specs are being met.
- The flooding constraint active → loss of a degree of freedom.
- The controller has to give up on one of the two product specs.
- From Fig. 5, ↓ *CV* priority → ↑ in feasible region.
- The controller will give up on the ppm lights in bottoms constraint but maintain OVHD purity.
- Since the LP cost factor for steam is higher than that for reflux, the controller will first reduce steam and then cut reflux to meet the LP targets.

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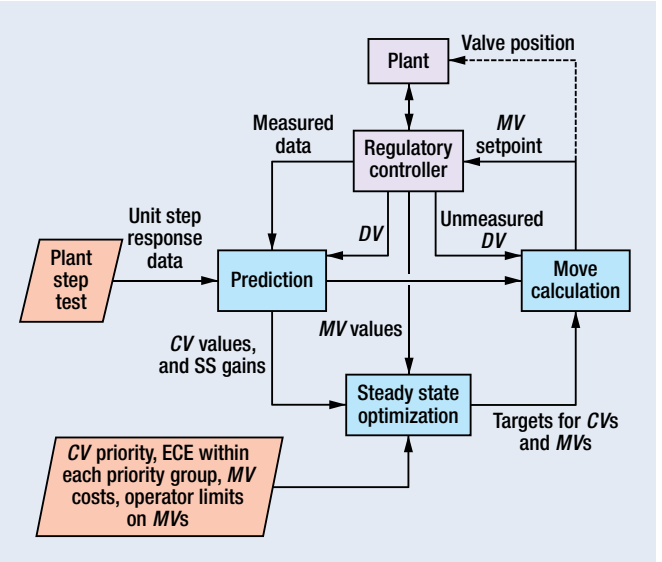


FIG. A-1 A DMC-based controller has three main modules (blue).

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APPENDIX A: HOW DMC WORKS[8–13]

In DMC, the dynamic matrix is generated from the plant step tests. The identification process begins with understanding the unit objectives and selection of the *MV*s, *CV*s and *DV*s. The step tests are conducted to capture data (numerical and graphical) regarding how each controlled variable responds to a step change in each manipulated variable. The unit step response curves are then used as the prediction model.

As the overview in Fig A-1 illustrates, a DMC-based controller has three main modules: the prediction module, the steady state (SS) optimization module and the move calculation module.

1. Each controller cycle begins with collection of measured or actual values of the controlled variables. A comparison is made between the actual and the predicted values (from the model), and the error is then fed to the prediction model. This error term is assumed to be the same for the prediction horizon used by the model and accounts for model mismatch with the plant. The Prediction module generates an estimate of the steady state values of the controlled variables. The current values of the manipulated variables and the future steady state values of the controlled variables are passed on to the SS optimization module.

2. The SS optimization module uses the controlled variable priority information and the steady state gain information from the unit response curves to check the feasibility of finding a solution. Assuming that one or more feasible solutions are found, the optimizer then uses the LP cost data to determine the economic optimum and send these targets as "desirable" setpoints to the move calculation module. The priority group structure of controlled variables enables DMC to find feasible solutions. DMC starts with the highest priority rank group of controlled variables. If no feasible solution is found, DMC uses the equal concern error (ECE) data within each rank group to find feasible solutions.

3. The move calculation module then uses the setpoint targets, data from the prediction model and disturbance variable data and finds the values of the MV moves by minimizing weighted sum of squares of the deviations of controlled variables from their setpoints. Factors such as move suppression and equal concern error affect the performance of the dynamic controller but are typically set during the design and tuning phases of implementation. The DMC controller calculates several control moves depending on the set control horizon (another design tuning parameter) but only implements the first move. Once the first move is implemented, the next control cycle begins.

APPENDIX B: GLOSSARY[8–13]

Term	Definition
CV	Controlled variable. Similar to output variable. Usually measured or monitored. May also be inferred. Setpoints and upper and lower limits are typically associated with a *CV*.
CV rank or priority	This parameter is used by the controller to prioritize the different *CV*s. It is especially relevant for determining a feasible region for optimization. The *CV*s are typically grouped depending on their importance.
DMC	Dynamic matrix control (originally developed by C.R. Cutler and others (1979)
DV	Disturbance variable. Sometimes referred to as a FFV or feed forward variable. There are two types of *DV*s: modeled and not modeled. A typical example of an unmeasured *DV* is ambient temperature.
ECE	Equal concern error. It is of two types. ECE used in the steady state optimization part is based on the operator concern for deviation of each *CV* from its limit. It is used to normalize the differences caused by different engineering units. Smaller value of ECE implies higher importance of the setpoint of a *CV*. Dynamic ECE allows the controller to take different actions depending on how far the prediction is from the setpoint.
MV	Manipulated variable. Similar to input variable. Must be independent, i.e., must not depend on another manipulated variable. May be a *PV* or an OP. Examples include reflux rate, steam valve position, etc.
LP cost	It is derived from plant operating costs and is consistent with the operating objectives of each unit. This parameter is used to drive the *MV*s toward the economic optimum.
Operator set limits	For each *MV*, the upper and lower limit that can be set and changed by the unit operator.
SSG or SS gain	Steady state gain is the net change in the *CV* value after the effects of the step change in the *MV* have settled out over time. A measure of how much the *CV* is likely to change relative to a change in the *MV* value. It is a coefficient used in the LP cost calculations.



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Y. ZAK FRIEDMAN, CONTRIBUTING EDITOR

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CDU overhead double-drum configuration

Fig. 1 shows one of many CDU overhead configurations, with naphtha cutpoint control accomplished by a column top temperature controller manipulating a top pumparound (TPA) circuit heat removal. This configuration is heat efficient although heat efficiency comes at the expense of top section separation. The TPA internally uses four trays, not for separation, but for internal condensing and heat transfer.

To regain those lost trays process designers often specify two overhead drums per the configuration of Fig. 2. Heat previously removed by the TPA circuit is now removed by a reflux condenser against crude, more or less at the same temperature levels. Vapor from the reflux drum is further condensed into a product drum. On the whole—a thermodynamic system that not only gives us more top section trays, but the reflux drum is also a separation stage.

Examine now the DCS control of Fig. 2. Naphtha cutpoint is controlled by manipulating reflux instead of TPA duty. Excess reflux drum material is blended into the naphtha product. Is it a good idea to mix reflux into the product? Reflux is heavier than naphtha, and mixing it into the product creates an undesirable heavy tail. Ten percent of the reflux is light kero material, and downgrading kero to reformer feed in today's prices carries a penalty of about $7 per bbl. Even if there is a price reversal, good separation between kero and naphtha would be profitable, and that is why the double drum is there in the first place.

Another feature I dislike about Fig. 2 is the method of inferring naphtha cutpoint. The temperature most indicative of naphtha cutpoint is not the TC on top of the column but rather the blue TI on the reflux drum.

What I consider a thermodynamically correct way of controlling a double-drum overhead system is illustrated in Fig. 3. The combination of reflux drum level control on the reflux, and naphtha cutpoint control on the reflux condenser elminates excess reflux. For good dynamic response, tune the blue level controller tightly. IE, apply a strong controller gain, but beware of making the reset action too aggressive and driving the controller unstable.

Fig. 3 permits recycle of product naphtha into the reflux drum but that is used only in abnormal situations. Such recycle may become necessary during hot summer hours, when even maximum reflux condenser operation cannot maintain the naphtha cutpoint at target. Bear in mind that the recycle of naphtha into the reflux drum is in the category of reflux going down the column and is not thermodynamically damaging, but it is not desirable because it replaces high-temperature cooling against crude by low-temperature cooling against air. **HP**

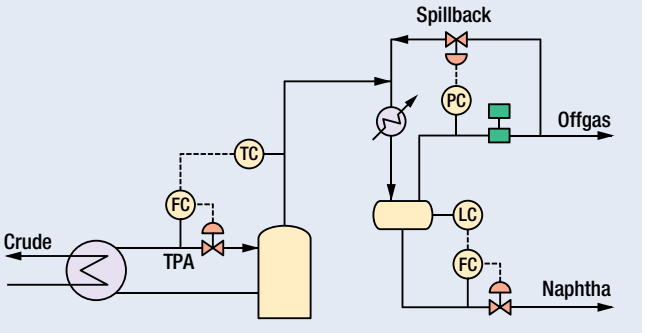


FIG. 1 Single-drum overhead.

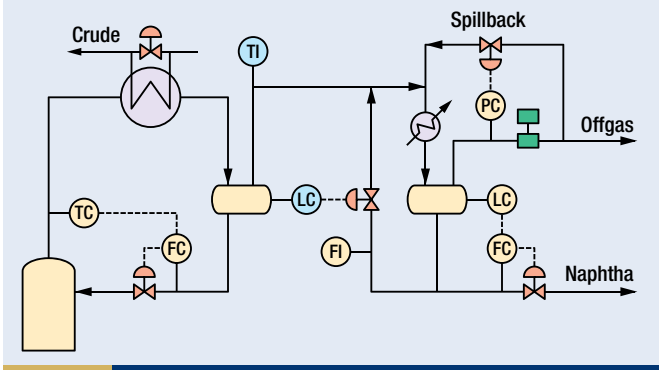


FIG. 2 Double-drum overhead.

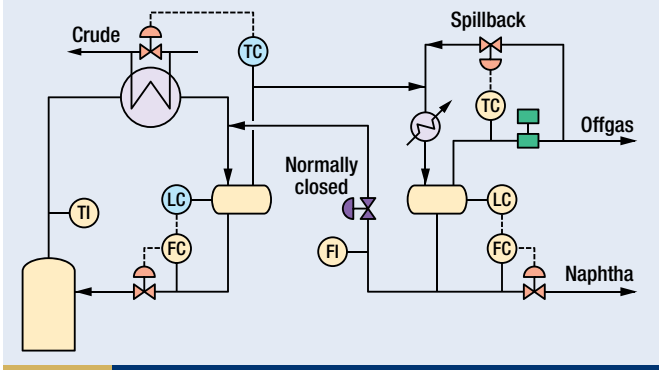


FIG. 3 Ideal double-drum control.

The author is a principal consultant in advanced process control and online optimization with Petrocontrol. He specializes in the use of first-principles models for inferential process control and has developed a number of distillation and reactor models. Dr. Friedman's experience spans over 30 years in the hydrocarbon industry, working with Exxon Research and Engineering, KBC Advanced Technology and since 1992 with Petrocontrol. He holds a BS degree from the Israel Institute of Technology (Technion) and a PhD degree from Purdue University.



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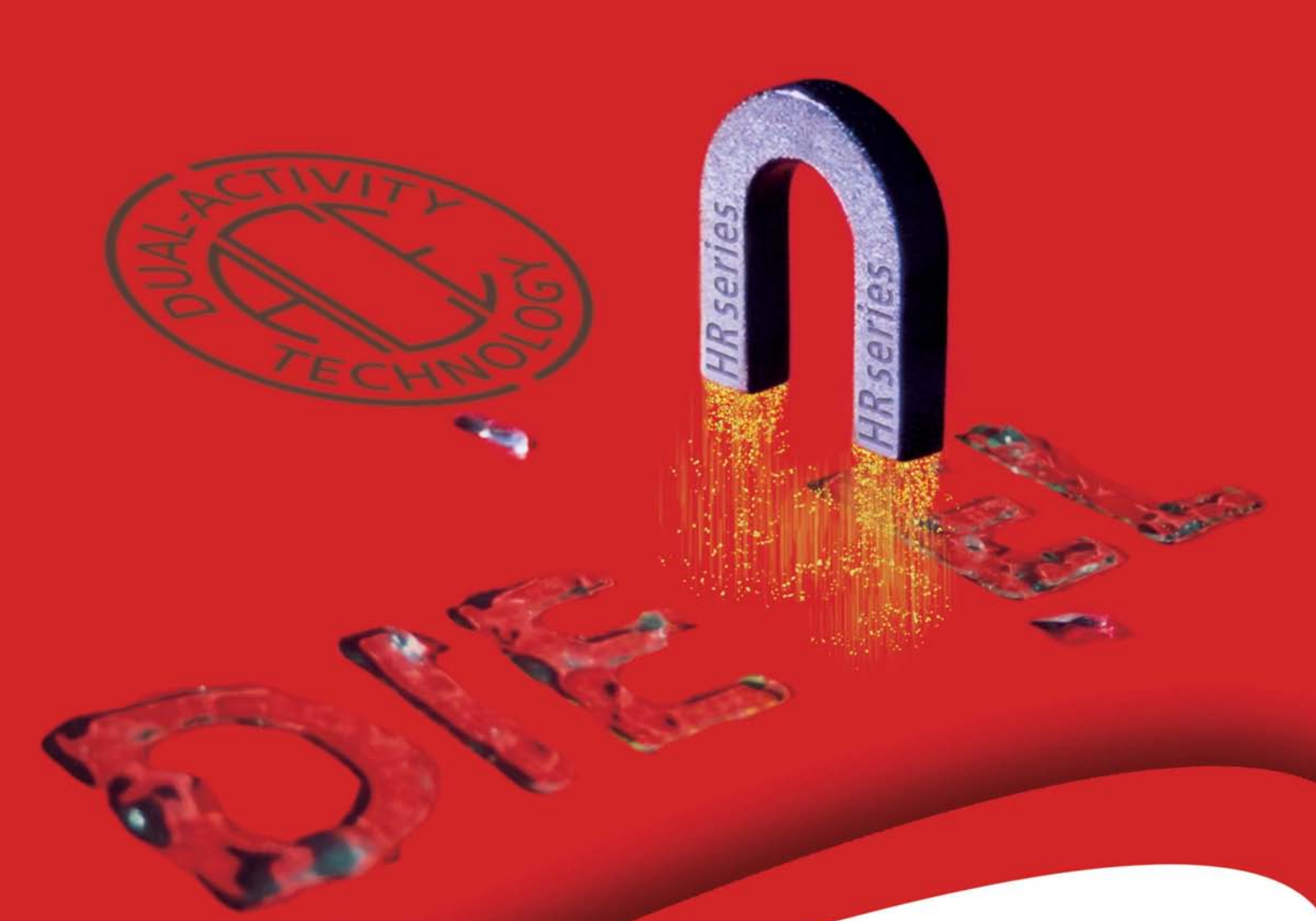
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