

Revamping crude unit increases reliability and operability

By improving the operation of nonrotating equipment, a refiner minimizes losses and raises process profitability

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Improving reliability increases profitability. When refinery margins are low, equipment reliability, or lack of, can be the difference between making a profit or losing money. Maintenance and rotating equipment engineers are aggressively improving rotating equipment reliability. Rotating equipment reliability programs are well established and have been successful in many cases. Yet, the same attention is not applied to nonrotating equipment.

Yardsticks. Rotating equipment reliability programs have successfully increased the mean time between failures (MTBF) for rotating equipment. MTBF is a yardstick for rotating equipment reliability; it is a measure of time between failures and is easy to monitor. But, how do you measure the reliability of a distillation system or a preheat train? Reliability—applied to nonrotating equipment—is a measure of its performance relative to its intended design performance. If equipment does not perform as well as design, then it is unreliable. This reduces profits.

Refinería de Panamá (Refpan) revamped its crude unit in the fall of 1996 to increase middle-distillate yield and improve crude-oil processing flexibility. Ultimately, the revamp increased middle-distillate yield by 10% volume on crude, improved both marine- and road-diesel quality, and enhanced crude-oil processing flexibility. This project had a simple payout of less than three months. Ref-

pan attributes the success of this revamp to the reliability gains for nonrotating equipment.

Unit description. Fig. 1 is a process flow diagram of Refpan's crude unit before the revamp. The refinery processes blends of Oriente, Arabian Heavy, Cano Limon, Leona, Maya and Isthmus crude oils. During the unit performance test, the atmospheric bottoms (ATB) yield was 56% of crude. The column's lowest side cut is a heavy diesel product (HDO) used for power-company gas turbine and marine diesel sale. Light diesel (LDO) product is used for road diesel and power generation. The HDO product contained 75% LDO boiling range material. ATB is feed to the visbreaker unit, asphalt unit, and fuel-oil blendstock. Twenty percent of the ATB was recoverable LDO and HDO boiling-range material.

Optimal crude unit fractionation depends on the refinery configuration and product market. Refpan's light-diesel product has higher value than heavy diesel. The local market can absorb all the light diesel produced. HDO and LDO boiling range material in the ATB are downgraded to fuel oil. The heavy-diesel product market is limited by local marine diesel sales. Therefore, LDO product yield and fractionation should be maximized. HDO boiling range material in the ATB should be controlled based on marine diesel sales.

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Minimum capital-cost revamp.

Revamping an existing process unit is a four-stage approach. Process engineering identifies processing options from field-survey results, and ultimately captures those opportunities with operating, process and equipment changes. Using a four-stage approach progressively moves the refiner toward a funded revamp that will produce *real* results while controlling engineering costs. The four engineering stages are:

- **Stage 1:** Feasibility—field survey
- **Stage 2:** Unit benchmarking—comprehensive performance test
- **Stage 3:** Conceptual design—eliminating bottlenecks

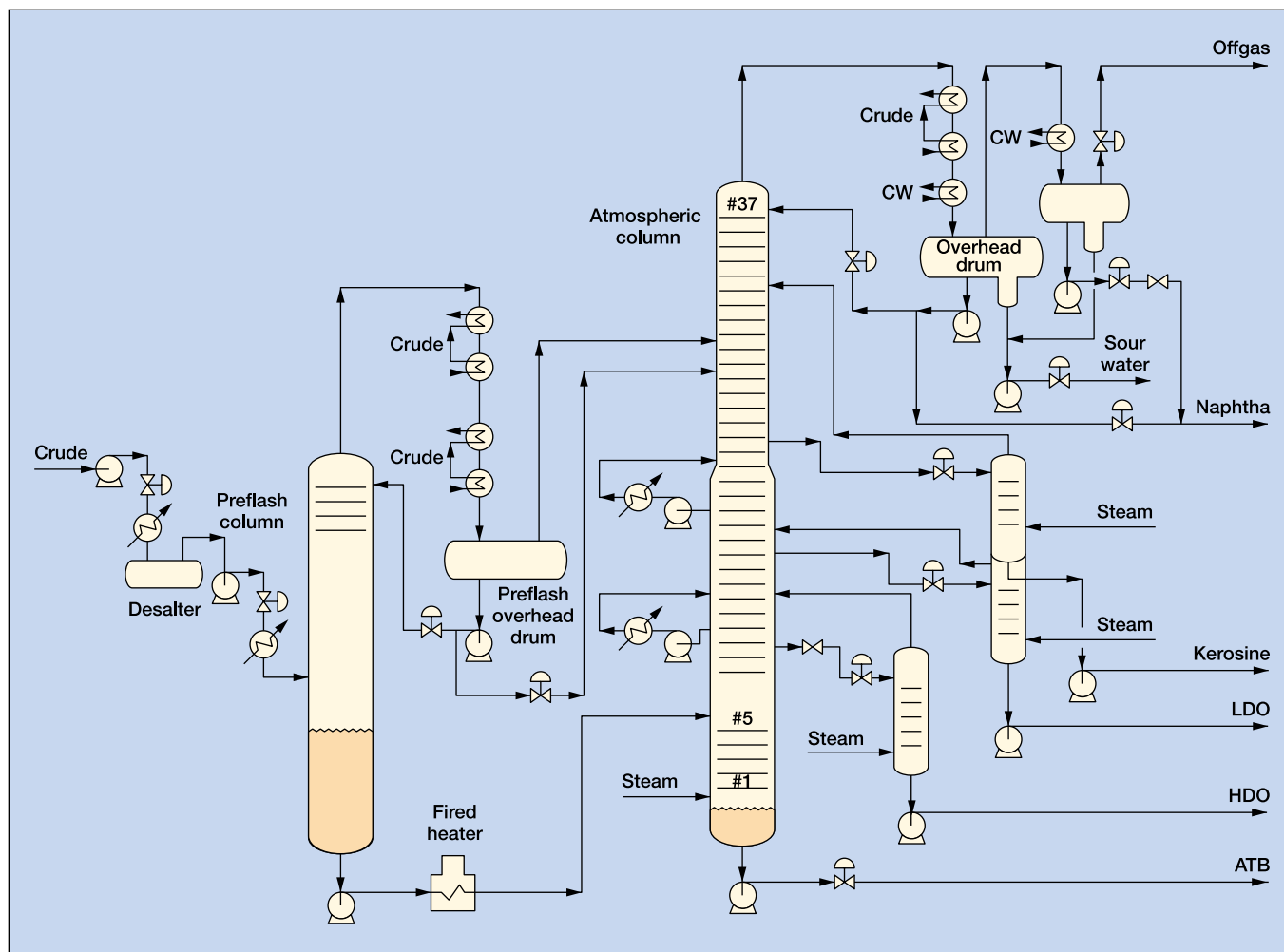


Fig. 1. Pre-revamp crude unit PFD.

- **Stage 4:** Process design package—major equipment design.

Feasibility and benchmarking identify reliability improvement areas.

Determine reliability—unit benchmarking. Rotating equipment reliability programs focus on identifying compressors and pumps with repetitive failures, determining the root cause of the failure and eliminating it. This same process has not been rigorously applied to other process equipment and equipment systems. During unit benchmarking, nonrotating equipment reliability is determined.

Nonrotating equipment reliability measures actual equipment performance compared to its intended design performance. If equipment is not functioning as intended, then it is not reliable. Underperforming equipment can lead to lower unit capacity, reduce product yields and generate poor product quality—all factors will lower profitability.

Identify process and equipment underperformance. Revamp engineers must identify the root cause of underperforming equipment before it can be fixed. While the fix for a reliability problem is often straight forward, diagnosing the root cause can be difficult and time consuming. Reliability problems stem from process and mechanical design flaws. Potential design flaws are numerous, and attention to detail is essential

when evaluating equipment. A thorough understanding of the process, *as well as* equipment operation and design, is essential when identifying the root cause of underperforming equipment. Wet feed, high liquid level and pressure surges are examples of process-specific conditions that can impact a unit's profitability.

A minimum capital-cost revamp must first *measure* equipment performance.¹ This identifies unreliable process and equipment designs. Successful revamps exploit the difference between actual and potential equipment performance to minimize capital expenditures. Otherwise, more capital is spent to achieve revamp objectives. In some cases, the *real* unit limits are never identified. These revamps fail to achieve an acceptable return-on-investment.

Unit benchmarking—comprehensive performance test. Unit benchmarking establishes *actual* performance. *Benchmarking is an expensive, time consuming task.* Often, this stage is skipped due to a perception that computer models alone can do this job. Field measurements are an integral part of benchmarking. Fieldwork consists of measuring temperature, pressure and composition profiles. These measurements are then used to calibrate process and equipment models, and they can be used directly to infer equipment conditions.² For instance, at Refpan, field measurements confirmed that the wash- and stripping-section trays were damaged. Fig. 2 shows the field-measured pressure drop. Trays require pressure drop

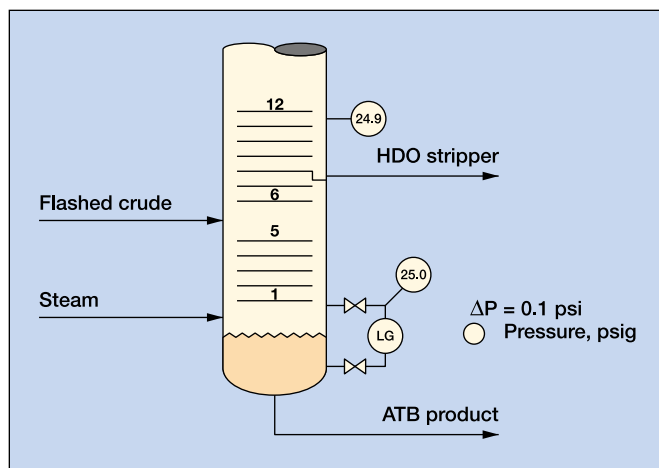


Fig. 2. Pressure survey of the crude column.

to work properly. When there is no pressure drop across a tray, then it is either damaged or poorly designed. The Refpan crude-unit benchmarking identified that these areas were affecting reliability and profitability:

- Practical process considerations
- Crude-column fractionation
- Equipment design.

Process design reliability—root-cause analysis.

Process design does impact unit profitability. The revamp conceptual design establishes a reliable process flow scheme, and the design package provides essential equipment details. While it is always possible to make operating changes to minimize the effects of poor process and equipment design, design flaws inevitably affect profits.

Crude-unit profitability is driven by product yields. Crude-unit product yields are dependent on heat input, heat removal, operating pressure and fractionation. Heat input into crude charge consists of crude-exchanger-network heat recovery and fired-heater duty. Pumparound and condenser equipment design and operation determine heat removal. Crude-unit operating pressure is largely determined by the condensing system capacity, fouling and corrosion.

Fractionation depends on the process design and equipment performance. Problems in any of these areas can affect unit capacity and product yields and quality. Improving crude-unit profitability requires reliable process and equipment design.

Practical process considerations. Revamps solely based on computer models often fail to meet their profit objectives. Not addressing practical considerations can result in unsuccessful and unreliable revamps.^{3,4} Some practical considerations are:

- Startup and normal unit upsets
- Corrosion and fouling
- Operability.

Refpan's original crude-unit design highlights some practical considerations that should be addressed in revamp projects.

Startup and normal unit upsets. Crude-unit startups and normal unit upsets can cause severe mechanical stress on the column internals.⁵ Startups can be particularly damaging to column internals if they are

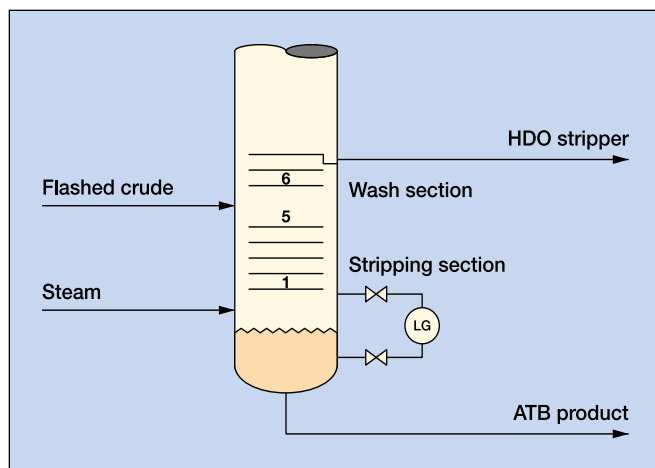


Fig. 3. Crude-column stripping and wash section.

not designed properly. These stresses are due either to normal startup conditions or inadequate operating procedures. Whatever the case, column areas that are susceptible to damage must be mechanically designed to handle the startup, shutdown and abnormal conditions.

Wet stripping steam and high liquid level can damage trays. Wet stripping steam introduces water to the bottom of the crude column. The water contacts hot oil and expands rapidly. As the water vaporizes into steam, a pressure surge is created that exceeds the column internal's mechanical strength. High liquid level also damages crude-column internals due to the energy of the liquid caused by steam or transfer-line vapor velocity. While wet stripping steam and high liquid level can knock out trays during normal operation, they are more likely to cause damage during startup.

The stripping-section and wash-section tray (Fig. 3) performance affects LDO and HDO product yields and unit profitability. The following symptom and root-cause analysis relationship was valid:

Symptom: Lower than expected LDO and HDO product yields

Root cause: Mechanical stress encountered during startup, shutdown and upset conditions.

Damaged stripping trays alone resulted in a loss of 2,200 bpd of heavy- and light-diesel product to fuel oil. Stripping- and wash-section tray damage is very common (Fig. 4). Standard mechanical design trays (0.2 psi uplift) had been installed in the wash and stripping sections. Standard strength trays work fine for standard conditions. However, stripping- and wash-section trays are not always exposed to standard conditions. They must be designed to stay intact during startup and normal unit upsets. The stripping-section trays were replaced with a heavy-duty tray design.

Crude-column overflash is the vaporized oil that returns to the flash zone as liquid. Minimum column overflash maximizes the HDO-product yield. Prior to the revamp, Refpan controlled the wash-oil rate by changing the HDO-product yield. These systems are difficult to operate and cause either low yield or poor HDO quality.⁶ The revamp used a total-draw tray with flow-controlled reflux to a packed bed. This design per-



Fig. 4. Stripping and wash section tray damage.



Fig. 6. Fouled overhead exchanger bundle.

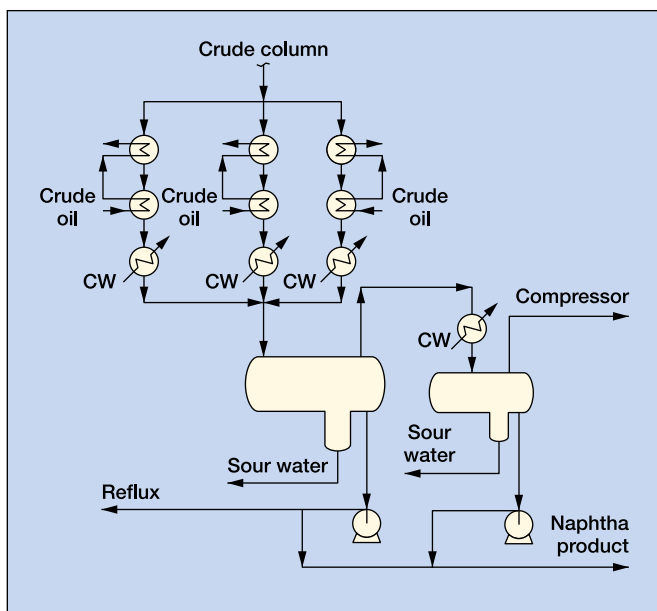


Fig. 5. Crude-column overhead condenser system.

mitted minimum overflash operation and maximum LDO and HDO yield. The wash-section mechanical design was upgraded.

Corrosion and fouling. Crude-column top trays and overhead condensers are susceptible to high levels of general corrosion and under-deposit corrosion and fouling.⁷ Thus, neutralizing and filming chemicals are used to reduce corrosion rates and extend condenser life. Corrosion of overhead condensers affects the condenser system performance, which affects the column operating pressure. Column top-tray corrosion decreases fractionation between naphtha and jet fuel. Top-tray corrosion is a function of reflux rate, temperature and water content.

Reduced condenser heat removal increases column operating pressure and decreases light- and heavy-diesel product yields. When light- and heavy-diesel yields decrease, profits are lowered. Root-cause analysis led to these factors:

Symptom: High column operating pressure/low LDO/HDO product yield

Root cause: Overhead condenser system design.

The crude-column operating pressure increases as the condensers foul. Large increases in the column operating pressure from start-of-run to end-of-run are a common cause of distillate-yield loss. The column operating pressure determines the amount of vapor generated at the heater outlet temperature for any given crude-oil mix and temperature. The heater outlet oil vaporization strongly affects product yields and economics.

Refpan's overhead condenser system uses three parallel and three series exchangers (Fig. 5). The first two exchangers, on each parallel train, exchange heat against cold crude oil from storage. The last exchanger is a water-cooled exchanger with seawater as the cooling water supply. In some cases, these designs work. However, in other systems, the exchanger fouling and corrosion is so severe that it reduces unit reliability and actually reduces profits due to product yield losses.

Condenser fouling has been a chronic problem at Refpan. Historically, the crude versus overhead-exchanger fouling has reduced heat transfer, and thus, loaded the downstream cooling water exchangers. Loading the water-cooled exchangers caused severe water-side fouling, further reducing condenser capacity. The overhead receiver temperature increases, which raises the compressor-gas load. Higher compressor-gas load raises operating pressure and reduces LDO and HDO product yields.

Crude-unit overhead systems that exchange heat against crude commonly experience corrosion and fouling (Fig. 6). The root cause is insufficient water at the point of salt deposition to dissolve the salt. The only effective way to remove these salts is by injecting water in front of the exchangers. Whenever column overhead vapor is exchanged against crude oil, the purpose is heat recovery. However, injecting sufficient wash water to remove these salts lowers the temperature to the first exchanger by 70°F, which reduces the driving force for heat exchange. Proper water washing of crude-column overhead systems is difficult.

The parallel exchangers installed at Refpan can be periodically isolated for cleaning. Cleaning overcomes the inherent reliability problems with these condenser-system designs. Living with the consequences of this system design is purely a business decision. The benefit of cleaning the exchangers is lower, average operating pressure. Reliable operation at lower pressure increases distillate yield and improves unit profitability.

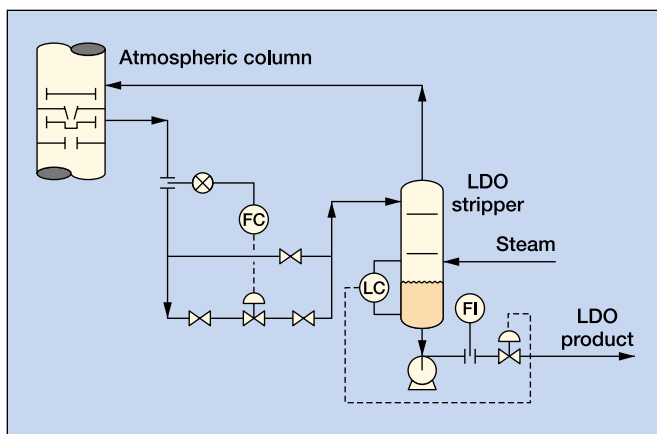


Fig. 7. LDO side-stripper draw.

Operability—normal operation and startup. Process flow scheme and equipment design affect operability. Unit operability is a measure of the unit's capability to function during startup, through normal unit disturbances, and the inevitable bounces associated with crude switches. Good unit operability comes from practical know-how of what works and what does not. Some units are difficult to startup, while others are designed with startup and operability factored into the process design.

During startup, being able to inventory the pumparound-draw trays and maintain liquid on the tray is essential to dryout (remove water) and reach stable operation. Long, drawn-out startups lead to unit upsets and equipment damage. Process and equipment designs that make startup difficult and normal operation sensitive to routine disturbances leads to equipment damage.

When the pumparounds and products are withdrawn from different trays, startup and normal operation is more difficult. During startup, the feed temperature to the column is slowly increased to remove water. The column heat input is not constant; therefore, heat removal from the pumparounds must be continuously adjusted. During normal operation, heat-balance changes associated with crude switches can effectively dry-out the product draws above the pumparound because of high heat removal. Once the internal liquid flow from the draw tray reaches zero, then the product side-stripper loses level. Thus, the stripper-bottoms pump will cavitate.

The Refpan crude-column pumparound and product draw-tray locations caused reliability problems. The following symptoms and root cause were identified:

Symptom: Loss of LDO stripper level

Root cause: Pumparound flow scheme and column heat balance.

With the diesel pumparound located between the light- and heavy-diesel products, it was possible to dryout the LDO-stripper draw tray. Varying crude slates and charge rates requires constantly changing heat removal in the diesel pumparound; otherwise, the LDO-stripper draw can dryout. Once this occurs, the LDO stripper loses level, and the stripper-bottoms pump will cavitate. The operators had to constantly

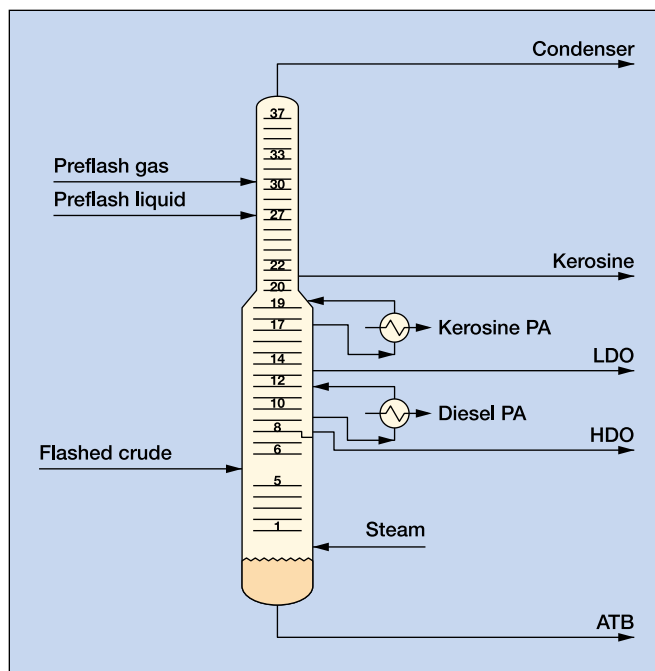


Fig. 8. Crude-column pumparound/product draws.

shift the heat balance to maintain stable operation; therefore, maximum LDO yield could never be achieved. Fig. 7 shows a previous modification to the LDO-stripper and product-draw system; a flow controller was installed to feed the stripper. This design was used to overcome the dry out problem. LDO product was drawn to storage on level control. This control system treated the symptom, but not the fundamental problem.

Crude-column fractionation. Heat balance and fractionation efficiency control the crude-column fractionation. Heat removal is controlled by the condenser and two pumparounds. The two pumparounds were designed to exchange heat against crude oil. Both location and the design of the distillation equipment determine operating flexibility and reliability. The type and design of the internals control fractionation efficiency.

Pumparound locations—column heat balance. The LDO-product end point control was poor because reflux below the LDO draw could not be maintained throughout crude switches, charge rate changes or normal unit upsets. The diesel-pumparound pump and exchanger surface area sizes were large. Diesel-pumparound heat removal reduced the reflux from the LDO-product draw tray. Reduced reflux downgraded light diesel to heavy diesel. Ultimately, the diesel pumparound was taken out of service because it reduced LDO yield. This reduced total column heat removal capacity, which limited the fired-heater duty, and lowered the light- and heavy-diesel product yields.

Root-cause analysis shows how incorrect pumparound location will result in operability problems from poor control of internal reflux. The following cause/effect relationship was occurring with this existing design:

Symptom: Poor LDO quality and yield control

Root cause: Incorrect pumparound location.



Fig. 9. Pumparound draw nozzle and piping.

Fig. 8 shows the original atmospheric-column flow scheme. The pumparounds were located between the product draws. When pumparounds are located in the middle of fractionating sections, it is usually because the designer is trying to increase the pumparound-draw temperature and provide higher exchanger LMTD values. This design can improve energy efficiency; however, it also increases the system's complexity and makes operations more difficult.

Pumparound location has significant impact on column internal liquid and vapor rates. Increasing diesel pumparound heat removal at constant heat input lowers the vapor rate leaving the pumparound section. This, in turn, reduces the internal reflux flowing from the LDO-product draw tray. Reduced reflux increases the LDO-product endpoint. When the internal reflux from the LDO-draw tray reaches zero, there will be insufficient liquid flowing to the LDO stripper to maintain stable operation.

Equipment design. Ultimately, equipment design determines how the unit operates. Computer models represent theoretical ideals; yet, they often do not reflect the actual design or performance of the equipment.

Column draw-nozzle size. Field data and observations are used to identify actual equipment performance. During the performance test, product draw rates and maintaining stable pumparound system performance were two major areas limiting this unit's performance. These problems led to this cause and effect relationship:

Symptom: Yield limitations/pump cavitation

Root cause: Column draw nozzle undersized.

Pumparound and side-stripper hydraulic limitations are relatively common problems. Measuring the pressure at either the pumparound-pump suction or the side-stripper level control valve identifies these limitations. These lines should be full of liquid. Therefore, the pressure should equal column pressure at the tray where the liquid draw is located plus the static head of liquid at the point where the pressure is measured. If the line is not full, then the pressure will be lower than expected.

Refpan's diesel pumparound had experienced chronic problems. Generally, column internal draw-tray design

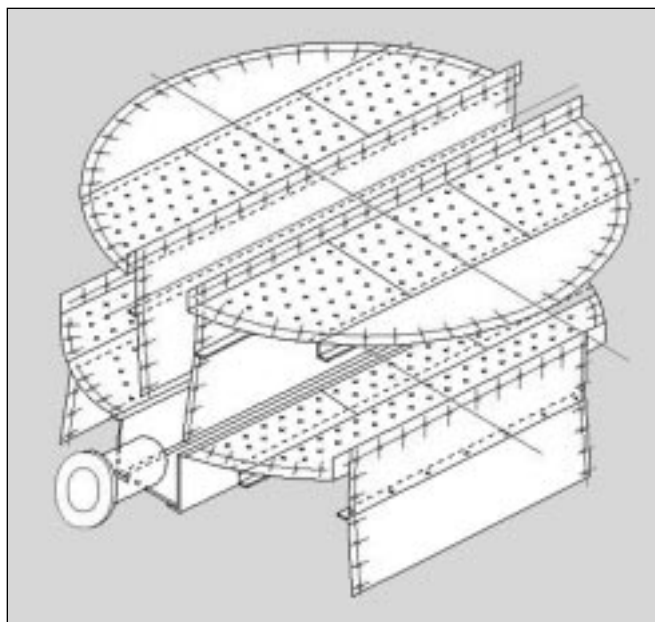


Fig. 10. Crude-column draw tray.

or small draw-off nozzle sizes cause pump NPSH problems.⁸ Pumparound or product-draw piping should not be reduced until 6–10 ft below the draw-nozzle elevation. This permits pressure buildup of static head. If the pump suction and draw nozzle are sized properly, the line will always be liquid full to the draw-off location. An undersized draw nozzle can lead to a pump NPSH problem.

Review of the system showed that the suction line to the pump had been designed improperly. The draw nozzle was a 4-in. nozzle that increased in line size to an 8-in. line (Fig. 9). Ultimately, the hydraulic limit in the system was the 4-in. line. As the operators increased the pumparound flowrate to improve heat removal, the liquid level in the draw-off piping decreased, and the available NPSH dropped below the required NPSH. Thus, the pump would cavitate.

Column operating stability was poor due to erratic heat removal. Low heat removal causes more vapor to flow up the column, which increases the condenser load and raises the overhead receiver temperature. High overhead temperature increases the gas load to the off-gas compressor. Higher compressor load increases compressor-suction pressure. Higher column operating pressure increases the atmospheric tower bottoms (ATB) yield. The high ATB product yield reduced heavy- and light-diesel yield. Pump problems are not apparent unless the pump suction is measured. Basic equipment design must be correct; otherwise significant profitability losses will result from unreliable equipment.

Column draw-tray design. The crude column draw-tray designs did affect operability. Refpan's design for the stripper-feed and pumparound-draw streams used sumps from active trays. These problems led to this cause-and-effect relationship:

Symptom: Yield limitations/pump cavitation

Root cause: Column draw-tray design.

Fig. 10 shows a typical valve tray with a sump designed to draw liquid either to a side-stripper or a

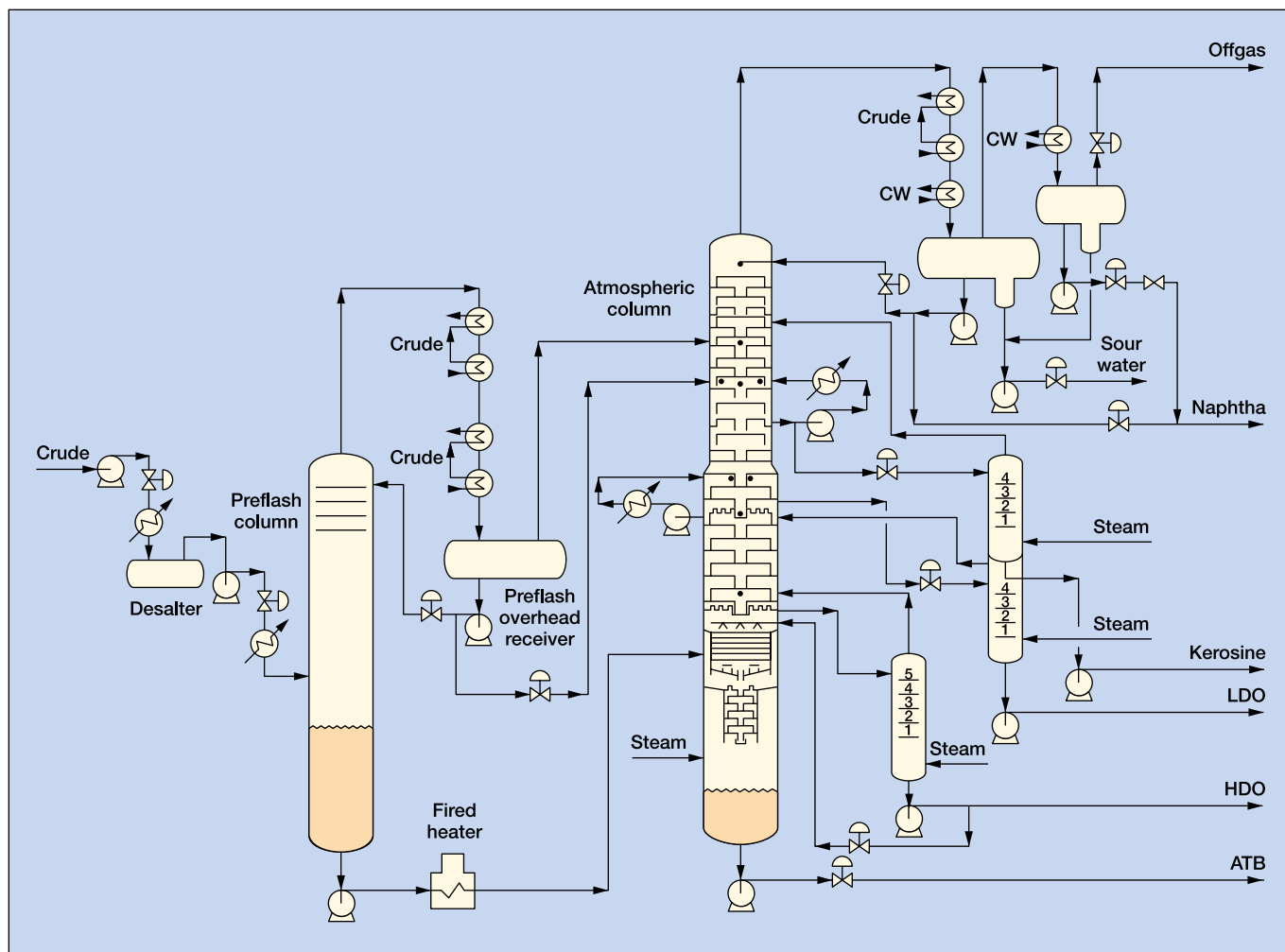


Fig. 11. Revamped crude unit simplified PFD.

pumparound pump. Withdrawing liquid from the tray sump requires that the liquid crosses the tray—feeding the sump—and flows into the downcomer. For an active tray-draw sump to work properly, the leakage rate through the tray must be less than the internal reflux rate to the tray below. Once the tray leakage rate is higher than the internal reflux rate, the external draw from the column will not be full.

Product- and pumparound-draw trays should use a seal-welded collector tray wherever possible. This ensures that liquid entering the tray can be withdrawn. All valve, sieve or bubblecap trays leak. The quantity of leakage is a function of tray design and the process-vapor rate to the tray. Trays are designed as a series of panels that fit together at a metal-to-metal seal. Vapor flow through the tray deck's sieve, valve or bubblecap holes determines the dry-tray pressure drop. The hole area and type of hole set how much leakage occurs through the trays. Understanding vapor flowrate variation through a tray deck helps identify why—under certain conditions—pump operating and reliability problems are more common. Startup conditions, pumparound location, heat balance and specific tray equipment design all affect the draw rate from the column.

Pumparound draws from active trays significantly increase the difficulty of starting up a unit. During startup, the fractionator must be purged with steam

to remove air. Part of the steam is condensed and accumulates inside the column. Circulating the pumparounds helps remove water from the exchangers, piping and column internals. Startup procedures call for pump switches to drain water from the idle pump and all low points throughout the pumparound system. Once the column is hot, any water that enters the column will vaporize violently. The resulting pressure surge can damage the column internals.

Fractionation efficiency—LDO/HDO section.

LDO-product yield and fractionation between LDO and HDO product should be maximized. Root-cause analysis shows that the existing LDO/HDO section had poor fractionating efficiency. Seven fractionating trays were getting less than one theoretical stage of efficiency. The following cause/effect relationship was occurring with the existing design:

Symptom: Poor LDO quality and yield control

Root cause: Low tray efficiency.

The LDO/HDO fractionation section experienced large changes in vapor and liquid rates from the top to bottom trays. The liquid rate decreased by 50% from the top tray to the bottom. The vapor rate also increases by 30% from the bottom tray to the top. A single-tray design used throughout the LDO/HDO section will cause low efficiency or reduced capacity in the column.

The revamped LDO/HDO section trays used two different tray designs to handle the process requirements. Often, small equipment design changes result in significant profit improvements; details are important.

Increased profitability—improved reliability.

Improving crude unit profitability with low capital-cost revamps requires modifying only the required systems and equipment.^{9–11} Revamping a unit should address the practical process considerations that determine reliability, operability and flexibility (Fig. 11). MTBF should not only be a consideration for rotating equipment, but for nonrotating equipment, as well. The unit reliability, operability, flexibility and ultimately profitability of the modifications have been proven by three years of stable operation. ■

LITERATURE CITED

- ¹ Golden, S. W., "Minimum investment revamps: process design and achieving attractive economics," 1997 NPRA Annual Meeting, March 16–18, 1997.
- ² Martin, G. R., "Heat-flux imbalances in fired heaters cause operating problems," *Hydrocarbon Processing*, May 1998, pp. 103–109.
- ³ Barletta, T., "Practical consideration for crude unit revamps," *Petroleum Technology Quarterly*, Autumn 1998, pp. 93–103.
- ⁴ Barletta, T., "Revamping crude units," *Hydrocarbon Processing*, February 1998, pp. 51–57.
- ⁵ Martin, G. R., S. W. Golden, and B. Fleming, "Distillation column inspection," Third International Conference & Exhibition on Improving Reliability in Petroleum Refineries and Chemical Plants, Houston, Texas, Nov. 15–17, 1998.
- ⁶ Golden, S. W., "Prevent preflash drum foaming," *Hydrocarbon Processing*, May 1997, pp. 141–153.
- ⁷ Strong, R., "Field history with low-salting crude unit neutralizers," 1998 NPRA Annual Meeting, March 15–17, 1998.
- ⁸ Martin, G. R., "Refinery experience provides guidelines for centrifugal pump selection," *Oil & Gas Journal*, March 11, 1996, pp. 80–86.
- ⁹ Golden, S. W., "Minimize capital investment for refinery revamps," *Hydrocarbon Processing*, January 1997, pp. 103–112.
- ¹⁰ Martin, G. R., and B. E. Cheatham, "Keeping down the cost of revamp investment," *Petroleum Technology Quarterly*, Summer 1999, pp. 99–107.
- ¹¹ Barletta, A. F., C. Macfarlane, and M. Smith, "Crude unit revamp increases diesel yield," *Petroleum Technology Quarterly*, Spring 2000, pp. 45–51.



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