Crude Unit Start-up: Consequences of High Liquid Level

Following a crude unit revamp high liquid level during start-up caused the heavy diesel product to turn black. Yet because the internals were designed for severe uplift, no damage occurred.

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National Petroleum Refiners of South Africa Ltd. (Natref) revamped their crude unit in 2002 to increase capacity. Natref revised the start-up and operating procedures to reflect the extensive flow scheme changes, which included many new pieces of equipment. Nonetheless, even after careful planning abnormal events can take place during start-up. Experienced operators often talk about high liquid level that can occur during start-up as a normal event, not an unusual occurrence. Relying on level instrumentation alone is not sufficient to avoid high level and its consequences during start-up. Pressure is a very simple, yet often overlooked measurement that operators and start-up personnel can use to help avoid high column levels and the resultant problems (Photo 1).

Start-up can be a very dangerous time. Flow rates and levels are changing rapidly. Many things are occurring all at one time. Many crude units experience internals damage during start-up. Most engineers associate start-up damage with wet steam. Pressure surges from the rapid expansion of water into superheated steam are capable of damaging internals. However, high liquid level occurs so often during start-up that it is the most common cause of internals damage. Damage occurs when high velocity steam in the bottoms or two-phase feeds from the transfer line generates sufficient forces to dislodge equipment from the stripping, flash, or wash sections.

When crude unit stripping sections are damaged during start-up, atmospheric crude and vacuum column distillate yield losses can be as high as 4% and 3% of whole crude, respectively. Furthermore, when flash zone and wash section internals do not function properly the distillate product can be contaminated with metals and carbon residue. With such large potential economic consequences, operating procedures should be reviewed for practical ways to ensure liquid level is monitored. Also, column internals directly above and below the flash zones need to be designed for higher uplift forces that inevitably result from high level or wet steam.

Case 1: Measure Level with Pressure

Liquid level generates differential pressure between any two points. Figure 1 shows the calculated (expected) and measured pressures for a vacuum crude column designed with a stripping section. In this example, a refiner was having problems maintaining low operating pressure and the heavy vacuum gas oil (HVGO) product yield was low.

Even though the vacuum column bottoms level controller showed the height of liquid at 60% of the instrument range, which would have maintained level in the boot section, the level was checked. The exact height of liquid in a column can be determined by measuring the differential pressure between elevations. Accurate vacuum column measurements require absolute pressure mercury manometers or appropriately ranged electronic gauges. In this case, two electronic absolute pressure-measuring devices were used. Before taking field measurements exact elevations were established for all pressure measuring points. Typical locations are level instruments, pressure instruments, or other taps. Pump suction


Photo 1. *Measure level with pressure*

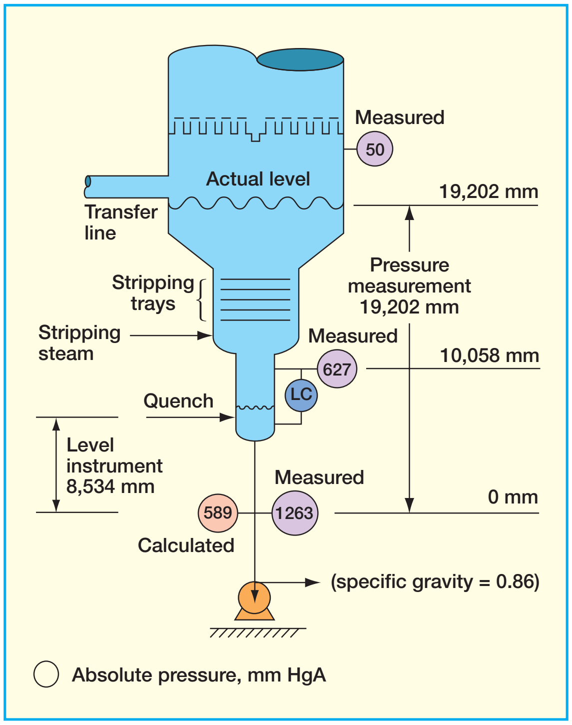

Figure 1. *Calculated (expected) and measured pressures*

Photo 2. *Damaged stripping section trays*

pressure can be used as the reference point (elevation zero) for the other elevations. Pressure difference between any points and the fluid specific gravity is all that is needed to calculate level. When a system is liquid full the pressure difference between any two points will correspond to the pressure exerted by the static head. Hence measuring three locations always provides a consistency check.

In Figure 1, if the instrument reading 60% level had been correct, the absolute pressure at the pump suction would have been approximately 589 mmHg absolute pressure. Yet, when the pump suction pressure was measured, it was 1263 mmHg. Thus, measured pressure was nearly double the level instrument indication. In this case, the liquid level was nearly as high as the bottom of the transfer line. Because vacuum column transfer line velocity is 90 m/s or higher, a very high energy wave of liquid is created in the flash zone when liquid covers the transfer line. In many columns, internals above the flash zone have been severely damaged by high level.

Over time, gas flow from the ejector hotwell had increased and liquid level was being checked because there were no apparent changes in heater operation. The vacuum heater is the source of 90% or more of the non-condensable gases in most vacuum units. Therefore, once the measured pump suction pressure reading confirmed high liquid level the true level was pulled down until the measured pump suction was approximately 589 mmHg. At this point the level instrument reading was 0% level. But, once true level reached the boot, cracked gas production decreased by almost 25%.

Cracked gas is generated by high temperature and oil residence time. If either of these two increase, then cracked gas product will increase as well. When the level instrument malfunctioned, the liquid level increased until it reached the flash zone. This significantly increased the oil residence time. This is why vacuum column boots are typically small with only 30-45 seconds of residence time. The boot temperature is often reduced by recycling cold vacuum tower bottoms (VTB) quench from the heat exchanger network to further suppress thermal cracking and gas formation. When the liquid level reached the larger diameter stripping or flash zone sections, the liquid above the quench inlet was at the same temperatures as the flash zone. Flash zone temperatures on deep-cut units can be as high as 410°C, thus severe thermal cracking results if there is high level.

Because high column operating pressure alone could not explain the low HVGO product yield, the stripping section tray pressure drop was checked. Thus, a consequence of high level was probable stripping tray damage. Once level was reduced, measured pressure drop across the stripping section was nearly zero. A well-designed tray in this service will generate between 3.5-4.5 mmHg pressure drop. All the stripping section trays had been dislodged by high liquid level.

Avoiding Wet Stripping Steam

Wet steam can also cause column internals damage (Photo 2). When the column operating temperature is high, stripping steam needs to be dry before it is put in service because water will rapidly vaporize creating a pressure surge. The stripping steam system needs to be designed with the provisions to blow the line to atmosphere to ensure no significant amounts of water enter the column. In vacuum service, the isolation block valve is normally installed just downstream of the stripping steam control valve because the steam line size increases dramatically after the control valve and most refiners do not install an isolation valve at the column. If water accumulates in this line it should not be a concern because water boils at very low temperature under vacuum. Water will vaporize at very low temperature when the ejectors are put in service. However, for atmospheric crude columns an additional isolation valve should be at the column and the start-up vent located as close as possible to the check valve that typically is located next to the column. For atmospheric service the isolation valve downstream of the stripping steam control should not be blocked in during start-up. The isolation valve at the atmospheric column should be closed and the vent used to dry the system including steam through the control station.

Figure 2 shows the start-up vent for vacuum and atmospheric services. By venting the steam line to atmosphere, water that has accumulated in any of the steam system low points is purged. The start-up vent line size needs to be large enough so that line velocity during venting is high enough to sweep the water from the line. If the vent line is too small the steam velocity during venting will be too low, thus when stripping steam is put in service and the rate increases, water in the low points will be swept into the column. Another precaution is to design the stripping steam distribution pipe with extra heavy wall pipe, sonic

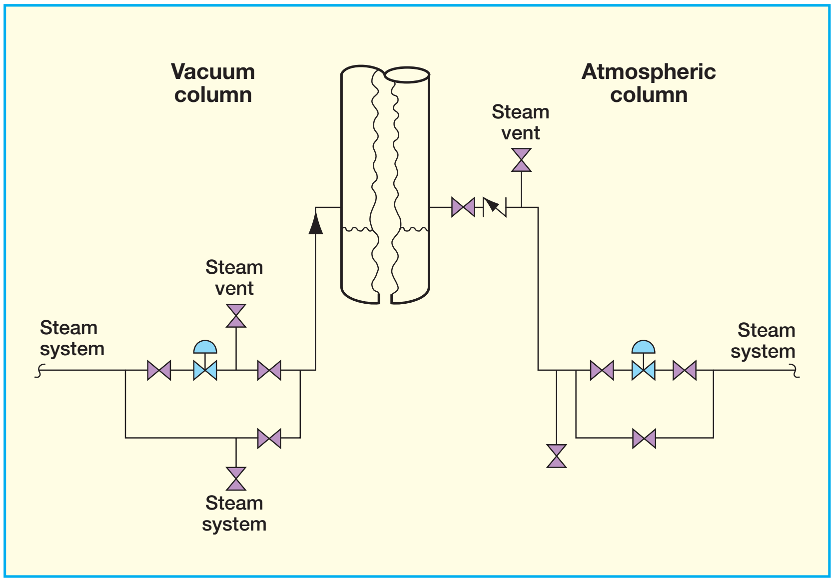

Figure 2. *Start-up vent for vacuum and atmospheric services*

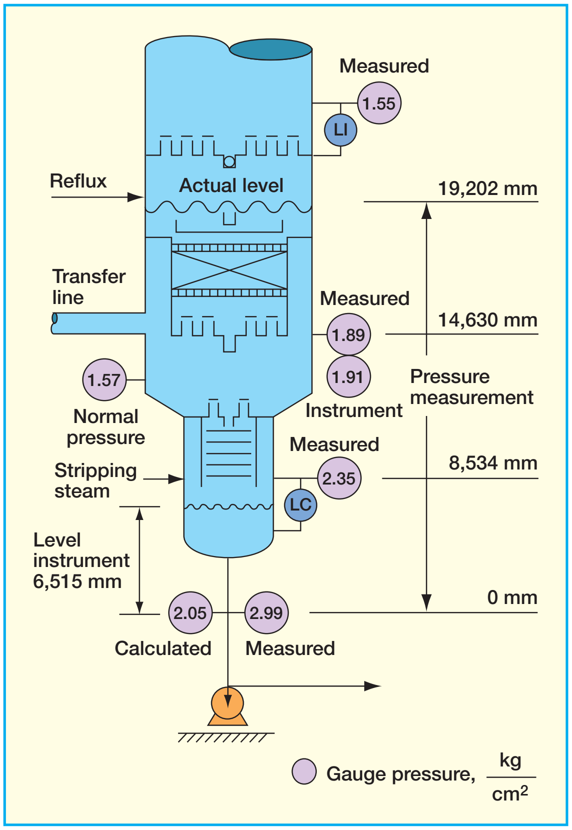

Figure 3. *Atmospheric column measured pressure*

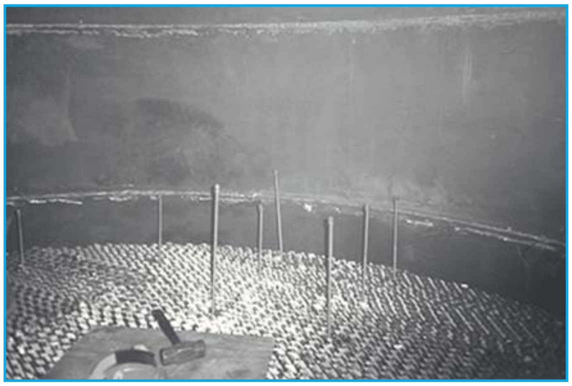

Photo 3. *Thru-rodded packed beds*

velocity through the distribution holes, and distribution holes above the centerline to trap water. This design has minimized pressure surges from slugs of water that have entered columns in spite of good start-up procedures.

Case 2: Maintaining Distillate Yield

Much of Natref's atmospheric crude column internals had to be revamped to process higher crude throughput. Even with the higher capacity internals, the crude and vacuum columns were at shell limits. Therefore, new atmospheric and vacuum preflash columns were added to unload crude and vacuum columns, respectively. Post-revamp, each preflash column would need to meet its distillate yield; otherwise, downstream columns would flood. Because the column internals performance was such a critical part of meeting processing objectives, small incremental investment was used to ensure they would not be easily damaged. Consequently, the internals mechanical design features in the lower part of the column were based on abnormal events not day-to-day operation. Prudent revamp designs will assess the likelihood of abnormal events occurring, such as high liquid level and wet steam, and make adjustments in the design. Properly sized atmospheric vents were provided to dry-out the steam system and start-up procedures addressed the need to monitor liquid level with pump suction pressure. Yet, in spite of training and planning, high liquid level occurred. Because Natref recognized the importance of keeping the trays intact, the more robust mechanical design ensured the internals were not damaged by high level excursions.

When revamping crude units, atmospheric column internals generally need to have higher capacity for higher distillate product yields so that overall capital investment is minimized. Replacing columns should be avoided unless absolutely necessary. Thus, stripping section performance is essential to meeting distillate product yield. Well-designed stripping sections will vaporize 5-8% of the flash zone liquid, while the wash section should produce atmospheric gas oil (AGO) product with a yellow/orange color even while operating at less than 0.5 volume % overflash. Other essential design considerations include high mechanical uplift and good fouling resistant features that ensure the equipment functions throughout the run. Because high liquid level is likely during start-up and the forces created below the stripping section and in the flash zone can easily damage standard mechanical design column internals, a robust mechanical design is a must.

Interpreting Pressure Readings

Atmospheric tower bottoms (ATB) pump suction pressures should be routinely monitored during start-up. Pressure readings should be taken periodically as a check of liquid level. Figure 3 shows the lower portion of an atmospheric column and some of the pressure measurements to illustrate how it can be used to calculate level. The left side of Figure 3 shows normal flash zone operating pressure of 1.57 kg/cm^2 and the calculated ATB pump suction pressure assuming typical stripping section pressure drop of 0.04 kg/cm^2. The right side of Figure 3 shows some pressure measurements that can occur during start-up. Because most atmospheric crude columns have an instrument to measure

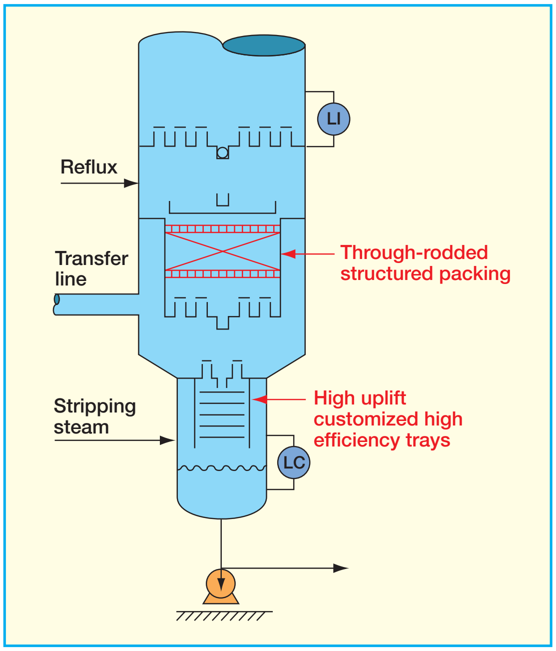

Figure 4. *High uplift design*

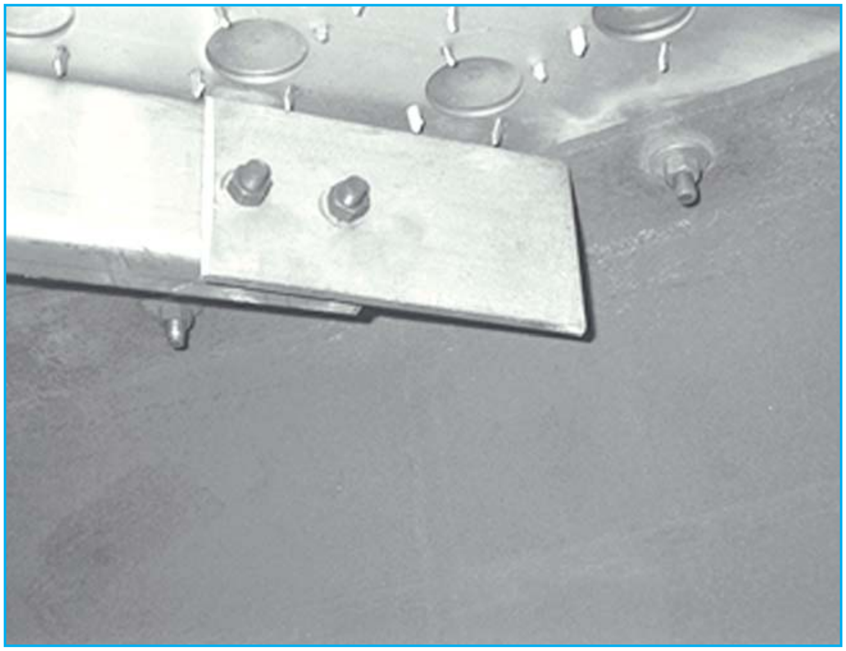

Photo 4. *Tray shear clip below tray ring*

pressure on the top head of the column and the flash zone, these instruments can also be used to determine when the column is filling with liquid above the flash zone.

In this example, the top head pressure was 1.2 kg/cm^2 and the flash zone instrument measured 1.91 kg/cm^2. What does this mean? First, column differential pressure is caused by column internals pressure drop or liquid level. Trays generate approximately 0.01 kg/cm^2 pressure drop per tray when operating at maximum vapor/liquid loadings. Higher measured pressure drop means liquid is beginning to accumulate and fully developed hydraulic flood is beginning. Thus, 10 trays on 610 mmHg spacing will generate approximately 0.1 kg/cm^2 pressure drop, while the same space filled with 0.75 specific gravity hydrocarbon will produce 0.41 kg/cm^2 pressure drop. Each meter of hydrocarbon in the bottom of most atmospheric columns generates 0.07 kg/cm^2 pressure drop. These general rules can be used to determine liquid level in an atmospheric column. In this example, the measured pressure is higher than the calculated pressure, therefore, the bottoms level is 4.57 m above the flash zone.

Robust Equipment Design

Since high liquid level is common, column internals need to be designed to withstand the forces created during high level (Figure 4). Wash zone internals directly above the flash zone should be designed to withstand severe uplift forces (Photo 3). Tray designs should use heavy-duty construction with through bolting of adjacent panels, integral truss shear clips under the tray ring (Photo 4) and to the downcomer panels, 10 millimeter thick downcomer panels, and 3 millimeter thick tray panels should be used. Thicker tray panels alone provide very little additional mechanical strength because the uplift forces will either pull the adjacent panels apart or lift the panels off the tray ring. Packed column internals, including structured packing, can be designed for improved mechanical strength by unitizing the packing hold-down and supports by driving rods through the packing and attaching them securely to the top hold-down and bottom supports.

Stripping section trays are subject to downward forces from the flash zone and uplift forces initiated from the wet stripping steam. Adding truss lugs to avoid damage from downward forces is also needed. Stripping sections should use customized rectangular tray designs with fouling resistant features such as high weir loading, increased downcomer clearance, short weirs, and minimum cross-sectional area downcomers. Thus stagnant zones are eliminated and solids accumulation is absolutely minimized. Furthermore, in those instances where wet steam cannot be avoided, specialty design steam distributor to mitigate pressure surges should be used. If flash, wash, and stripping section internals are designed properly they will withstand abnormal forces associated with high level and wet steam.

THE AUTHORS

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