

Foam control in crude units

Installation of vortex tube clusters in crude unit preflash drums has eliminated foam carry-over, increasing diesel and atmospheric gasoil product yields. By avoiding preflash drum replacement, these retrofits have cut revamp investment

Tony Barletta and Edward Hartman *Process Consulting Services Inc*
David J Leake *EGS Systems Inc*

When revamping the crude unit to increase feed rate, improve distillate yield or quality, the preflash drum must be checked to ensure that foam will be contained inside the drum. Preflash drums are notorious foaming systems. When foam is entrained into the atmospheric column with the preflash vapour, many unforeseen consequences have occurred. Some of these unforeseen consequences include low distillate yield, poor kerosene and diesel product quality, and high carbon residue and metals in atmospheric gasoil (AGO). Total diesel and AGO product yield losses as high as 5 vol% on crude have been measured following revamps (Figure 1).

By retrofitting preflash drums with vortex tube clusters, incoming foam has been destroyed even at higher charge

rates. In many instances these devices can eliminate the high cost of preflash drum replacement.

Preflash drums are used in crude units to “flash off” light boiling range hydrocarbons from the crude oil so that vaporisation is minimised or eliminated in the hot end of the exchanger train. In the back end of the hot exchanger train the temperature is high and pressure is reduced. The combination of high temperature and low pressure can cause the crude/water mixture to partially vaporise.

Vaporisation in the preheat train exchangers can cause very high pressure drop. For many crude units, crude hydraulics is one of the most costly revamp constraints that must be overcome. Therefore, preflash drums can be an effective debottlenecking tool if they are sized adequately to contain the foam.

However, many existing preflash drums are undersized and care needs to be taken to ensure that the foam is contained inside the drum (Figure 2) by making the drum larger. Otherwise, separating devices specifically designed for foam prevention should be installed when a revamp is being contemplated. Without these separating devices the preflash drum becomes very large.

Foam is created in the preflash drum when pressure is reduced across the upstream control valve. As long as the foam is contained inside the drum, it typically causes few problems other than difficulty with level measurements and occasional flashed-crude pump cavitation. However, when the drum is too small, foam is entrained with the preflash drum vapour and carried into the atmospheric crude column. Even small

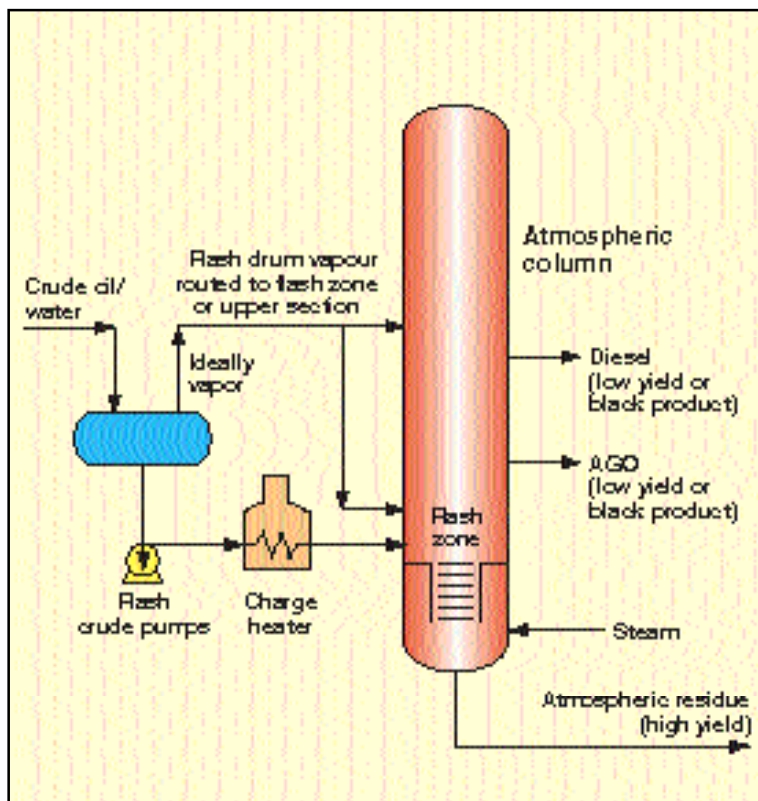


Figure 1 Typical preflash drum/charge heater/atmospheric column system configuration

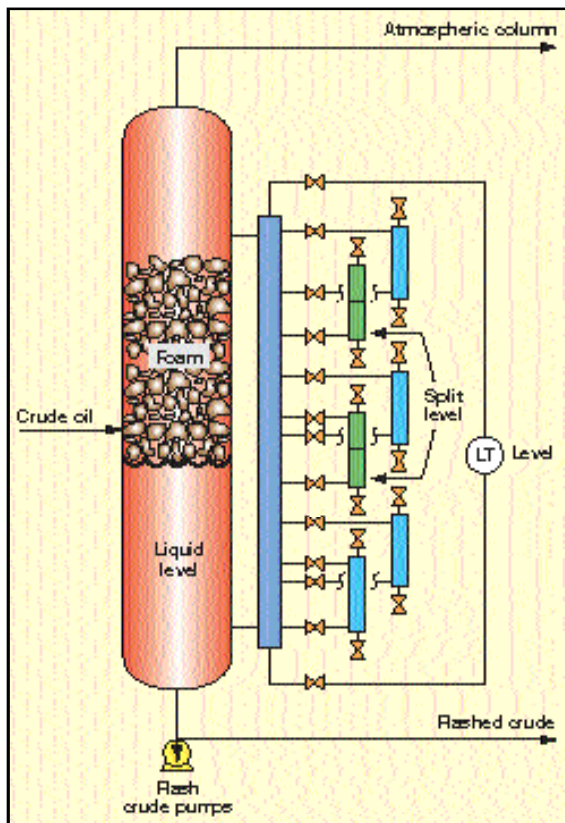


Figure 2 Foaming inside preflash drum

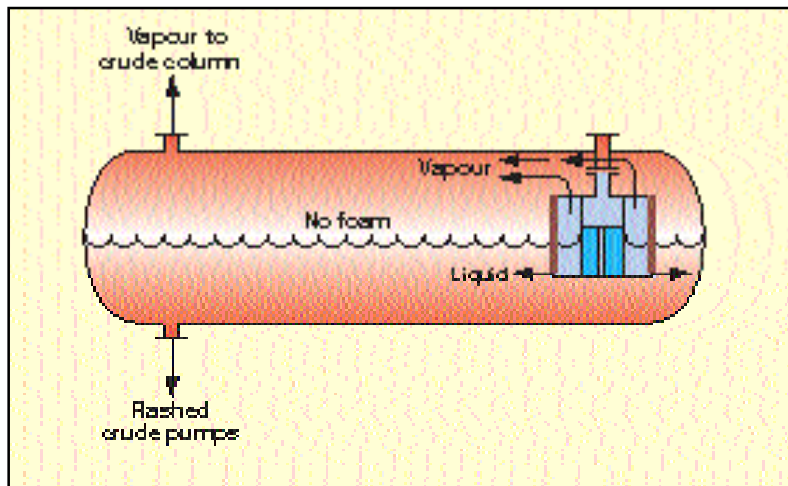


Figure 3 Preflash drum with vortex tube cluster (VTC) system connected to drum's inlet nozzle

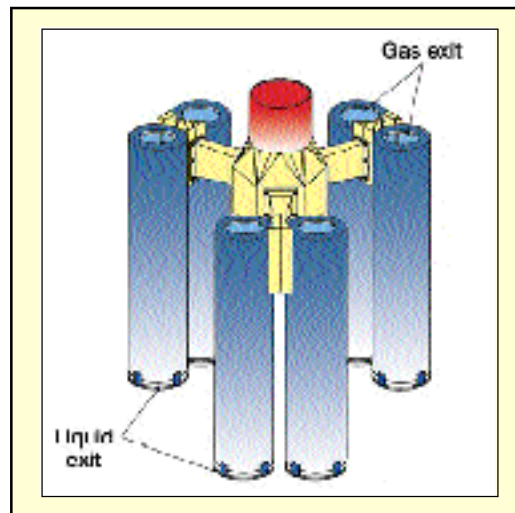


Figure 4 Detailed image of VTC system

quantities of foam can cause off-specification distillate. Large quantities of foam carryover can significantly reduce diesel and AGO product yields. In some cases foam carryover will significantly increase vacuum unit feed rate and overload the vacuum jets.

VTC system

As indicated in the previous section, foaming not contained within the preflash drum causes distillate yield loss in the crude unit. In fact, foaming in any separator, be it in upstream or downstream applications has been the cause of operational problems for many years, whether as foam exiting with the gas stream and/or with the liquid stream as gas carry-under.

The vortex tube cluster (VTC) system was developed for use in the upstream industry almost 20 years ago specifically to combat foaming in production separators. Following its success there, it has been applied in refinery applications including hydrotreater hot high-pressure separator and more recently in preflash drums and columns.

The VTC is connected to the drum's inlet nozzle, as shown in Figure 3. The two-phase flow is fed to the vortex tubes by a central duct or manifold that is designed to distribute the flow equally to each tube. A side opening, at the top of each tube, admits the stream tangentially. The phases are separated from each other by the enhanced gravitational effect generated. The gas migrates to the centre and exits through the holes at the vortex tube tops. The liquid exits via the peripheral openings at the bottom of the vortex tube (Figure 4).

In actual operation, the tubes are partially immersed in the liquid, which provides an effective seal, preventing gas from blowing out of the vortex tube bottom openings. Adequate immersion is required to overcome the pressure differ-

ence generated over the vortex tubes. The liquid level is controlled in the same manner as with any conventional drum. Since there is no splashing or bubbling in the vessel, and any incoming foam is destroyed in the vortex tubes, the separator operates free of foam.

The VTC system can be designed to suit almost any vessel configuration and application.

Design of the optimum VTC for a particular application is done with software developed in tandem with the cluster and continually updated to reflect knowledge gained from those VTC systems in operation.

Foaming

Foam is carried out with the overhead vapour stream when the preflash drum is undersized. Foam is a mixture of gas bubbles and liquid. Because foam contains flashed crude that is low temperature, black in colour and has a large amount of 600°F minus boiling range material that vaporises at flash zone conditions, the entrained foam causes problems when it enters the atmospheric crude column. When the preflash drum vapour stream enters the atmospheric column above the flash zone, all product streams below the entry nozzle will contain flashed crude if foam is contained in the vapour stream.

Flashed crude is black and has an endpoint greater than 1500°F. Even small amounts of foam carryover will cause colour and endpoint problems with kerosene and diesel product quality. When the preflash drum vapour stream containing foam enters the atmospheric column in the flash zone, distillate and AGO yields are reduced because the low temperature liquid quenches the flash zone.

Preflash drum feed location into the atmospheric column depends on the stream endpoint. Theoretically, it

should be fed into the column at the tray location where preflash vapour and column internal liquid streams endpoints are equal. Thus, if the preflash drum vapour endpoint is 530°F, then the correct location would be at or somewhere below the kerosene product draw. In practice, because the preflash drum operating temperature and pressure vary, and crude blends change, the feed location needs to be low enough to avoid atmospheric distillate product quality problems. For example, if preflash vapour has an endpoint of 600°F while entering above the kerosene product draw, kerosene will not meet specification.

Many preflash drums installed in crude units are undersized. Therefore, many of these drums entrain foam with the vapour. Consequently, many preflash drum overhead stream feed locations have been relocated to the flash zone or the transfer line because there is no other place to put the black oil. Occasionally, when asphalt is produced from the bottom of the atmospheric column, preflash drum overhead vapour is routed below the bottom stripping tray in lieu of stripping steam.

This only works because these units have no desalter, and the preflash vapour is mainly water. However, when foam is entrained the asphalt becomes contaminated with flashed crude. This increases the asphalt loss-on-heat. Thus, the flash zone is the only place to route this stream when foam is entrained.

Rerouting preflash vapour containing foam to the flash zone eliminates off-specification distillate, but this reduces distillate yield and raises feed rate to the vacuum unit. Distillate yield loss is a function of the amount of entrained foam. Even when the stream is all vapour it still causes yield loss because it must still be heated to flash zone temperature by condensing a portion of the flash zone vapour. When foam is present,

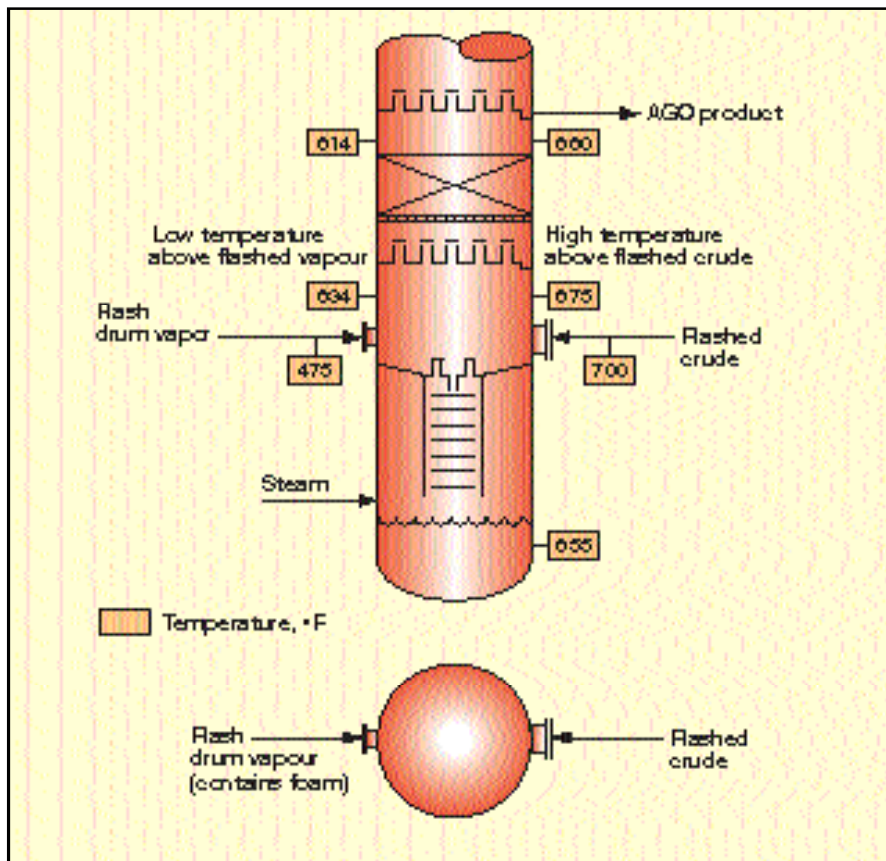


Figure 5 Revamped 100 000bpd atmospheric column experiencing foam entrainment

distillate yield losses are much higher. Entrained foam must be heated from preflash to flash zone temperature. In the heating process, condensing some of the flash zone vapour vaporises the light portion of the entrained liquid. In one case, an 80 000bpd crude unit had 5000bpd of flashed crude entrained with the preflash vapour, reducing total distillate yields by more than 4% on whole crude and diesel yields by more than 2%. Furthermore, vacuum unit feed rate increased, vacuum column vapour load was higher and total vacuum unit pumparound heat removal also increased.

Preflash drum myths

Preflash drums are used to debottleneck crude hydraulics and prevent vaporisation at the crude heater pass control valves. Metering and flow control is essential to ensure heater pass balancing. Otherwise, incorrect flow measurements and poor flow control can lead to rapid furnace tube coking and tube failure. Additionally, vaporisation in the crude preheat exchangers increases pressure drop. When crude hydraulics limits charge rate, vaporisation increases pressure drop; thus forcing crude rate to be reduced. It is a myth that preflash drums materially improve energy efficiency.

Preflash drum operating conditions vary depending on location in the preheat train and whether the drum pres-

sure “floats” on the atmospheric column pressure or is controlled with a valve in the overhead line. The drum can be located anywhere in the exchanger train. Thus, temperatures vary from 275°F to as high as 550°F. But as operating temperature increases, the amount of vapour generated increases; thereby making the crude heater feed heavier and bypassing more flow around the heater.

Heavier feed is more difficult to vaporise. Therefore, atmospheric column residue flow rate is higher to the vacuum unit. Conversely, crude heater temperature can be raised or stripping section performance improved to maintain atmospheric distillate yield when preflash temperature increases. When designing a new unit, the preflash drum temperature should be the minimum required to prevent exchanger train vaporisation. During a revamp, it is sometimes necessary to increase preflash drum temperature to reduce crude heater pressure drop. Thus, atmospheric crude heater temperature must be raised or stripping section performance improved to offset the heavier feed.

Preflash drum sizing

Drum sizing depends on many crude-dependent variables, some are well understood like oil viscosity, surface tension and density. Others, such as type and quantity of surfactants are not.

Only in theory can these drums be sized precisely. In practice, surfactants concentrate on the surface of the gas bubble. The surfactants change the geometry of the gas bubble and affect the particle dynamics. Hence the vessel needs to be sized conservatively to account for the unknowns in the system. When the drum is sized properly, foam will be contained inside the flash drum as previously shown in Figure 3. However, when the vessel cross-sectional area is too small, drum vapour will entrain foam. When the vapour contains foam (flashed crude liquid), distillate yield will be reduced or off-specifications distillate is produced.

Case study: foaming

A crude unit processing 100 000bpd of a 25°API crude oil had low atmospheric distillate product yields following a revamp. Because the preflash drum and crude charge heater streams were routed to the flash zone on opposite sides of the column, and the column was properly instrumented, it was obvious foam was being entrained (Figure 5). Crude heater outlet and preflash drum feed stream temperatures were 700°F and 475°F, respectively. Thermocouples located directly above each feed stream showed temperatures of 675°F and 634°F. The 634°F temperature above the preflash drum feed was 51°F lower than the 675°F temperature above the crude heater outlet (flashed crude).

Interestingly, when processing lighter crudes the difference was only 35°F even though the amount of preflash drum vapour was higher on the lighter crudes. Clearly, lighter crudes entrained less foam than heavier crude oils.

Adding a preflash drum or increasing the preflash temperature raises atmospheric resid (AR) production at constant crude heater outlet temperature. Because preflash vapour bypasses the heater, it is colder than the heater outlet. Hence, total heat added to the crude oil is less. Installing a preflash drum or increasing temperature requires higher crude heater outlet temperature to maintain AR yield. This is normally accounted for in the revamp calculations and the heat and material balance. However, when preflash vapour contains entrained liquid, this material is not normally accounted for in the heat and material balance.

Often, the crude heater will not have enough capacity to compensate for the incremental cooler material carried into the flash zone, therefore the flash zone is quenched and distillate yields are lowered.

When the preflash drum stream feeds the flash zone, it mixes with the crude heater outlet stream. Even when there is

no foam, drum vapour condenses some of the heater outlet stream. The amount of condensation determines the distillate yield loss. In this case, the preflash drum was foaming before the revamp but went unnoticed. The simplest way to check would have been to sample the stream in a pressurised container, let it cool, vent the gas from the container under the laboratory hood and drain the condensed liquid into a beaker.

If the sample was black, then the stream contained foam from the preflash drum. Yet, this simple test was not performed because the designer worked from the office. To quote Norm Lieberman [*Troubleshooting process operations*, Penwell, 1981]: "one simple measurement is worth 1000 expert opinions." Following the revamp, the sampled stream was black.

Once foaming was identified, determining the amount of foam required some process modelling and material balancing using the plant flow-meters. The flashed vapour rate was calculated from the crude rate, crude oil composition and preflash drum temperature and pressure. Because crude charge rate and flashed crude streams were metered, when the meters were corrected for flowing conditions, the calculated difference was total preflash drum vapour plus entrained flashed crude flow rate. Furthermore, because the atmospheric column flash zone was properly instrumented (Figure 5), temperatures above the crude heater and preflash inlets showed very large temperature differences, indicating that foam was quenching the flash zone temperature.

Distillate yield loss

Diesel and AGO product yields were reduced by entrained foam because less total heat was added to the crude oil. Heat is required to vaporise crude oil. When two streams feeding the flash zone mixed, heat was transferred from heater outlet stream to the preflash drum stream condensing some of the flash zone vapour. This raised AR production, which ultimately increased load on the vacuum column. Moreover, because liquid entering the top stripping tray was subcooled, the stripping section vaporisation decreased.

Figure 6 depicts mixing that occurs in the flash zone. Preflash vapour and entrained foam enter the flash zone at 475°F, the same operating temperature as the preflash drum. Because this stream is much colder and contained entrained foam (part flashed crude), a portion of the 600°F stream vaporised. In this instance, the preflash overhead stream contained 5500bpd of flashed crude oil (entrained liquid in foam), in addition to the equivalent of 12000bpd of oil that vaporised in the preflash drum. Both the vapour and entrained flashed crude had to be heated from 475°F to an average flash zone temperature of approximately 660°F.

Entrainment lowered the average flash zone temperature because it condensed a portion of the flash zone vapour stream. In this case, assuming there was no entrained flash crude, the flash zone temperature would have been approximately 30°F lower than the

furnace outlet temperature. But the observed temperature difference was approximately 51°F.

Entrainment quenched the flash zone, reduced distillate yield and increased AR production. Temperature was the simplest plant measurement to identify entrainment. Since these temperature measurements were located directly above each feed stream, the temperature differences were apparent.

Stripping section performance was reduced because the liquid temperature entering the top stripping tray was colder and it contained more naphtha, kerosene and diesel boiling range material caused by condensation. Hence, the AR rate was even higher and the amount of light ends entering the vacuum unit increases condensable load on the ejector. This increases vacuum column operating pressure; thereby reducing HVGO product yield.

Crude unit revamps and foam

When revamping to increase charge rate or "heavy-up" the crude blend, the preflash drum must be thoroughly evaluated. In many instances foam is entrained prior to the revamp. Yet it goes unnoticed because yield loss may be small as a percentage of whole crude. But when the unit is revamped and preflash drum viscosity or feed rate increases; the amount of entrained foam can increase dramatically. In this example diesel and

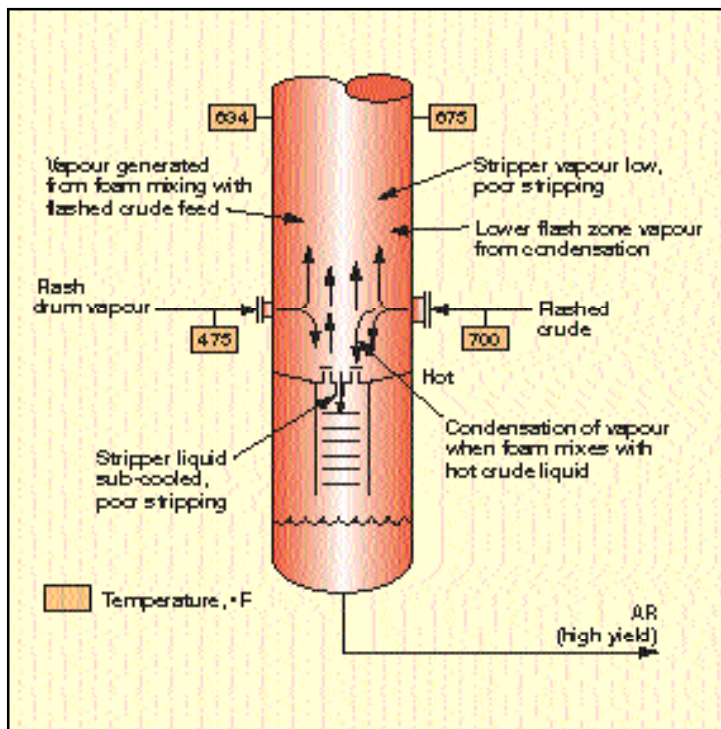


Figure 6 Flash zone performance with foam

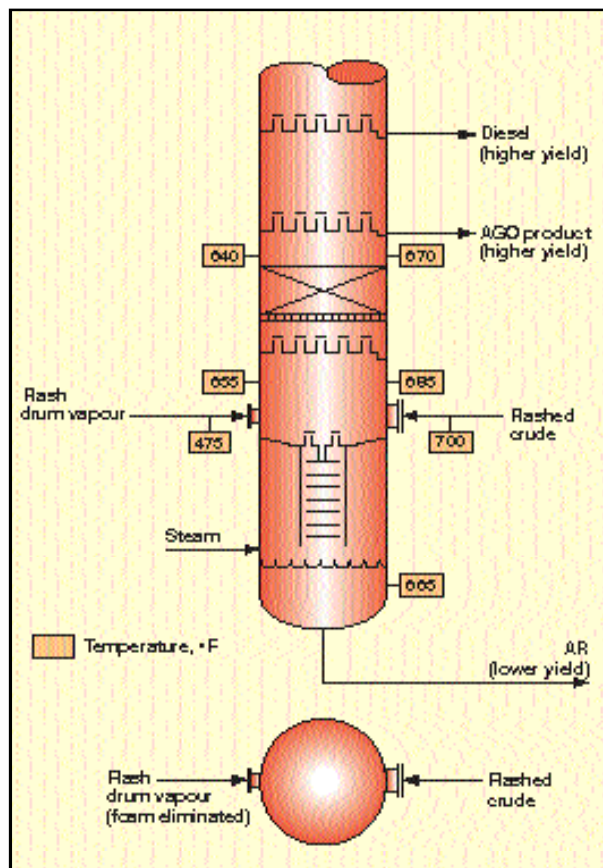


Figure 7 Crude unit revamp: improved yield by destroying foam

AGO product yield dropped by 5% following the revamp.

Because the refiner had increased crude rate, foaming dramatically increased. As part of the revamp, some trays in the atmospheric column were replaced with packing. Hence, the yield losses were blamed on the packing because no one suspected that foaming was the real problem. Total distillate yield was lower than predicted by almost 5%.

Low distillate yields

Prior to the revamp the preflash drum nozzle was located at the same elevation as the AGO product draw. Entrained foam resulted in black AGO product, yet the yield of AR was not affected. At times the AGO product contained as much as 30ppmw nickel, vanadium and high carbon residue. During the revamp, the flash drum vapour line nozzle was relocated to the flash zone. Since the consequences of foam entrainment were not understood, diesel and AGO product yield decreased unexpectedly.

Entrained foam also reduced fractionation between diesel and AGO products because it initiated composition gradients across the column cross-sectional area. Trays in the wash zone, diesel/AGO fractionation and diesel pumparound sections were replaced with packing to increase vapour-handling capacity. Furthermore, the wash zone was packed to reduce the overflash from 3 vol% to less than 0.5 vol%. Following the revamp, the unit capacity and AGO product quality targets were achieved. However, ATB yield was 5% higher than expected and the amount of 650°F minus material in the AGO product increased.

When revamp performance does not meet expectations, the problem needs to be diagnosed in the field and not the office. During the revamp, several new thermowells were installed in the column 180° apart located directly above the crude heater and preflash drum feed nozzles. The relative elevation and orientation of the thermowells are shown in Figure 5. In large-diameter columns, packing will not correct poor initial vapour distribution or composition gradients.

Once composition gradients are created in the flash zone, the packing did not correct it. Hence, fractionation in the packed beds directly above deteriorated.

The refiner attempted to offset the preflash drum entrainment by increasing the furnace outlet temperature. With 5000bpd of foam entrained into the flash zone, furnace outlet temperature had to be increased from 700°F to

735°F to meet the design distillate and AR production. While this increased yield, it also caused coking in the heater and fouling in the stripping section.

The crude unit was designed for two different crude oils – a heavy and light crude oil. Heavy crude had higher viscosity, while the light crude produced more preflash drum vapour. Because viscosity has a major influence on preflash drum foaming, when light crude was processed, distillate yield losses were lower than with the heavy crude. Furthermore, lighter crudes generated more vapour in the preflash drum, reducing the liquid flow rate through the drum cross-sectional area. Liquid superficial velocity also affects the height of foam generated, consequently lighter crude had less entrained foam and lower distillate yields losses.

Destroying foam

Before a crude unit is revamped, it must be determined whether the preflash drum will contain the foam or if it will be entrained to the atmospheric column. Preflash drums always foam, the concern is the height of foam. If the foam is contained, level measurement may be difficult but there will be no yield losses. However, if the drum is not adequately sized for revamp conditions, then it must be either replaced with a larger drum or fitted with vortex tube clusters.

Because new preflash drums are high capital-cost items and require plot space that is sometimes not available, this should be considered only as a last resort. Installing vortex tube clusters have proven to be a cost effective alternative to preflash drum replacement. When entrained foam is eliminated, heat input to crude oil is higher and flash zone temperature increases. In this example, Figure 7 shows the flash zone temperature changes when foam is eliminated, raising distillate yield by 3.5% on whole crude oil.

Tony Barletta is a chemical engineer with Process Consulting Services Inc, Houston, Texas, USA. His primary responsibilities are conceptual process design and process design packages for large capital revamps. E-mail: tbarletta@revamps.com

Edward Hartman is a process engineer with Process Consulting Services and specialises in revamp, process design and refinery processes. E-mail: ehartman@revamps.com

David J Leake is senior engineer at EGS Systems Inc, Houston, Texas. He has over 30 years experience working for separation design companies in the USA and the UK. He was involved with starting the company in 1998.