Mitigating fouling in crude distillation columns

Case study on increasing crude column throughput by using fouling-resistant trays in the kerosene section

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This case study delves into the troubleshooting and resolution of fouling issues in the crude distillation column of a petroleum refinery. The column, equipped with distillation trays, experienced fouling concerns in the light and heavy kerosene sections, accompanied by a significant pressure drop limiting crude throughput. The fouling, attributed to phosphorus deposits from chemicals used to process high total acid number (TAN) crudes, was confirmed in a detailed study. Subsequent intervention involved the implementation of special fouling-resistant trays, leading to improved reliability and column performance.

The Nayara Energy Ltd. (NEL) Vadinar refinery atmospheric (crude) distillation column (CDU) is equipped with trays in the fractionation, pumparound, and steam stripping sections and a packed gasoil wash section above the flash zone. Overhead light naphtha is routed to the saturated gas unit, and reduced crude oil (RCO) bottoms are routed to the vacuum tower as a feed. Five side draw products – heavy naphtha (HN), light kerosene (LK), heavy kerosene (HK), light gasoil (LGO), and heavy gasoil (HGO) from the crude tower – are further processed in secondary units of the refinery. The tower has four pumparounds (PAs): light kerosene, heavy kerosene, light gasoil, and heavy gasoil. **Figure 1** illustrates the overall crude column arrangement.

After about 1.5 years of operation, the crude distillation column started experiencing a higher pressure drop across the upper section. The pressure drop increased by 40-60%, with fluctuations during a month of operation. In the upper part of the column, section-wise pressure drops were monitored to understand the pressure drop across individual sections. **Table 1** indicates the average pressure drop across individual sections during normal operation and after one month of

Average pressure drop across individual sections

Section	Pressure drop at normal column operation, kg/cm²	Pressure drop after 1 month column operation, kg/cm²
HN draw to LKPA return	0.07	0.14
LKPA return to LK draw	0.04	0.13
LK draw to HKPA return	0.05	0.08
Column top to flash zone	0.48	0.70

Table 1

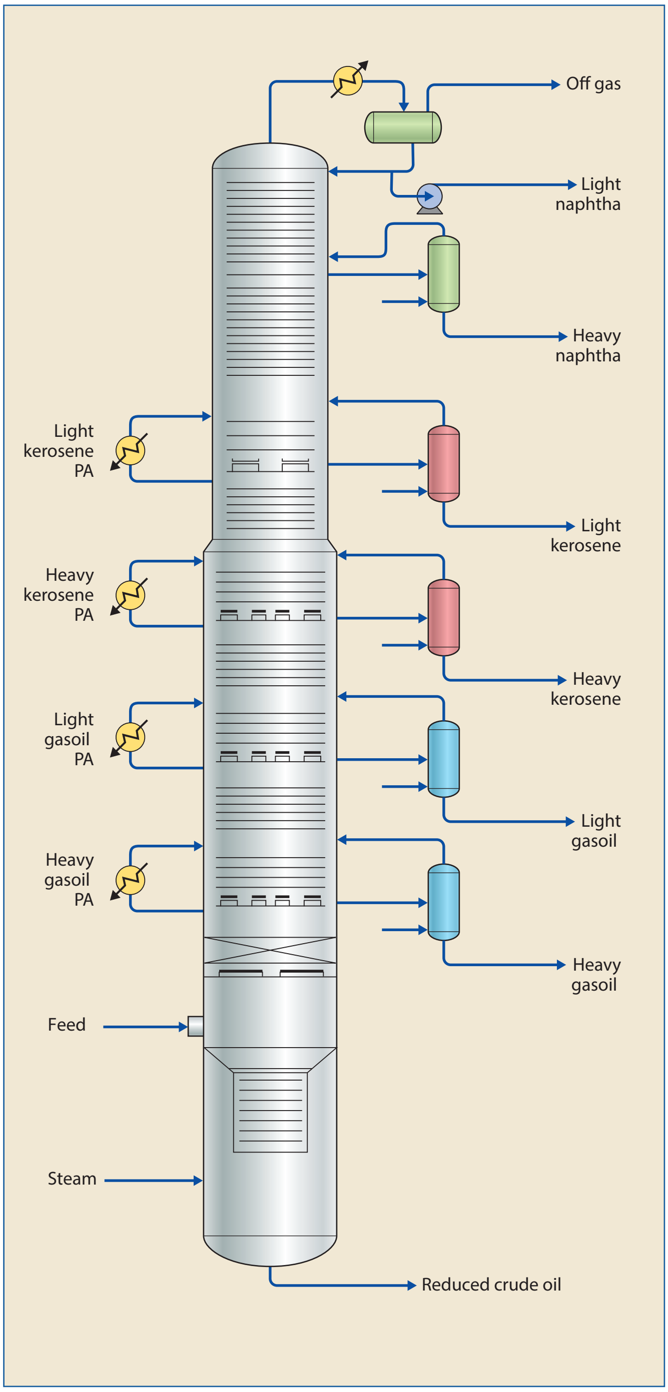

Figure 1 Arrangement of crude distillation column

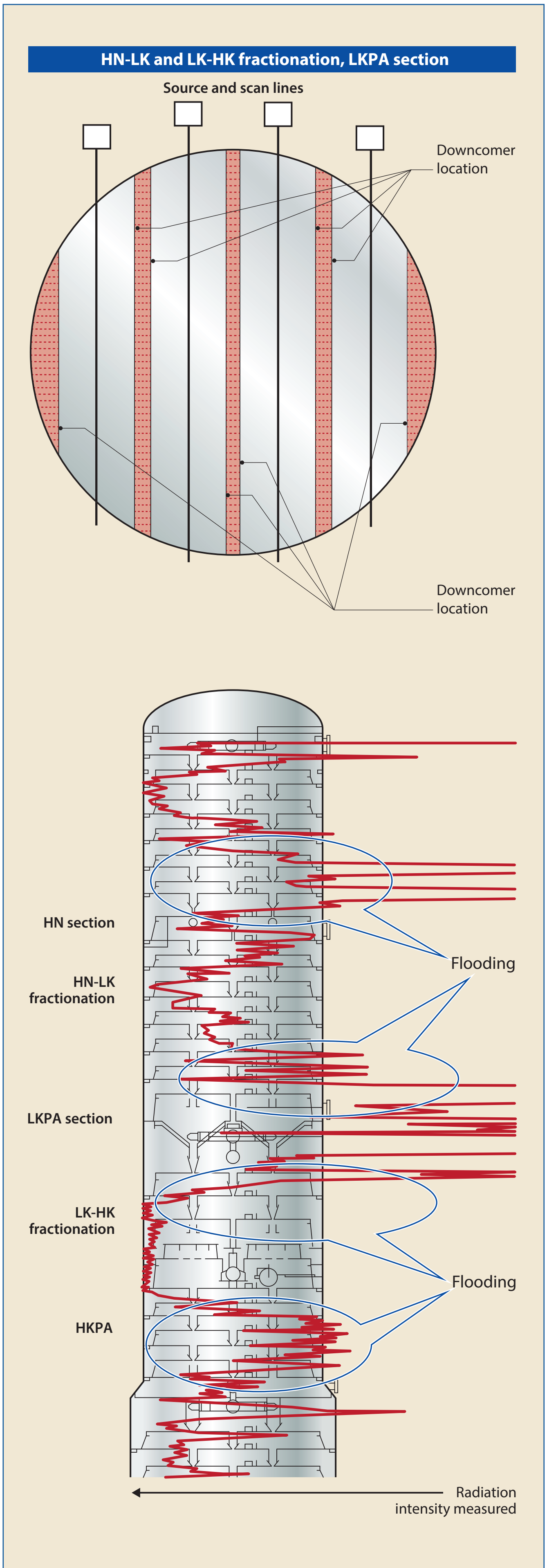

Figure 2 Column gamma scan

operation. The pressure drop across individual sections and the entire column had increased significantly.

The pressure drop across the individual sections of the column in the upper section was very high, indicating some of the trays were operating close to their flood point. Thus, it was necessary to reduce the vapour load. To achieve this, the column was forced to operate at elevated pressure. Operating the column at elevated pressure lowered the feed vaporisation and reduced the product distillate yields. Pressure drop fluctuations in the upper section of the column affected LK product qualities, hence crude charge to the unit had to be cut down.

Troubleshooting process

To understand the abnormal increase in pressure drop, a detailed study of the complete column operation was conducted. The possible reasons for the increase in pressure drop could be:

- Faulty instrumentation measuring incorrect pressure readings.
- Damage to the trays resulting from an upset, obstructing the passage of vapours.
- Fouling of the trays, resulting in resistance to vapour flow.

Upon evaluation, it was found that all pressure instrumentation indicators were working correctly, ruling out faulty pressure instrumentation. Damage to the trays was found unlikely as the column was operating without loss in separation or heat transfer efficiency at lower throughput. Observations showed that the rise in pressure drop first occurred in the LK draw-HKPA return zone, followed by the LKPA return-LK draw zone, then the HN draw-LKPA return zone, and finally the column top-HN draw zone. This indicated that limitations were originating from the HKPA zone and moving upward.

Tray sections near hydraulic limits can experience flooding with resultant high pressure drop and instability. The high pressure drop in the top sections, coupled with inconsistencies in LK product qualities, indicated that the LK section trays were operating near hydraulic limits. This was not confirmed by process simulations and tray ratings, which indicated that the existing trays and internals were suitable to handle the corresponding vapour-liquid traffic with significantly lower pressure drop than current operation. An analysis of LK product pump suction strainer deposits detected high phosphate content, indicating possible fouling of trays in these sections. The phosphorus is attributed to crude and high TAN corrosion inhibitor injection to treat high TAN crudes. Chemical cleaning of the column top section was carried out by injecting an anti-foulant but did not produce the desired results.

To understand the source of phosphate deposits in the crude column, NEL examined the performance of the desalter, the most crucial contaminant removal process in the refinery. Phosphate esters, whether added to the crude oil or introduced as high naphthenic acid crude treatment corrosion inhibitors, enter the crude column and cause fouling in the crude column. Thermally unstable partial phosphate esters exhibit acidity similar to phosphoric acid. The OH bond in these esters is thermally unstable and decomposes at temperatures typical of the crude distillation unit (CDU), resulting

Comparison of pressure drop in the crude distillation column		
Section	Pressure drop after 1 month column operation, kg/cm²	Pressure drop after implementing split stream, kg/cm²
HN draw to LKPA return	0.14	0.07
LKPA return to LK draw	0.13	0.05
LK draw to HKPA return	0.08	0.05
Column top to flash zone	0.70	0.5

Table 2

in volatile phosphorus compounds that can accumulate in the crude column.

Although the study indicated that fouling was the possible root cause of the increased pressure drop across the column, a gamma scan of the crude column was performed to pinpoint the exact location of flooding. Four scan lines were used to evaluate the column's hydraulic performance, with one of these scan lines represented in **Figure 2**. The scan results provided the following interpretations:

- Liquid accumulation and flooding were observed in the top section of the column down to the HN draw section, predominantly in the mid-zone. The bottom of this section showed very little liquid, indicating that the top section trays were holding the liquid while the bottom was drying up.
- Liquid accumulation and flooding were also noted in the mid-section between the HN draw and LKPA return.
- The LKPA section trays were found to be flooded at the bottom, with a significant pile-up of liquid.
- The trays in the LK draw to HKPA return section appeared to be flooded at the top, with less liquid observed at the bottom of this section, indicating a liquid build-up at the top.

The column could provide stable operation if:

- The vapour-liquid traffic in the LK section is reduced. Reducing internal traffic in the LK section was necessary to overcome flooding caused by fouled trays in that zone.
- Operating the column at a lower throughput until the turnaround.
- Considering a short shutdown for rectification.

An immediate shutdown to carry out modifications was not feasible. Although the pressure drop across the top sections was higher, the pressure drop across the HKPA section was lower compared to other upper sections. This indicated the possibility of transferring the load from the high pressure drop LK section to the HK section. By doing so, the loadings in the LK zone and the overall pressure drop could be reduced, thereby allowing the column to handle additional load.

To achieve this without shutting down the unit, an unconventional method of routing a slip stream from the LKPA to the HKPA return was devised by NEL. This approach aimed to partially bypass the internal reflux from the LK to the HK zone. The slip stream of LKPA to HKPA return was implemented without affecting the column profile and with minimal adjustment to pumparound duties.

The main challenge was to complete the modification on the operating column and perform a hot tap. A process scheme was developed by NEL, which included taking a hot tap to route a portion of LKPA from the immediate LKPA

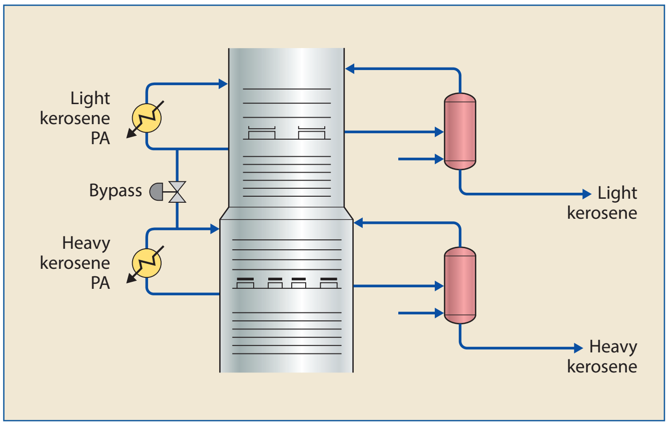

Figure 3 Arrangement of routing LKPA to HKPA

pump discharge to the outlet of the last HKPA pumparound exchanger. This scheme was executed and commissioned within a few days (see **Figure 3**). Post commissioning of the slip stream scheme included the following improvements:

- Pressure drop across the column top sections came down to normal values.
- Instability in product qualities disappeared. LK product qualities such as colour, flash point, and freezing point improved.
- Crude throughput to the unit could be regained.

Table 2 presents a comparison of the pressure drop in the crude distillation column before and after the implementation of the split stream from the LK section to the HK section.

A detailed analysis of operating data, simulation studies, and field activities conducted by NEL led to the timely identification and resolution of crude column underperformance. This approach provided a short-term remedy that maintained production levels until the next turnaround.

Turnaround observations

After about one year of operation, during the refinery turnaround in 2018, the crude distillation column was inspected, revealing pitting and fouling of trays across different sections of the column.

- In the HN-LK fractionation section, top trays have observed severe pitting in the tray deck and downcomer area, along with minor to moderate fouling. Bottom trays observed severe fouling, though pitting was minor or insignificant. Valve openings were plugged, potentially restricting vapour flow and increasing pressure drop during operation. Cleaning required significant effort using a wire brush.
- In the LKPA zone, fouling was noticed on the tray deck, with deposits increasing from top to the bottom tray.
- In LK-HK fractionation and HKPA zones, hard and severe fouling was observed on the tray deck and downcomer area (see **Figure 4**). Most of the valve openings were blocked by deposits, with fouling more prevalent in the mid-section of the tray (see **Figure 5**). All trays were removed, cleaned with a hydro jet followed by grit blasting, and reinstalled. The LK-HK fractionation trays were replaced with new, identical trays. Laboratory analysis of tray deposits revealed significant quantities of phosphorus, along with iron and sulphur.
- In the HK-LGO fractionation section, all trays were found to be clean, intact, and free from corrosion or fouling.
- In the LGO PA, LGO-HGO fractionation, and HGO PA

Figure 4 Fouled tray in LK-HK fractionation section

Figure 5 Fouled tray in HK section

sections, all trays were in good mechanical condition without any fouling deposits.
- The HGO wash bed was also found to be in good condition and clean.

The analysis of the tray deposits revealed varied appearances, with colours ranging from reddish-brown to black, and a high phosphorus content of approximately 21% by weight. Based on the extent of fouling and the analysis of deposits on the LKPA and HKPA zone trays, it was concluded that fouling was primarily due to phosphate salts, mainly contributed by the type of crude processed and, to some extent, by the high TAN corrosion inhibitor dosage. To prevent such occurrences in the future, it was recommended to replace the trays in these sections with fouling-resistant trays.

After cleaning the trays and resuming operation, the pressure drop across the column started increasing again after a few months. To maintain unit throughput, some parts of the LKPA section continued to slip to the HKPA section.

Severe fouling solutions

To address fouling concerns on the trays in the LH-HK section of the column, NEL and Koch-Glitsch collaborated and studied the column with the following objectives:
- Improve the fouling resistance for trays in the naphtha and kerosene sections.
- Minimise required modifications to the existing trays and internals.
- Maximise the vapour-liquid handling capacity with minimal modifications.

Proper design of internals for severe services requires identifying potential severe conditions and understanding the nature or cause of the problem. Modifying operating conditions or the process scheme may help minimise potential hazards. For severe conditions that cannot be eliminated, appropriate equipment designs can provide longer run times.

To extend run times in severe fouling service, fouling-resistant trays with anti-fouling valve options promote self-cleaning of the active areas. These trays have fouling-resistant fixed valves that use vapour energy to create a forward lateral push to the froth, maintaining proper tray activity and reducing the residence time of solids on the tray deck (see **Figure 6**). Special attention is given to the peripheral areas of the deck where stagnation may lead to solids deposition. Directional valves in these areas increase bubbling activity and promote a uniform flow profile. These components work together to reduce residence time distribution and enhance the fouling resistance of the trays. The final design combines features suitable for specific applications to produce a tray capable of longer run times between cleaning shutdowns. This solution has been demonstrated in similar applications (see **Table 3**). Superflux trays were accepted by NEL and installed during the 2020 shutdown.

Shutdown 2020 observations and action

In 2020, after approximately two years of operation, the crude column was opened for inspection and modifications. During the inspection, pitting and fouling of trays were observed, varying between the sections described below:
- **HN-LK fractionation section**: In the upper section, pitting and deposits were observed, while in the lower section, heavy deposits were found in the valve openings.
- **LKPA section:** Severe fouling was observed, with approximately 70-80% of valve openings choked with hard deposits. Fouling was mainly in valve openings, with less on the tray deck and valve top surface. Downcomers were slightly dislocated from support brackets.

Fouling-resistant solutions for crude columns

Year	Country	Diameter	Quantity (trays)
2024	India	9,600 mm	4
2021	India	9,600 mm	12
2020	India	8,500 mm	4
2020	India	7,500 mm	21
2019	India	9,600 mm	5
2018	India	9,600 mm	5
2016	India	9,600 mm	22
2015	India	9,600 mm	22
2015	India	9,600 mm	17
2014	India	9,600 mm	17

Table 3

Improved stability and column performance following installation of Superflux trays

Section	Pressure drop post installation of Superflux trays, kg/cm²	Pressure drop after two-year operation, kg/cm²
Column top to HN draw-off	0.06	0.06
HN to LKPA return	0.05	0.05
LKPA return to LK draw	0.01	0.01
LK draw to HKPA return	0.03	0.03
Pressure drop column top to flash zone	0.4	0.4

Table 4

- **LK-HK fractionation section**: Very hard and severe fouling was noted; valve openings were choked. Moving downward in this section, the fouling severity increased. Heavy solid deposits were observed in the HK draw chimney tray.
- **HK-LGO fractionation zone**: All trays were found clean and intact, with no signs of corrosion or fouling.
- **LGO PA, LGO-HGO fractionation, and HGO PA sections**: Trays showed good mechanical integrity, with no fouling material present.
- The HGO wash bed was also found to be clean.

As a result of these observations, a total of 25 trays from the HN to HK zones were replaced with new Superflux trays to improve fouling resistance. Post-replacement, significant improvements were observed in overall column parameters, including sectional and overall column differential pressure (DP), which remained stable at approximately 0.4 Kg/cm² at equivalent throughput levels. **Table 4** shows the DP profile of the column's top section after replacing the trays.

After two years of operation, at the end of 2022, the column was opened and inspected. All trays were found in good condition without fouling (see **Figure 7**). A slight pitting was observed in the top few trays. In the HN-LK section, minor deposits were observed on the tray deck, displaying a blackish colour. Analysis of these deposits indicated a very small phosphorus content, less than 2% by weight. The low concentration of phosphorus compared to the 2018 shutdown clearly indicates the effective flushing of salts from the tray deck, which is attributed to the fouling-resistant properties of the Superflux trays.

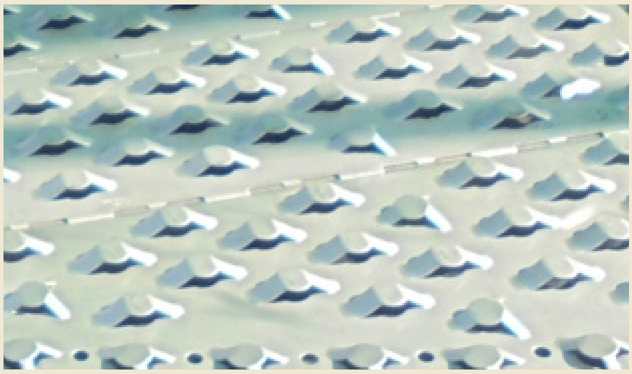

Figure 6 Superflux tray with fixed valves to reduce residence time of solids on tray deck

Conclusion

This article discussed the successful collaboration between NEL and Koch-Glitsch in troubleshooting and resolving fouling challenges in their crude distillation column. As the first column to process petroleum in any refinery, the crude column's performance is critical, influencing overall refinery throughput and feed to downstream units. Identifying the root cause of fouling required a thorough review of column operations, data analysis, and interpretation.

To maintain column operation and throughput at desired levels, the intermediate solutions developed by NEL were instrumental. In addressing long-term fouling concerns, the utilisation of fouling-resistant tray technology emerged as an effective solution. This intervention significantly improved reliability and extended run lengths, showcasing the advantages of tailored solutions for specific operational challenges.

The findings presented contribute to the broader understanding of the troubleshooting process, the solutions to maintain column operation, and fouling mitigation strategies in crude distillation columns. They underscore the combined importance of innovative solutions and advanced tray technologies in enhancing performance and reliability.

We acknowledge the gamma scan conducted by the Board of Radiation & Isotope Technology (BRIT) to confirm the location of fouling in the crude column. SUPERFLUX is a mark of Koch-Glitsch.

References

1 Scott Hebert and Neil Sandford, Koch-Glitsch LP, "Considering Moving to Fixed Valves," Chemical Engineering Progress (CEP), May 2016.

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Figure 7 Superflux tray after two-year column operation