TROUBLESHOOTING AND OPTIMIZING REFINING VACUUM TOWERS

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Introduction

Vacuum distillation of atmospheric residue is a standard process of oil refineries. The technology is well known for many decades and equipment design had been standardized, apparently leaving little room for surprises.

This paper will demonstrate how methodological troubleshooting exercises can help plant operators determine root causes of vacuum tower malperformance and implement corrective solutions.

Case Study #1: Troubleshooting vacuum system package

Tower pressure is a crucial parameter for optimum VDU tower performance. The available vacuum is a limiting factor for product yields and quality. Increased operating pressure cannot be compensated by increased reboiling simply because vacuum tower has no reboiler. Furthermore, heater outlet temperature is limited by coil metallurgy and hydrocarbons cracking.

Problem Description

A vacuum distillation unit located in Europe was revamped for capacity increase. During the revamp, vacuum tower internals were partially replaced and charge heater was upgraded.
After the startup, vacuum tower could not hold the vacuum. Air leakage was detected at the water ring vacuum pump suction and repaired. Nevertheless, after the repair, operating pressure of the VDU tower was slowly rising. Within a couple of months, vacuum tower top pressure increased from the design pressure of 3 kPa abs. (23 mmHg) to 6 kPa abs. (45 mmHg). Such a high operating pressure was making vacuum residue quality unacceptable for bitumen production.

Tower internals vendor claimed the problem was not in the column. Client then focused on vacuum system efficiency for potential equipment wear and undetected air leakage. The troubleshooting effort; however, did not yield any positive result. Desperate, Client planned for another shutdown for inspection and preventive maintenance. In order to shorten shutdown duration, GTI Solutions was invited to perform a plant survey with the goal of identifying faulty equipment.

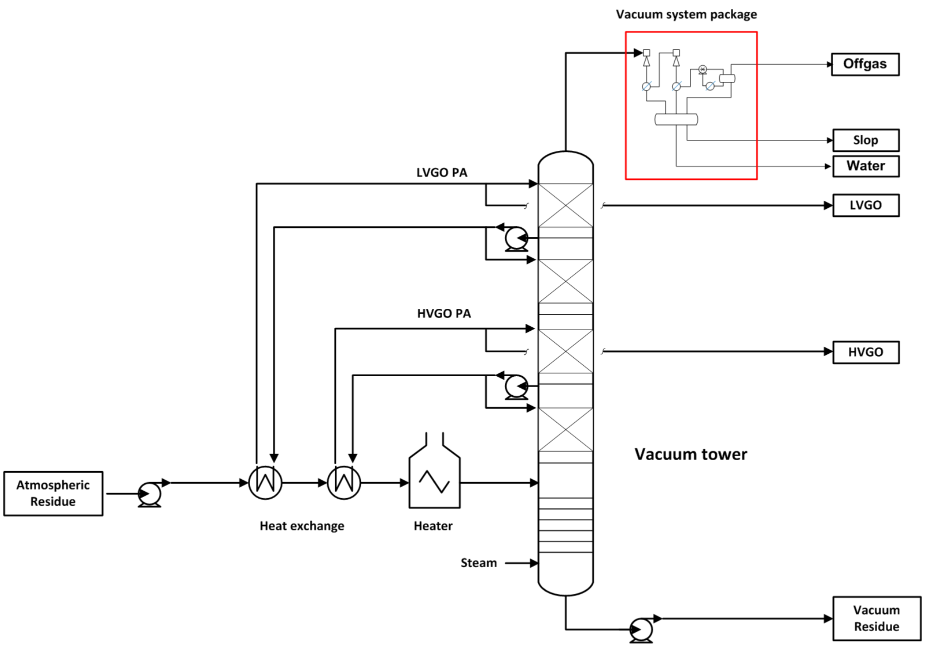

Figure 1: Vacuum distillation unit

Problem Analysis

High column operating pressure can be caused by:

- Vacuum system overload (air leakage or excessive stripping steam)
- Vacuum system equipment defect (wear and tear)
- Excessive system pressure drop (hydraulic restriction)

Vacuum system load was crosschecked with sour water flowrate from hotwell. It was concluded the load was the same as before the revamp. This finding excludes stripping steam overload from the list.

Potential air leakage and vacuum system equipment defect were checked by means of pressure survey. Vacuum system pressure profiles before and after revamp were compared at similar system loading (stripping steam flowrate measured as sour water flowrate from hotwell).

Table 1: Vacuum system pressure survey results

Pressure tap	P1	P2	P3	P4	System loading
Location	**Tower top**	**2nd stage suction**	**3rd stage suction**	**After 3rd stage**	**Sour water rate**
Before revamp	3 kPa abs	8 kPa abs	22 kPa abs	110 kPa abs	4.9 t/h
After revamp	6 kPa abs	8 kPa abs	21 kPa abs	110 kPa abs	4.7 t/h

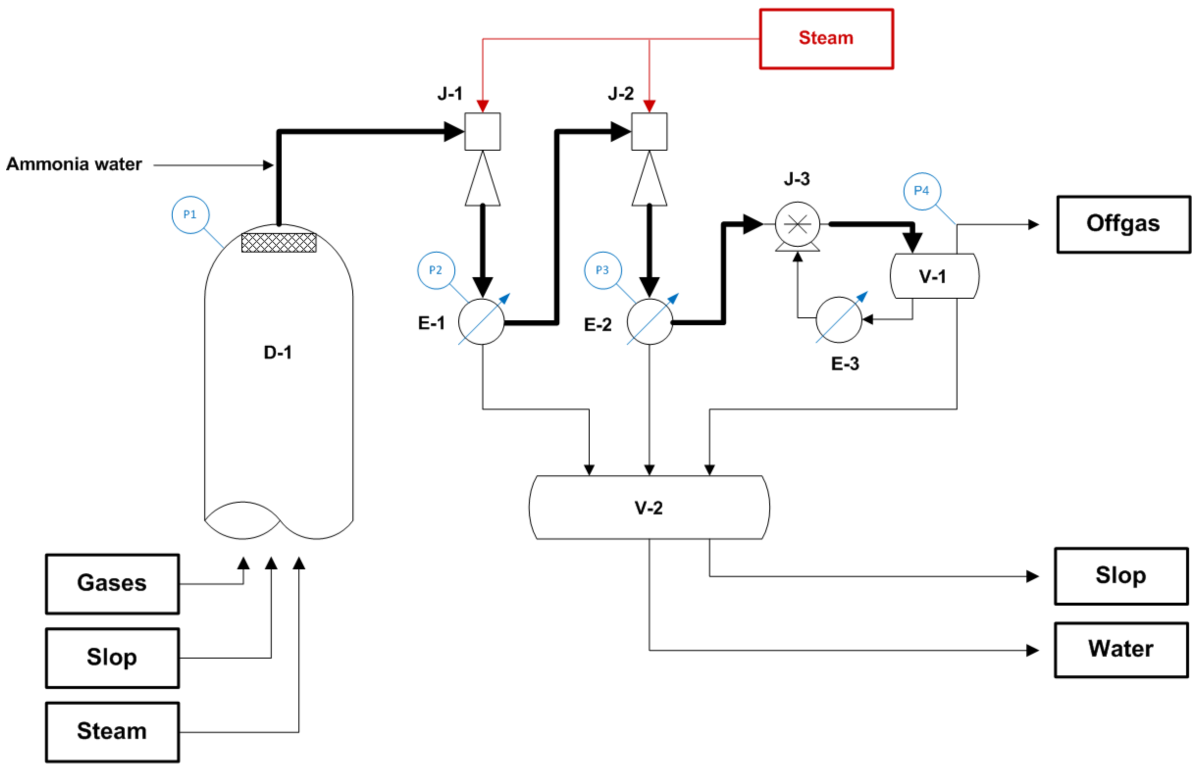

Figure 2: Vacuum system pressures survey

Vacuum system package works as a 3-stage constant volumetric flowrate compressor. This means:

- Vacuum system suction pressure as well as suction pressure of every compressor stage, are proportional to the gas volumetric flowrate. Significant air leakage would result not only in vacuum tower pressure increase but all inter-stage pressures would also rise.
- Equipment wear would result in compression ratio drop at the faulty compressor stage.

Suction and discharge pressures at 2nd and 3rd stages did not change after the revamp. This means:

- The 2nd and 3rd stages are working well as they did before the revamp (no wear).
- The 2nd and 3rd stages gas load is the same as before the revamp. This observation and offgas analysis for oxygen content excluded massive air leakage from the list.

At the 1st stage, the suction pressure was much higher after the revamp. This signifies possibility of either 1st stage ejector wear or column overhead line blockage.

Now it is crucial to pinpoint the exact location where column top pressure was measured. Pressure tap was not located at 1st stage jet suction but at top of the vacuum tower, below the demister pad. As there was no pressure tap, a digital manometer was installed temporarily at the ammonia water injection point while ammonia water injection was temporarily interrupted.

Conclusion: High column pressure was caused by plugged demister.

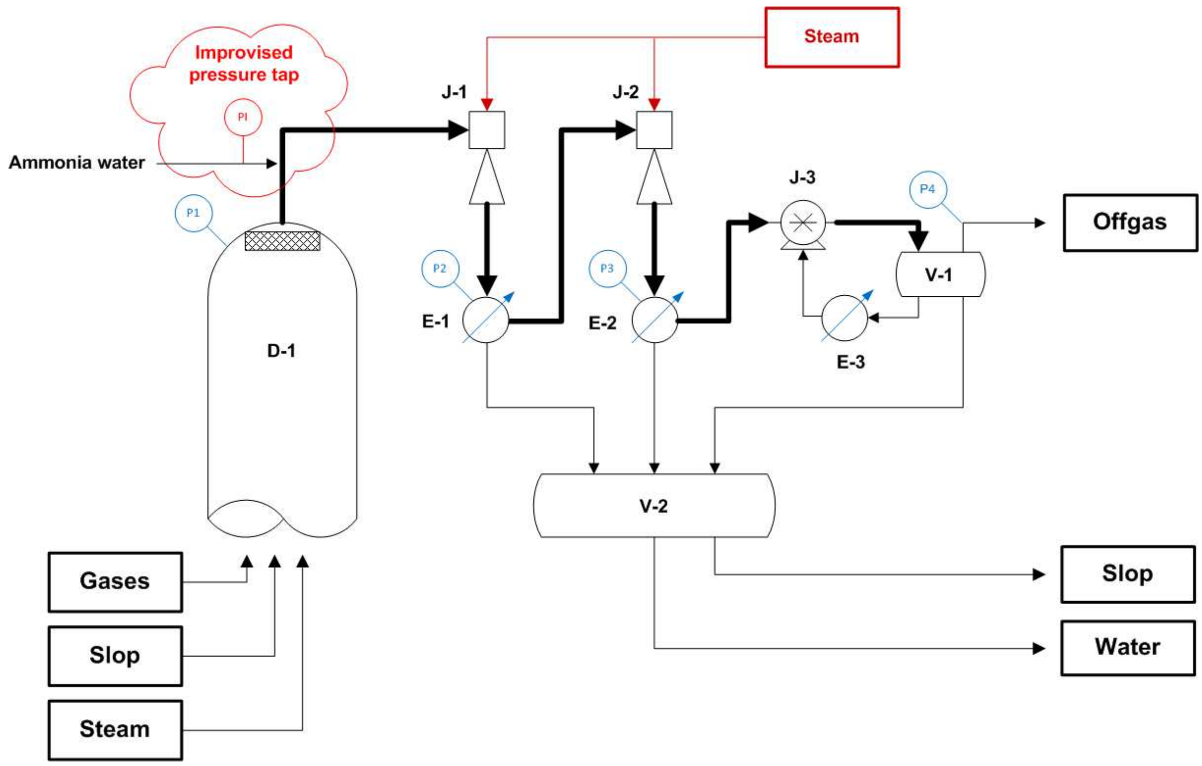

Figure 3: Vacuum system pressures survey

Table 2: 1st stage jet suction pressure measurement

Colum top pressure (P1)	6 kPa abs.
1st stage jet suction pressure (after demister)	3 kPa abs.
Demister pressure drop	**3 kPa**

Finding the Root Cause

Potential causes of plugged demister were analyzed:

- Heavy hydrocarbons (paraffins) solidification
- Ammonium salts deposition
- Coke or polymer formation

Paraffins deposition was considered unlikely, based on top product analyses (low cloud point).
Coke or polymer formation was not excluded but considered unlikely because of low column top temperature.
The most likely cause was ammonium salts deposition in the demister pad.
Ammonia water injection point design was poor – instead of spray nozzle there was just a simple 1" line connected to the vertical part of vacuum tower overhead line. Ammonia water then could flow downwards along the overhead pipe wall to the demister pad where ammonia would then react with hydrogen sulfide from the offgas forming salt deposits.

Solution

Since ammonium bisulfide salts decompose at elevated temperature, GTI Solutions recommended Client to increase column top temperature and to add more stripping steam. Following the proposed actions, the tower pressure stopped rising and some time later it dropped down to 4 kPa abs.
As a result, an emergency shutdown was not required and vacuum unit could be smoothly operated for another half year until the planned turnaround.

Column internals inspection during the turnaround confirmed ammonia salts deposits in the demister pad. To prevent similar problems in future, the demister pad was removed and ammonia water injection point was redesigned.

Lessons learned from the Case Study

1) This case study demonstrates the importance of troubleshooting technique, data collection, reconciliation, and interpretations. The detailed plant survey helped identified the root cause(s) and enabled GTIS engineers to provide solutions without a plant shutdown, saving both time and money for Client.
2) Do not draw conclusions from one's desk without completely understanding the problems and proper investigations. Original tower internal vendor claimed the problem was not in the column without visiting the plant or conducting a thorough investigation. Their "assessment" only confused the Client and delayed corrective actions.
3) Ammonia water injection should be designed properly.

Case Study #2: Troubleshooting vacuum tower wash section

In certain cases, licensor's process design package and specifications require special attention to critical equipment design know-how and considerations.

Problem Description

A refinery vacuum distillation unit located in Asia was due for a maintenance turn-around. Over time the performance of the tower had deteriorated. This was a common theme and cycle for this particular vacuum tower. In particular, the large size of the tower along with distributor fouling, high transfer line velocity, and separation requirements resulted in equipment design that had limited operation length and reduced product recovery over time.

Figure 4 shows the arrangement of this particular vacuum distillation unit. Running in wet mode, the tower consisted of four packed pumparound beds, one fractionation bed, a wash bed and stripping trays. The majority of the packing was structured packing type with surface areas ranging from 125 to 220 m^2/m^3. In view of fouling & fractionation requirements, the wash bed was packed with a combination of structured packing and grid. Some specifics of this tower include:

1) Large Diameter: Over 15 meter (50'- 0") ID column
2) Pumparound and Pumpdown.
   All beds contained pump-down circuits from the section above, meaning that certain fractionation was required out of pumparounds that is normally reserved for heat transfer.
3) Sonic Velocity Design of Transfer Line. The transfer line was designed for near sonic velocity resulting in atomization of droplets and massive entrainment from the flash zone. Cost expenditures, limited plot plan for access and complex field modification work meant transfer line geometry was to remain unchanged.
4) Trough type gravity distributors were used in the HHVGO, HVGO pumparounds and wash bed. The pumparound circuits operated under moderate to low liquid loads compared to typical pumparounds and thus required relatively small hole size for liquid distribution.

In particular, the maximum yields and highest level of operation were only achieved during the early months of operation. As fouling of the packing and plugging of distributors occurred, fractionation performance declined over time. The steadily increase of column pressure drops and poor fractionation that has occurred over time resulted in operators taking actions to reduce yields. In this case, the task of the operator was to extend the high yield / high quality operation mode as long as possible.

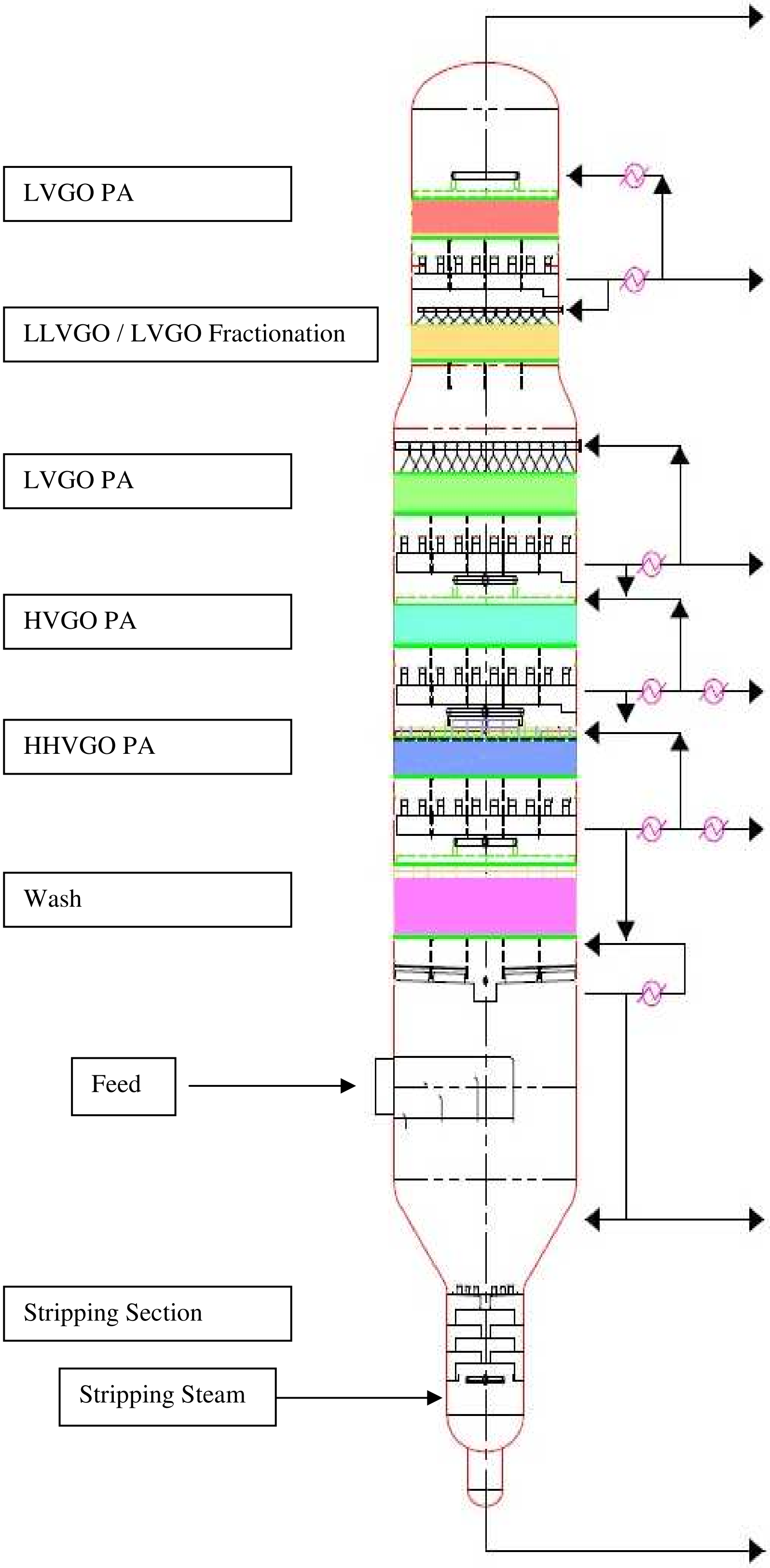

Figure 4: VDU configuration

Distributor Fouling

In particular, one observation from previous inspections was the plugging of the trough distributors. The trough distributors all used drip point multiplying effect to reduce the hole quantity and increase the hole size, however; for the existing Wash, HVGO, and HHVGO distributors, the hole size was in the range of 5.0 to 6.0mm.

How fouling Occurs in Trough Distributors

Pumparound distributors are generally at risk of particulate fouling and this is one of the reasons that spray nozzles are the preferred type of distributor. The hydrocarbons in these systems are recycled through a heat exchanger bank effectively for several years. This means that corrosion particles, coke particles, and any other solid materials could pass through the trough diffusers. Even strainers typically installed outside the tower may not be sufficient to stop all particles from entering the tower. In addition, long residence time in the gravity/trough distributors not seen in pressure/spray nozzle distributors at high operating temperatures can result in coke formation inside the troughs. Figure 5 shows exactly what can happen.

Liquid Spreading Problem

In addition to reducing the packed bed performance, the plugged distributor can lead to additional problems that included the fouling and plugging of the packing. A dry area of packing that no longer gets liquid will run hot, which will encourage coke formation of droplets. This typically start out small and then will grow rapidly over time as coke itself is an excellent nucleation site for more coke formation. Eventually the packed bed will become plugged causing higher pressure drop due to reduction in void area and thus poor fractionation or heat transfer performance.

Figure 5: Plugged trough distributor

Distributor Modifications

1) Changing the design specifications

This is important as design specifications from a licensor or basic package can indeed impact run length. The main one being operating range. More turn-downs means smaller hole size. Smaller hole size increases the risk of plugging. In this case, reducing the operating range of each distributor will allow for increased hole size and more fouling resistance design. Instead of a 40 percent to 120 percent operating range, a 70 percent to 120 percent will allow designers to increase hole size for liquid distribution. This design concept is practical since wash bed operability has direct correlation with true wash rate (before accounting for entrainment) and over-flash rates.

2) Elevated Holes

Increasing the hole elevation from the deck of a gravity distributor can also help increase column run length. In this case, an additional volume of solid material will be collected below the hole elevation before onset of plugging of the holes. It should be noted that this design consideration also increased the residence time dramatically as liquid leaves the area below the elevated holes only by drain holes, typically few in quantity and also small in size.

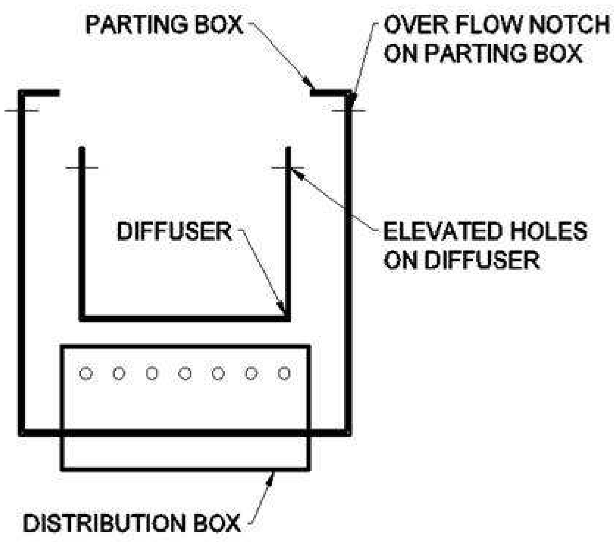

Figure 6: Multiple stage design of trough distributor

For this particular case, the hole size was increased from 5~6mm up to 7~8mm and all hole elevations were increased. This was at the expense of turndown operation that was not critical since in over a decade of operation the tower had not operated at substantially reduced charge conditions.

Post Revamp Results

Immediately after revamp, which included replacement of packing, a substantial improvement in fractionation efficiency was observed in distillation overlaps.

Table 3: Key product distillation overlaps at EOR, before and after revamp

Distillation Overlaps	Before revamp	After revamp	Improvement
HVGO 5% - LVGO 95%	-81°C	-68°C	13°C
HHVGO 5% - HVGO 95%	-120°C	-81°C	39°C

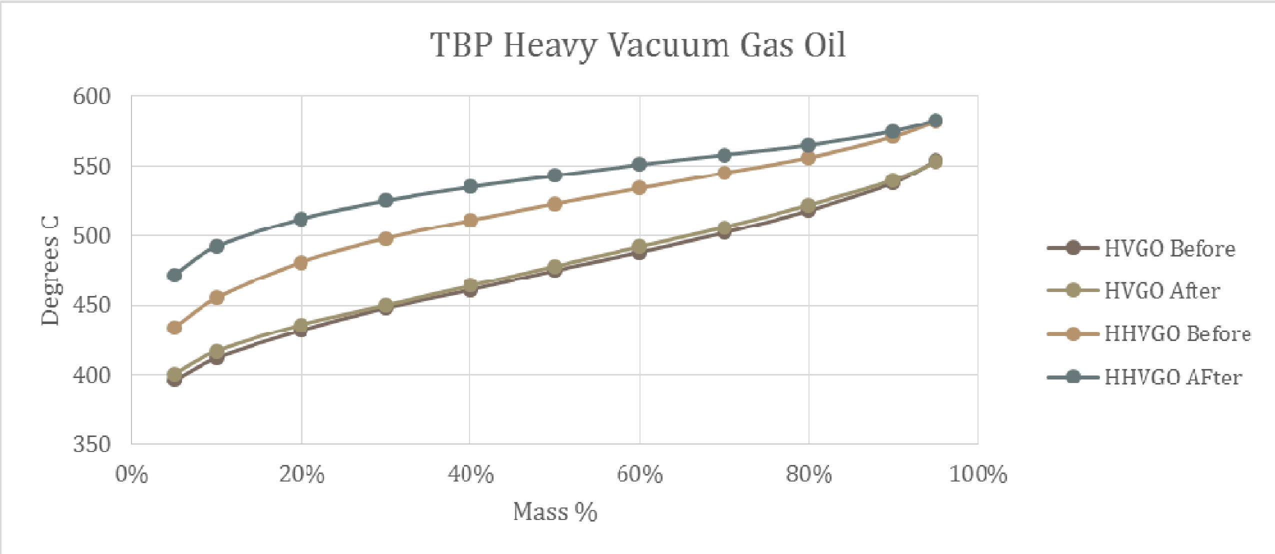

Figure 7: Key product distillation overlaps, before and after revamp

Table 4: Heat Transfer Performance before and after revamp

Pumparound Summary		Before revamp	After revamp
LLVGO Duty	M*Kcal/hr	16.8	18.0
LVGO Duty	M*Kcal/hr	18.3	18.9
HVGO Duty	M*Kcal/hr	15.8	33.1
HHVGO Duty	M*Kcal/hr	36.8	24.9
Oveflash PA Duty	M*Kcal/hr	0.4	0.4
TOTAL HEAT REMOVAL	**M*Kcal/hr**	**88.1**	**95.3**

GTI Solutions calculated an increased total heat removal when comparing before and after revamp data – these are reflected in Table 4.

While the improvements observed would be expected with replacement of fouling equipment, long term data trends have shown that the rate of fouling and the decreased fractionation have lessened over time with better performance observed in the first two years of operation.

More Severe Operation

The tower is currently operating at 3.9 mmHg to 4.5mm Hg(A) overhead pressure. Originally the tower operated with 4,200 kg/hr to 4,500 kg/hr steam, however; a leaking vacuum pump has limited capacity and in order to pull the desired vacuum total steam consumption is reduced to 2,800 kg/hr to 3,600 kg/hr. The product recovery is maintained by increasing higher flash zone temperatures, up from 385°C to 395-399°C. Despite these higher flash zone temperatures, the tower continues to operate with better results when compared to middle of run operation after previous turnaround.

Final Conclusion

Long term operation in severe service applications can be improved by modifying equipment and design guidelines. While a total elimination attributed to coking and fouling may not always be possible, extending operating run-length with higher yields and better product qualities is something that equipment vendor and operating engineers can set out to achieve.