High performance internals in severe service

Application of a severe service grid achieved 10% higher throughput with improved reliability in a vacuum tower revamp

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While the recent shale energy revolution and supply infrastructure issues from heavy oil producing countries have steered the majority of US refineries towards being set up for processing light, sweet crude oils, the situation in Western Canada is starkly different.[1] Refineries there were originally designed to process light sweet crude oils, but over time have had to make the necessary adjustments to process heavier crude oils due to growing oil sands production.[2]

As the operator of Canada's first heavy oil upgrader, the Consumers Co-operative Refinery Limited (CCRL) refinery has pioneered its way through the ever-changing Canadian energy landscape. Founded by eight enterprising farmers amid the great depression to reduce their reliance on major oil companies, the refinery has since gone through numerous upgrades and expansions.[3] CCRL is a wholly owned subsidiary of Federated Co-operatives Limited (FCL) and owns and operates the refinery and upgrader facilities.

While major capital projects are one way to increase value to refinery operations, opportunities such as end of life vessel replacement or five-year maintenance shutdowns should not be overlooked with a replacement in kind (RIK) scope. This is an opportune time to improve unit performance without incurring significant costs, and often can be done without incurring any incremental cost when compared to a RIK scope.

This article goes on to discuss the changes made during a vacuum tower replacement project, where new technology was incorporated instead of taking the RIK approach.

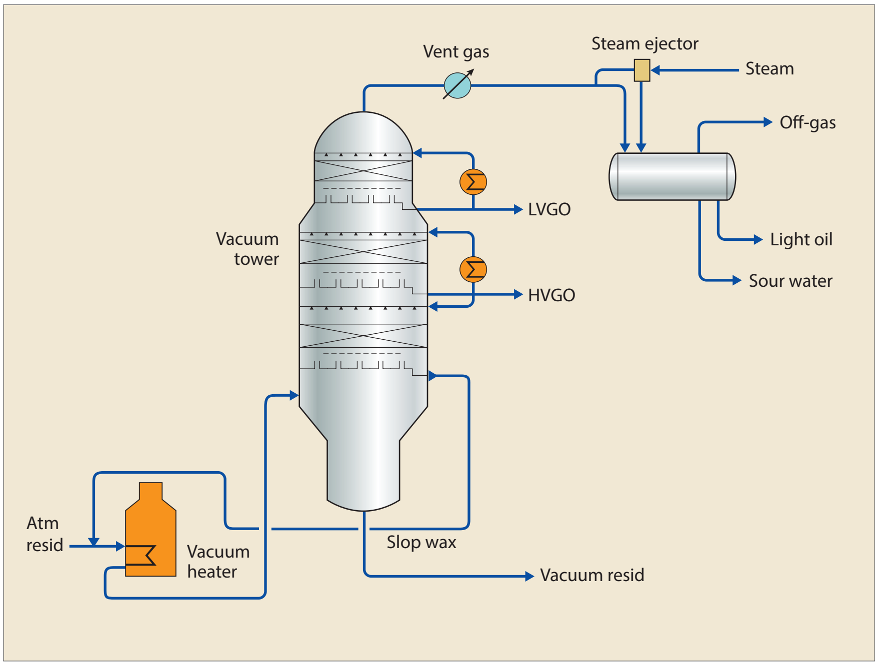

Figure 1 Schematic of a typical dry vacuum crude unit

The changes made increased throughput by 10% while reducing pressure drop, resulting in significant savings in operating costs as well as a more reliable operation for a typically severe service. CCRL became the first refinery in the world to use Proflux severe service grid in a vacuum column wash bed, and the article will discuss the reliable operation achieved and performance benefits realised since start-up in 2013.

Project overview

Crude vacuum distillation units are responsible for maximising gasoil recovery from atmospheric residue. While this service is generally severe due to the origin of the feedstock, the importance and severity are further underscored in the Western Canada region where the front-end feed to the refinery is already a low quality, heavy crude.[4]

The feed to the vacuum column is heated to temperatures in the range 700-760°F which can result in cracking and subsequent carbon residue formation, known as coking. The transfer line is sized so that the two-phase stream enters the column at close to critical velocity through a feed device designed for severe service applications. A well designed wash bed should reduce and withstand fouling in order to increase column run life, as well as protect the quality of the HVGO product from entrainment from the flash zone. The low operating pressure is instrumental to extracting gasoils from the atmospheric residue.

As part of the company's initial RIK equipment inquiry, CCRL communicated a desire to increase the column throughput. This opened discussions to look for higher performance tower internals within the framework of an RIK vessel

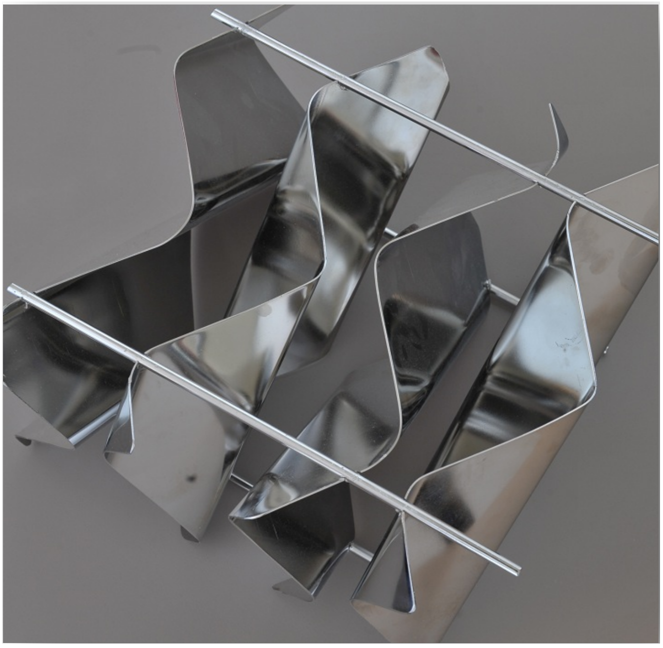

Figure 2 Proflux severe service grid

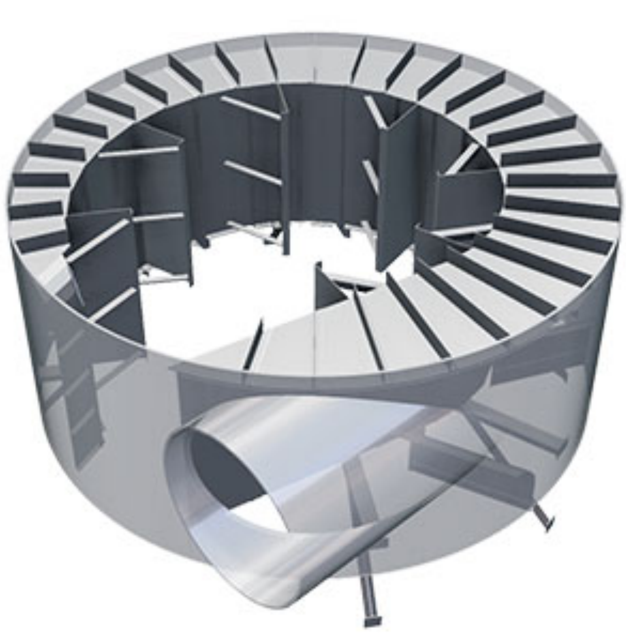

Figure 3 Enhanced Vapor Horn

project so that throughput could be increased while maintaining product quality. The column operates as a dry vacuum column (see **Figure 1**).

Enhanced process technology

Utilising new technology to increase capacity, reliability, efficiency and minimise pressure drop across the tower provides benefits that can be realised in a variety of ways. These include:

- Reduced operating costs from the auxiliary equipment
- Increased product recovery
- Stable operating conditions
- Reduced equipment replacement cycle

While this article specifically talks about the enhancements added in this vessel replacement project, it is important to realise that typical five-year maintenance outages are an opportune time to replace old technology with new designs – and reap some of the benefits mentioned above. Many design enhancements can be explored for vacuum column operation, however focus here is on three areas: high performance packing – grid and structured – and a high performance inlet feed device.

The wash bed, along with the flash zone, is the most critical section of the vacuum column and the optimal design approach can be a source of rigorous debate within the industry.

Wash bed – Proflux severe service grid

The function of the wash bed is to eliminate entrainment of residue in the feed to the HVGO product, and to provide some fractionation to improve the HVGO end point. The main entrainment concern to be addressed is minimising the amount of micro Concarbon residue (MCR) and heavy metals that end up in the HVGO. The results section of this article will discuss the impact of high performance tower internals on the MCR found in the HVGO product – a lower MCR was obtained at higher throughput for similar feedstocks.

There are many competing interests in the design of the wash bed and the packing types traditionally used in this application; first generation grid packing and structured packing have limitations. Maximising gasoil product can potentially come at the expense of insufficient wash oil to maintain adequate packing wetting, a key requirement of preventing coke formation. The use of an open, low surface area, first generation grid packing for severe service offers good fouling resistance but does not provide adequate de-entrainment in vessels that are pushed past a moderate operating point (Cs > 0.35 ft/s). The use of a medium crimp structured packing offers high de-entrainment properties and provides good fractionation, but it comes at the expense of less reliability – it is susceptible to fouling, and too much fractionation can cause the bed to dry out the wash oil and promote coke formation. A deep bed provides more efficiency than a short bed does, but it also increases residence time which can lead to increased fouling. The ideal approach is to balance the de-entrainment and fractionation requirements while maintaining reliability and maximising gasoil yield.

In 2009, Koch-Glitsch set out to provide the industry with a better packing product for fouling applications. With hundreds of existing vacuum column installations to draw from, the company looked to provide a packing that offered the de-entrainment characteristics of structured packing while improving upon the reliability of a traditional grid packing. De-entrainment tests that emulated vacuum column wash bed operating conditions were performed in the Koch-Glitsch pilot plant. The results confirmed what operating engineers have experienced in vacuum column wash beds around the world:

- Structured packing provides better de-entrainment than traditional grid packing at moderate and high gas velocities (Cs > 0.35 ft/s).
- For a given packing style, the amount of fouling is proportional to the surface area – higher surface area increases the fouling tendency.

• For the same surface area, the shape of the packing will influence the pressure drop and amount of fouling.

With respect to the last point, testing also confirmed that the structured packing geometry itself contributes to the fouling tendency. Contact points between sheets provide locations for solids to bridge and propagate. Experiments showed a novel structure that employs sheets that are shaped to prevent material from building up, and spacing these sheets apart would minimise the fouling potential.[5]

The Proflux severe service grid was developed to address the shortcomings of traditional grid and structured packing that have been observed in operating columns and through our pilot testing.[6] As **Figure 2** shows, the following design features differentiate the construction compared to traditional structured and grid packings:

• Corrugated sheet structure provides better efficiency, pressure drop, and de-entrainment compared to conventional grid packing.
• Spacing between the sheets eliminates contact points where solids can potentially collect.
• Welded rod construction provides greater durability compared to conventional structured packing.

Flash zone – Enhanced Vapor Horn

Properly feeding the vacuum tower is crucial to overall performance. The feed entering the tower is typically near the critical velocity and enters the column as a high momentum two-phase feed. The velocity of the feed is such that entrainment will be generated; the degree to which it occurs is a function of the device chosen and the gas velocity in the column.

A well designed feed device will perform the following functions:

• Dissipate high inlet momentum and provide uniform vapour distribution while taking minimal pressure drop.
• Provide bulk phase separation between the vapour and liquid in the feed, thereby minimising entrainment.

A uniform vapour velocity is critical as localised vapour superficial velocities can be detrimental to good wash bed performance, resulting in localised flooding and coke formation. This can consequently lead to inadequate gasoil quality and yield, along with propagation of coke over the run length of the unit. Furthermore, the ability of the feed device to provide good vapour distribution and minimise feed entrainment is paramount to maximising vacuum column capacity. The majority of vacuum columns have throughput constrained by entrainment into the HVGO product, not by the hydraulic capacity of the packing. The operating improvements obtained with the use of a vapour horn have been discussed previously[7,8], with the higher performance of an Enhanced Vapor Horn relative to other feed devices documented at high column gas velocities.[9,10]

The ability of the feed device to provide good vapour distribution and minimise feed entrainment is paramount to maximising vacuum column capacity

Phase separation is also critical to not overload the wash bed with material that is high in metal and MCR. While some overflash is inevitable and can help with maintaining wetting of the bottom layer of packing, minimising entrainment is critical to ensuring that good wash bed performance is achieved and gasoil product yield is maximised (operating with minimum wash oil). The combination of the Koch-Glitsch Enhanced Vapor Horn feed device and Proflux severe service grid in the wash bed was selected to handle the increased gas velocities the column would operate at post vessel replacement.

Figure 3 shows an Enhanced Vapor Horn similar to the one used in the CCRL vacuum column. It utilises:

• Turning vanes, in a proprietary arrangement break the high feed inlet velocity for improved vapour distribution and de-entrainment.
• Anti-swirl baffles, positioned on the outside of the horn, eliminate the cyclonic motion of the vapour as it leaves the flash zone.
• Tapered profile to reduce device footprint, thereby reducing gas velocity through the core area within the vapour horn, resulting in lower entrainment leaving the flash zone.

LVGO pumparound – Flexipac HC structured packing

With many refineries designed with old technologies, it is quite common to find conventional structured packing inside the tower. Conventional structured packing's capacity limitations stem from the liquid that is held at the interface between layers. This results in a higher pressure drop across the bed.

Flexipac HC structured packing combines improved capacity and efficiency characteristics, resulting in lower pressure drop per theoretical stage. The construction is like its predecessor, however the HC packing has a modification in the geometry of the corrugation at the top and bottom of each packing layer. This change in geometry:

• Eliminates the abrupt change in flow direction of the liquid and vapour phases at the packing layer interface
• Eliminates the premature build-up of liquid
• Helps maintain the low pressure drop characteristics of structured packing throughout the efficient operating range of the packing

From the operator's perspective, upgrading to high capacity structured packing during a RIK maintenance turnaround can be considered found money as the performance benefits realised outweigh any minimal cost impact incurred. The HC version provides the same surface area (and thus the same heat transfer coefficient in the pumparound) while reducing pressure drop.

In addition to the changes in the LVGO pumparound, a larger crimp packing was used in the HVGO

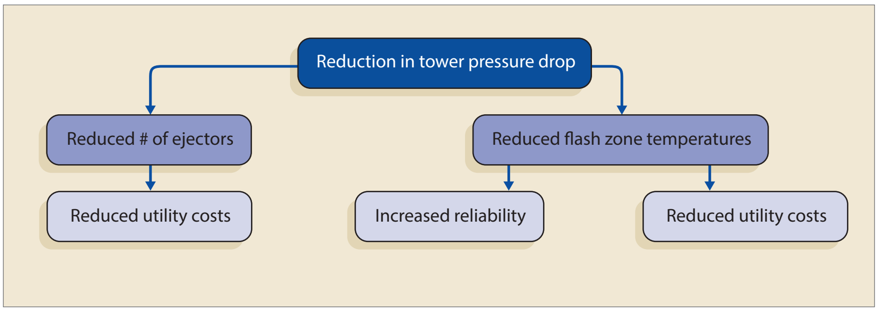

Figure 4 Operating cost savings realised with new tower configuration

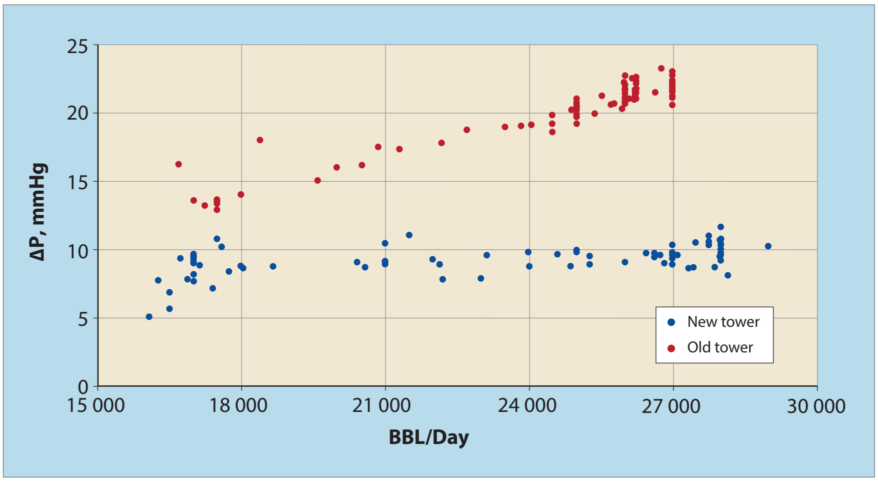

Figure 5 Column pressure drop vs feed rate, all feedstocks

pumparound to increase capacity and consequently reduce tower pressure drop. An additional layer of packing was added to the HVGO pumparound without increasing the vessel height as the spacing between the bottom of the bed and the chimney collector tray was reduced.

In order to project the benefits of offering an equipment enhancement over an RIK scope, operating data were collected from the existing operation and modelled in a simulator to obtain the vapour/liquid traffic in the column, as well as the velocity through the feed device. From this, a second simulation was done that modelled the effects of the change in mass transfer equipment in the column.

Results

While this project started as a RIK scope, based on the technical proposal offered by Koch-Glitsch, CCRL showed a willingness to entertain the most current mass transfer equipment technology. The objective of the modifications was to increase throughput without sacrificing product quality or reliability. Not only was an increase in throughput obtained, there was a marked improvement in product quality, reduction in operating cost, and improved reliability over the subsequent five-year run length. The new tower operated with the same wash oil rate as the old tower configuration. A by-product of this upgrade was a lower overall column pressure drop which had resulted in downstream benefits to the overall operation of the tower. The pressure drop savings resulted from a combination of more advanced structured packing and severe service grid being utilised instead of conventional structured packing and grid, more uniform distribution from the Enhanced Vapor Horn, and less fouling over the run length of the column. This is illustrated in **Figure 4** and further characterised by the plant process data in the subsequent graphs.

Pressure drop

The following data represent the plant's operations for crude feeds with an API gravity of 16-17. The upgrade in structured packing and severe service grid, as well as a modified design to the chimney tray internals, resulted in a pressure drop reduction over 10 mm Hg while operating at higher throughput. **Figure 5** compares the overall pressure drop pre- and post-revamp.

This significant decrease in pressure drop allowed the refinery to move from utilising six ejectors to four. The decrease in ejector usage resulted in a cost saving of C$20 000/month.

Feed temperature

The reduction in pressure drop enables reducing the temperature of the feed to the vacuum tower while not compromising vacuum gasoil (VGO) recovery. A comparison of VGO recoveries is shown in **Figure 6**. The average temperature for API 16-17 feeds for the old design was approximately 755°F, while after column replacement this temperature decreased to approximately

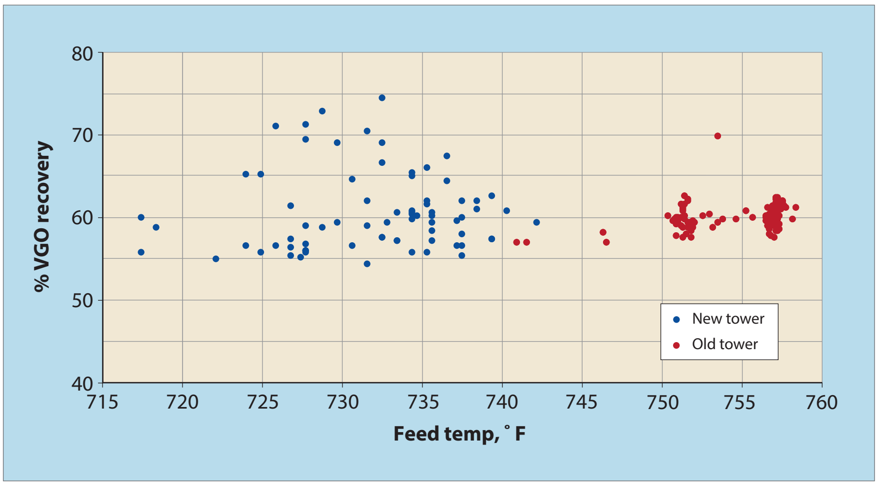

Figure 6 Gas oil recovery comparison for API 16-17 feedstock

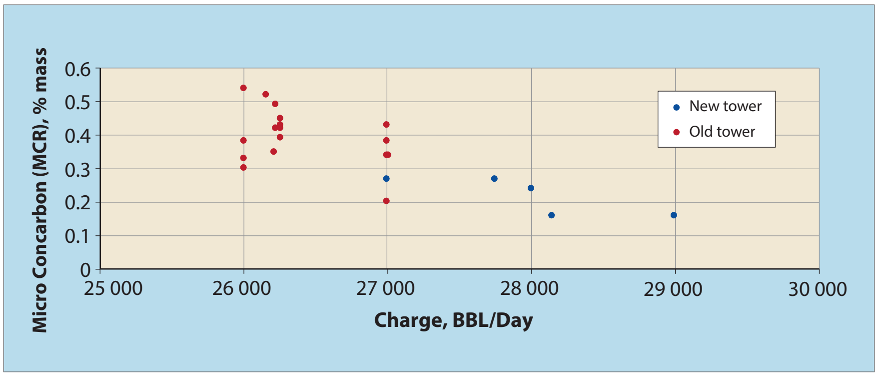

Figure 7 Micro Concarbon (MCR) in HVGO comparison for API 16-17 feedstock

Operating performance comparison normalised for API 16-17 feedstock

Parameter	Old tower	New tower
Max feed rate	27 000-28 000 b/d	30 000-31 000 b/d
Pressure drop	20.0-23.0 mmHg	10.0-11.5 mmHg
Feed temperature	750-760°F	725-740°F
HVGO quality (MCR)	0.5-0.55 wt%	0.25-0.27 wt%
Wash oil rate	← Unchanged	→
# of runs	1 (4 years)	2 and going (7 years+)

Table 1

730°F. This equates to a reduction in duty of 8.5 MM BTU/h (12.5%). This saving in energy can be valued at approximately C$15 000/month considering a C$2.50/MM BTU cost (similar to natural gas in the region).

Product quality and wash bed reliability

Product quality and wash bed reliability often go hand in hand. When wash bed performance begins to suffer, the results are generally witnessed in the HVGO bed above, where entrained contaminants produce off-spec product. Product contaminants such as MCR and heavy metals can be minimised through adjustments made in the operating conditions as well as with the technology used in the flash zone and wash bed.

Increased feed temperatures have a direct influence on contaminants in the HVGO. As feed temperatures increase, thermal cracking increases, generating harmful products such as carbon residue and corrosive non-condensable gases, translating to lost crude product yield.[11] Reducing pressure drop across the tower allows operations the flexibility to reduce feed temperatures without compromising product recoveries.

With both the operational and equipment upgrades, the wash bed performance improved significantly, and is substantiated through analysis of the HVGO product draw. These improvements were not made at the expense of

Reducing pressure drop across the tower allows operations the flexibility to reduce feed temperatures without compromising product recoveries

increasing wash oil, as this was held constant between each tower configuration, even though the new tower was handling up to 10% additional throughput. As a result of the reduction in feed temperature, the installation of the Enhanced Vapor Horn, and the use of new severe service grid packing, the MCR values in the HVGO reduced significantly (see **Figure 7**). Also, the HVGO ASTM D1160 95% cut point and final boiling point (FBP) alludes to wash bed performance issues in the old tower, as these were in the range of 1040-1050°F and 1070-1080°F. In the new tower design, there is a 10°F drop for both HVGO 95% cut point and FBP ranges – a sign that heavier components were being entrained in the old tower configuration.

A summary of operating conditions and performance characteristics is shown in **Table 1**. The old tower design had undergone one turnaround, in which the wash bed packing had to be replaced. The new tower is approaching the mid-point of its second five-year run with the same internals. The user does not have any concerns with the wash bed performance so far and, if everything goes smoothly, will be leaving the wash bed as it is for its third five-year run.

Conclusion

Different strategies can be employed when operating a wash bed. One extreme would be to push the tower as hard as possible and minimise the wash oil usage to the point that it is approaching failure just in time for a turnaround. Treating the wash bed packing as a consumable can be challenging as it requires a detailed approach to monitoring the condition of the wash bed and its coking rate. However, if done successfully, the rewards would be in maximising VGO product.[12] At the other end of the spectrum, a more comfortable operating approach allows for the re-use of wash bed internals through multiple turnarounds. The industry norm is typically somewhere in the middle – however, having a well designed wash bed is a plus regardless of the operator's risk tolerance.

This project demonstrated the benefits an operating company can obtain when taking advantage of a maintenance turnaround as an opportunity to use modern grid and structured packings. In vacuum crude oil distillation specifically, the potential for performance gains is possible due to the role that Proflux severe service grid plays in maintaining a low column pressure drop and de-entraining feed contaminants in the wash bed. The annual cost savings realised from the reduced feed temperature and lower overall pressure drop are nearly C$0.5 million, in addition to the improvement in operating margin obtained with a 10% increase in throughput.

PROFLUX, FLEXIPAC and Enhanced Vapor Horn are marks of Koch-Glitsch.

Acknowledgement

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