Improved stripper efficiency raises upgrader production

Revamping a heavy oil upgrader's steam stripping tower increased tray efficiency and achieved record throughput

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Suncor Energy is Canada's leading integrated energy company, with a focus in the oil sands, and has been involved in heavy oil extraction and refining dating back to the Great Canadian Oil Sands project in the 1960s. At the time this was the largest private investment in Canadian history. The Base Plant Upgrader, located in Fort McMurray, Alberta, has been in operation since 1967.

This article reviews the use of Superfrac trays in a successful revamp of an underperforming steam stripping tower in the Base Plant. The increased tray efficiency provided by the trays allowed for debottlenecking of the downstream vacuum overhead condenser system, resulting in an overall upgrader production increase of 5% and record throughput.

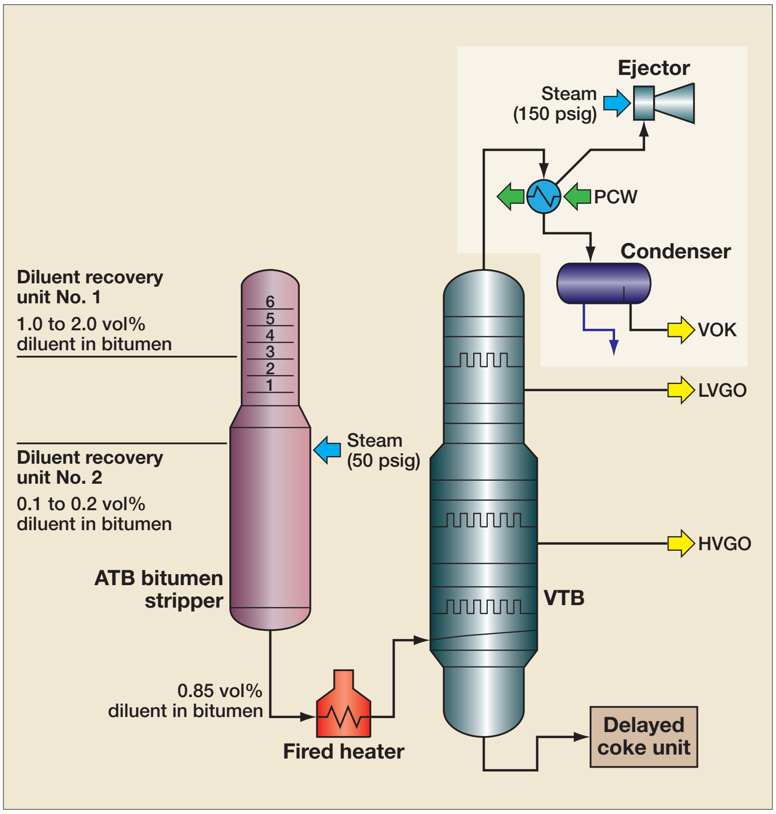

Figure 1 Simplified process flow diagram (the pink tower is the steam stripping tower)

Background

Suncor's Base Plant Upgrader operation recovers diluent from diluted bitumen feed in diluent recovery units (DRU). The recovered diluent is then sent to a vacuum distillation unit (VDU). In 1998, a steam stripping tower with six trays was put into operation in an effort to minimise diluent slip from the DRU distillation tower and to reduce the load on the downstream vacuum overhead ejectors (see **Figure 1**). The vacuum tower is a dry tower design with a pre-condenser and is particularly sensitive to slippage of light naphtha (diluent).

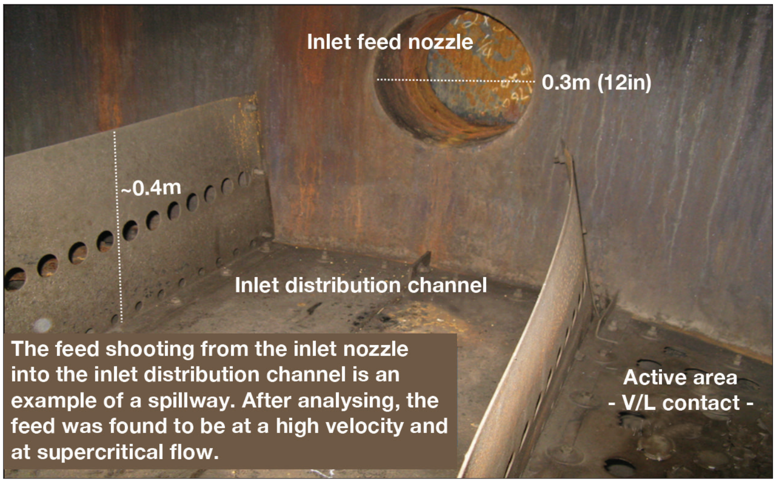

Figure 2 Existing liquid feed arrangement

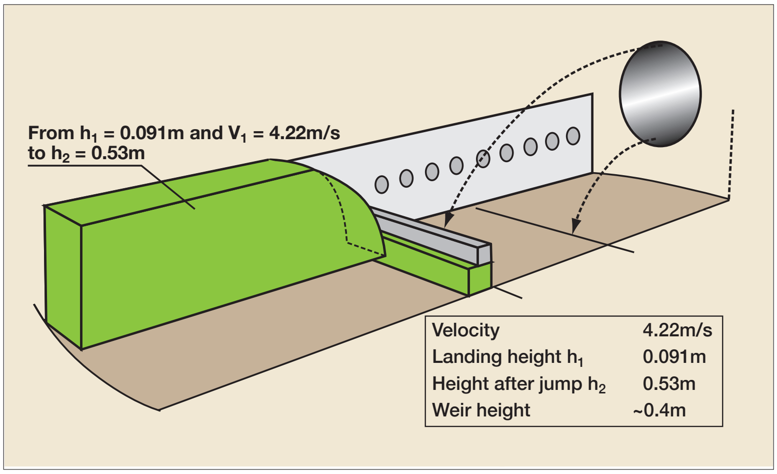

Figure 3 Hydraulic jump calculations for existing liquid inlet

Performance of the stripper has been poor from the outset, with very little, if any, stripping being measured. Operations saw a diluent slip of 0.85%, corresponding to 857 b/d diluent slipped to the vacuum unit and recovered in the overhead system as vacuum overhead kero (VOK). The pre-condenser is not designed to condense this amount of light naphtha, with most of it slipping to the first-stage ejector and impacting vacuum. As a result, the existing overhead system places a constraint on total upgrader production.

Technical evaluation

In 2012, Suncor and Koch-Glitsch performed a technical evaluation of the tower with a view towards improving performance. A simulation study was done to assess the

Figure 4 New liquid feed distributor

impact of improving the stripping tray efficiency on the overall unit. The existing tray efficiency (~0%) was modelled by treating the stripping section as a flash column with no steam flow. In addition, a typical efficiency range for this service was modelled. The evaluation also reviewed the stripping tower operation and existing mass transfer equipment, identifying serious operational and design issues. Both the bitumen and steam feeds were found to be areas of concern.

The existing bitumen feed distributor is a 12in (305mm) open nozzle flowing into a centre false downcomer above the top tray (see **Figure 2**). The existing nozzle was undersized for this type of feed arrangement, with a false downcomer inlet velocity of nearly 14 ft/s (4.2 m/s). With this existing arrangement, hydraulic calculations showed that the jump height would far exceed the open channel (false downcomer) height. The calculated liquid height after the first jump was 20.9in (0.53m), which is well in excess of the 16in (0.4m) tall false downcomer (**Figure 3**). As a result of the hydraulic jump, the performance of the top tray would be poor due to the majority of the liquid short-circuiting the tray flow path.

To improve liquid distribution, a perforated feed pipe distributor was installed (see **Figure 4**). The use of a feed pipe would ensure that all feed liquid would remain within the false downcomer, and that there would be uniform distribution feeding onto both active area panels. A new false downcomer was designed to match the inlet panel dimensions of the Superfrac tray. To minimise the turnaround time, a stab-in arrangement was used to eliminate welding to the vessel wall.

The existing steam distributor was modified from a V-baffle deflector plate to a perforated pipe distributor (see **Figure 5**). While the velocity through the nozzle is relatively low, it was determined that the increase in pressure drop associated with flow through an orifice would help ensure uniform vapour flow to both active area panels of the bottom tray. The new feed distributor design eliminated welding to the vessel wall.

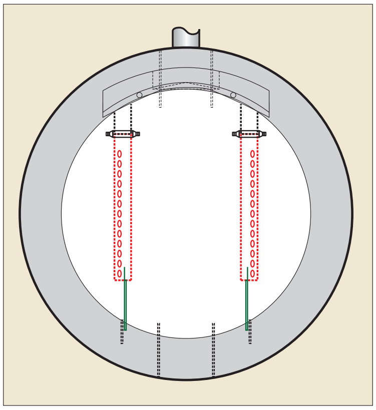

Figure 5 Modified steam distributor

Tray efficiency

Inherently low tray efficiency in the stripping section of heavy oil towers has been well documented in previous literature.[1,2] A well designed tray for this service could obtain upwards of 25-40% efficiency; however, values below 10% are common.[3,4] A typical grassroots project will specify 4-8 trays based on an assumed 25% efficiency.

There are many factors that contribute to stripping of hydrocarbons having an inherently low efficiency, including:

- Insufficient steam/oil ratio
- High relative volatility
- High liquid viscosity.

Because grassroots projects will often have multiple equipment vendors bidding, an effort is made to standardise the offering and compare based on price, working off little more than data sheets, and without proper review of overall tower layout, diameter and feed arrangements. This process leads to inadequate communication between the selected vendor and the EPC company, resulting in poor equipment selection and inadequate design. Inherent low tray efficiency is further compromised.

The following are common design errors that could lead to reduced efficiency:

- Having the same diameter for the flash zone and stripping section, which leads to severely oversized trays
- Applying a single valve layout (open area) across the entire zone even though there are large changes in vapour flow from tray to tray
- Poor liquid feed distribution to the top stripping tray
- Poor steam distribution under the bottom stripping tray
- Fouling that can negatively affect performance if not accounted for in tray design (valve selection, orifice size, and so on)
- Tray mechanical design not suitable for potential upsets, which can result in loss of trays.

Applying the high performance Superfrac tray to heavy hydrocarbon stripping

High performance trays traditionally are only considered for increasing capacity, with a reluctance to use in grassroots projects for the majority of

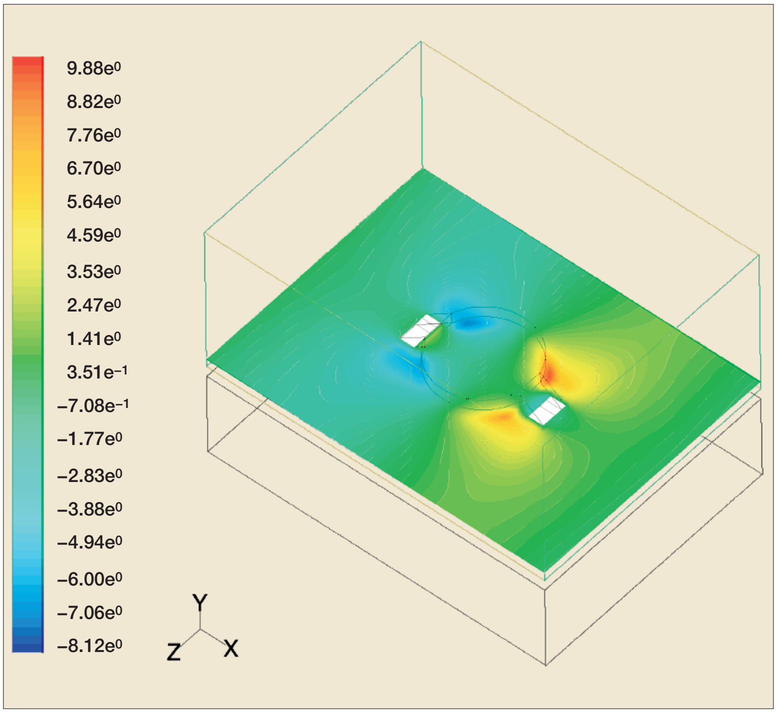

Figure 6 Computational fluid dynamics (CFD) study for single VG-0 valve

Diluent slip vs tray efficiency comparison

Stripping efficiency	Diluent slip, vol%	Diluent to pre-condenser, BPH	Reduction in diluent slip, BPH
0%[1]	0.850	36	-
20%	0.796	33	3
25%[2]	0.750	32	4
30%	0.696	29	7
37.5%[3]	0.650	27	9

1: Current operation 2: Estimated for conventional tray 3: Estimated for Superfrac tray

Table 1

refinery columns. However, application of technology should be based on economic impact. A hydrocarbon stripping tower is the perfect example of this concept. From a purely hydraulic capacity standpoint, it is rare that a high capacity tray is justified. That being said, if the maximum obtainable tray efficiency is considered when doing the grassroots design, their use would be much more commonplace. While the operating point of a typical hydrocarbon stripper tray is in the range of 30-60% flood (including the tower in this article), the following conditions conspire to reduce the efficiency of conventional trays:

- Long residence times and stagnant areas at high liquid flow rates resulting from use of conventional tray technology
- Excessive weir loadings
- High downcomer exit velocities leading to hydraulic jump across the active area
- Short flow path lengths through the use of large, straight downcomers
- Fouling due to coke formation, which is a function of long residence times.

Superfrac tray technology allows for a customised tray design, selecting design features that best address the liquid and vapour flow regime of a given application. In this tower, the use of high capacity rather than conventional trays would allow us to maximise the stripping efficiency using design techniques that will maximise plug flow, give a more uniform horizontal liquid velocity profile and minimise stagnant zones. This was accomplished through proprietary design features, including:

- Multi-chordal downcomers to maximise flow path length
- Optimised quantity and location of push valves and other directional flow devices (see **Figure 6**)
- Anti-fouling and mechanical upset resistant tray features.

Improvements in tray efficiency that increase recovery of a higher value product or lead to a reduction in energy consumption can have fast payback. Modelling the stripping section using actual trays rather than theoretical stages can provide clarity to the impact of the efficiency of various tray types. While an assumed efficiency of 25% for a well designed conventional cross-flow tray is reasonable, a Superfrac tray can provide an additional increase in efficiency of 10% over any other cross-flow tray on the market. This has been proven at the Fractionation Research Inc. (FRI) test facility using light hydrocarbons,[4] in a low relative volatility petrochemical application,[5] and in a heavy hydrocarbon stripping application similar to the one discussed in this article.[6] Koch-Glitsch has successfully used the Superfrac tray technology in over 1700 columns worldwide.

For this application, the corresponding reduction in diluent slip proved to be attractive as it would allow for

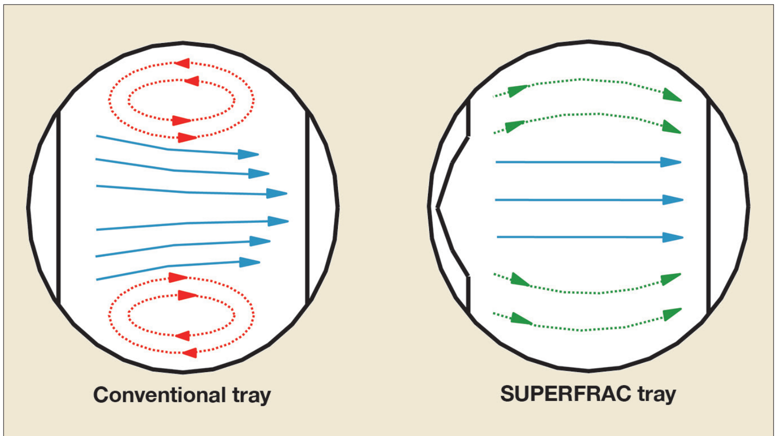

Figure 7 Liquid flow distribution comparison between conventional trays and multi-chordal Superfrac tray

debottlenecking of the upgrader (see **Table 1**).

Vacuum feed stripper – operating conditions

The Suncor vacuum feed stripper is a 10ft-0in (3048mm) ID column equipped with six two-pass trays. The L/V mass flow ratio ranges from 23-100 across the stripping section, with the most severe ratio occurring at the bottom tray. The weir load on the trays is very high, at upwards of 230 gpm/ft (171 m^3/hr/m). Although there is not a defined maximum value for weir load, various tray vendor design manuals recommend increasing the number of passes when weir loads exceed a range of 84-156 gpm/ft (62-116 m^3/hr/m)[8]. However, many stripping columns with two-pass trays run at excessive weir loads to avoid the complications of having to use a three-pass tray at low vapour velocity.

Results

The focus of the revamp was to increase the amount of light hydrocarbon stripped; therefore, special attention was paid to employing design techniques that would increase tray efficiency. The use of a vapour tunnel downcomer resulted in the flow path length increasing by 10.5in (267mm). While the number of eruption pools on the tray is low due to the tower operating pressure, the net effect of an increase in flow path length is still positive. Where the existing trays employed an economical design with a single valve open area, the new trays were designed with Minivalve fixed valves, with the open area on each tray varying to match the changing vapour profile. The actual tray vapour and liquid loadings were determined to optimise the pressure drop across the valves on each tray. This is an important step to take for this application, as the large change in vapour rate across the section is not captured with precision using only equilibrium stage outputs. Proprietary design features were employed to minimise stagnant areas and ensure good liquid distribution. Please refer to the 'liquid flow pattern comparison' insert for more discussion regarding the influence of flow enhancement devices on residence time. Lastly, because the stripping section is prone to upset, the trays' mechanical features were upgraded to be able to withstand a 2 psi uplift condition. While it is difficult to quantify the individual impact of each design change, the cumulative effect resulted in a major improvement in performance, with the Superfrac tray operating at around 37.5% efficiency post-revamp.

A summary of the performance of the tower pre-revamp and post-revamp is presented in **Table 2**.

Tower performance pre- and post-revamp

	Before	After
Tray type	Conventional	Superfrac tray
Deck type	Moveable valves	Minivalve fixed valves
Stripping steam	23 000 lb/hr (10 433 kg/hr)	23 000 lb/hr (10 433 kg/hr)
Flow path length	24.3in (617mm)	34.8in (884mm)
Open area, %	Uniform, 10%	Variable, max 6.5%
Tray mechanical design	Standard	2 psi uplift
Tray efficiency	~ 0%	37.5%
VOK to pre-condenser	182 BPH	150 BPH

Table 2

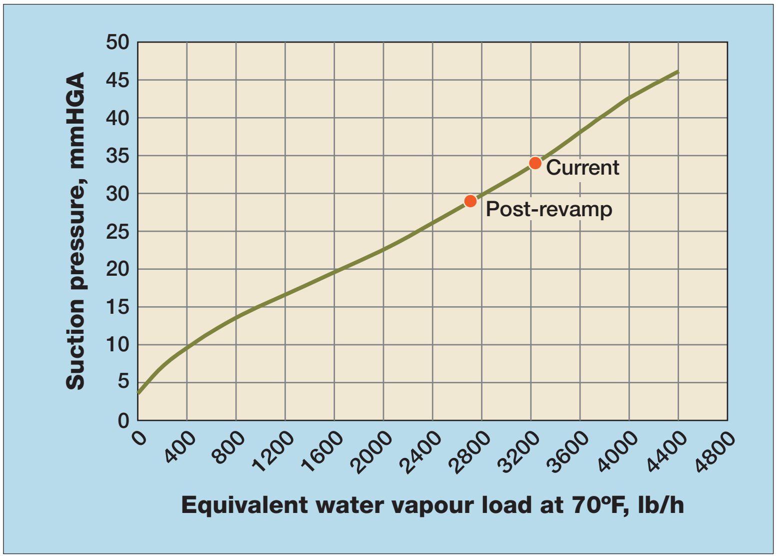

Figure 8 Vacuum overhead pressure comparison

Air/water residence time test data for two-pass trays (seconds)		
	Conventional	Superfrac tray
Flow to centre downcomer	36.0s	12.0s
Flow to side downcomer	7.0s	9.0s
Residence time ratio	5.1	1.3

Table 3

Performance after modification

- Diluent slip to the pre-condenser reduced by 8 bph
- VOK reduced by 32 bph
- Vapour load to the vacuum first stage ejector reduced by 20%; the vacuum tower operates at record lower vacuum (see **Figure 8**)
- Vacuum lift improved by 2% vol
- Upgrader reached record high production, with an increase of up to 5% compared to pre-revamp operation.

Steam stripping tray design – keys to success

- Consider tray geometry issues that arise when dealing with high liquid to vapour mass flow ratios, especially for multi-pass trays
- Avoid using parallel baffles to reduce the effective flow path width in fouling applications
- Consider the use of an internal can or shroud when revamping a tower that has the same diameter in the stripping section and flash zone (This was not necessary in this case, as the Suncor ATB bitumen stripper is a separate, dedicated, reduced diameter tower.)
- Do not rely solely on simulator equilibrium stage data to perform hydraulic design calculations
    - Simulations typically use 1-2 theoretical stages to represent 4-8 actual trays
    - There is a large change in vapour flow from stage to stage that needs to be accounted for when designing each physical tray
    - Koch-Glitsch has in-house knowledge to determine vapour and liquid load at each physical tray
- Superfrac tray technology will maximise the strip-out rate for a given steam/oil ratio.

Conclusion

Optimised design aspects applied at the grassroots project could have been achieved by proper joint design review with participation from EPC, vendors and owner's engineers. All of the design concepts presented, and technology used, have been well established in the marketplace. From a technical standpoint, due attention should be paid to check the feed device design and ensure proper tray selection to deal with heavy hydrocarbon stripping services. From a commercial standpoint, effective communication among EPC and equipment vendors is critical to ensure a sound engineering design.

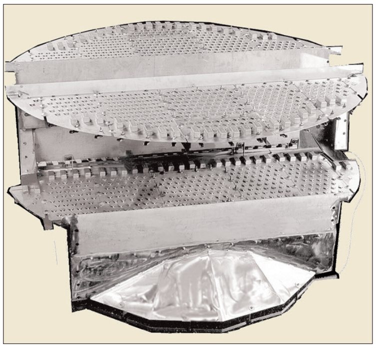

Figure 9 Two-pass Superfrac tray

Liquid flow pattern comparison and its impact on fouling potential

Koch-Glitsch has previously studied two-pass tray liquid flow profiles using its 7ft-0in (2134mm) Air/Water Pilot Plant column. This column is of a similar size to the Suncor vacuum stripper and was tested under similar weir loadings. A dye was injected into the water to measure the residence time for both flow directions using a conventional valve tray and the Superfrac tray (see **Figure 9**).

The results of the test show a large differential in residence time between side and centre flow conventional trays due to stagnant zones and retrograde flow (see **Table 3**). Conversely, the Superfrac tray uses push valves and other directional devices to provide a more uniform velocity profile. Stagnant zones around the periphery of the side flow tray are minimised, as shown by the large reduction in residence time of the Superfrac tray versus a conventional tray for side flow.

Stagnant liquid pools promote multiple types of fouling mechanisms including thermal cracking (coking), solids deposition and polymerisation. In some heavily fouling refinery applications, the use of baffle trays is preferred due to their low residence time and lack of stagnant zones.[9] However, baffle trays are notoriously low efficiency devices and require high vapour velocities (Cs >0.2 ft/s (0.06 m/s)) to drive mass transfer. Typically a heavy hydrocarbon stripping section has low vapour velocities (Cs ~0.02-0.10 ft/s (0.006-0.03 m/s)), and a baffle tray may obtain only a quarter of the efficiency of a well designed cross-flow tray. Furthermore, they are not fouling-proof, as there have been multiple cases reported of coke formation occurring on the underside of baffle trays.[10]

We would suggest that the flow enhancement devices that are part of the Superfrac tray toolbox would allow for the best of both – maximisation of tray efficiency while employing a design that minimises the fouling potential resulting from stagnant liquid zones.

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