Debottlenecking a refinery fuel gas absorber

A refinery fuel gas absorber was revamped to increase capacity while maintaining H_2S in the product well below specification

DARIUS REMESAT *Koch-Glitsch Canada*
MICHAEL BESHARA *Irving Oil Refining*

The purpose of a fuel gas absorber is to selectively remove components, primarily H_2S and to a lesser extent CO_2, using a solvent (amines) that absorbs these specific components. The product fuel gas can then be burned with reduced environmental impact.

One of the fuel gas absorbers at the Irving Oil Refinery in Saint John, New Brunswick, Canada, had a maximum sustainable rate of approximately 980 mscfh. Increasing the gas flow rate beyond this point had resulted in increased column differential pressure (an indicator of the onset of column flooding) and amine carryover (increasing operating cost and operational challenges). This column was limiting the ability to increase overall plant capacity, since Irving Oil Refining has strict operating requirements for environmental stewardship.

Design objectives and path

Irving Oil Refining wanted to process as much material through the column while maintaining product quality (H_2S in fuel gas not to exceed 50 ppm[v]) with minimum modifications to the plant during a planned shutdown in the autumn of 2009. It considered multiple options to debottleneck the column and settled on studying changes to column internals for increased throughput while maintaining or improving product quality. The newly designed high-performance trays would need to address the following criteria:

- The new design will take into consideration the foaming tendency of amine
- The expected rich amine loading shall not exceed API guidelines for carbon steel in specific amine service at the anticipated temperatures.

Based on past successes with high-capacity trays at the site and from other references,[1,2,3] Irving Oil Refining commissioned Koch-Glitsch to:

- Model the operation of the fuel gas absorber (C14001) and validate current operation versus design, based on a comprehensive unit test run conducted in January 2009 and on existing internal drawings
- Recommend and model internal changes to increase column capacity while retaining 60% turndown capability (maximum throughput with given constraints is desired)
- Limit the extent of modifications to reusing the existing tray ring supports, including downcomers. Tray number and spacing to be retained, with 25 trays in total at 2ft spacing
- Retain current absorbent (amine at 25–30 wt%) and limit the flow and temperature that can be provided with existing equipment, such as recirculation pumps and exchangers
- Revamp work to fit within the set turnaround schedule.

Numerous programs are available to assist in representing a column that uses amines to remove H_2S and CO_2 from fuel gas streams

Methods and tools

The first and most important step in any revamp study is to generate an accurate characterisation of the process.[3] The test run performed in January 2009 gathered data using calibrated instrumentation, creating a closed mass and energy balance. The next step is to take the data from the test run and to create a representative model of the plant that can be used to predict the future performance with the new tower internals.

Choice of modelling program

Numerous programs are available to assist in representing a column that uses amines to remove H_2S and CO_2 from fuel gas streams. From the authors' experience, rate-based models provide the best overall representation for new columns in this service, especially for packed columns. As an example, the rigorous, mass transfer rate approach used for all column calculations eliminates the need for empirical adjustments to simulate new applications correctly.

However, for column revamps, especially with trays, the use of an equilibrium-based model that has the necessary, proven adjustable parameters from operating experience is a suitable alternative to rate-based models, provided the necessary specific equipment characteristics of the high-capacity tray can be appropriately represented in the simulation model.

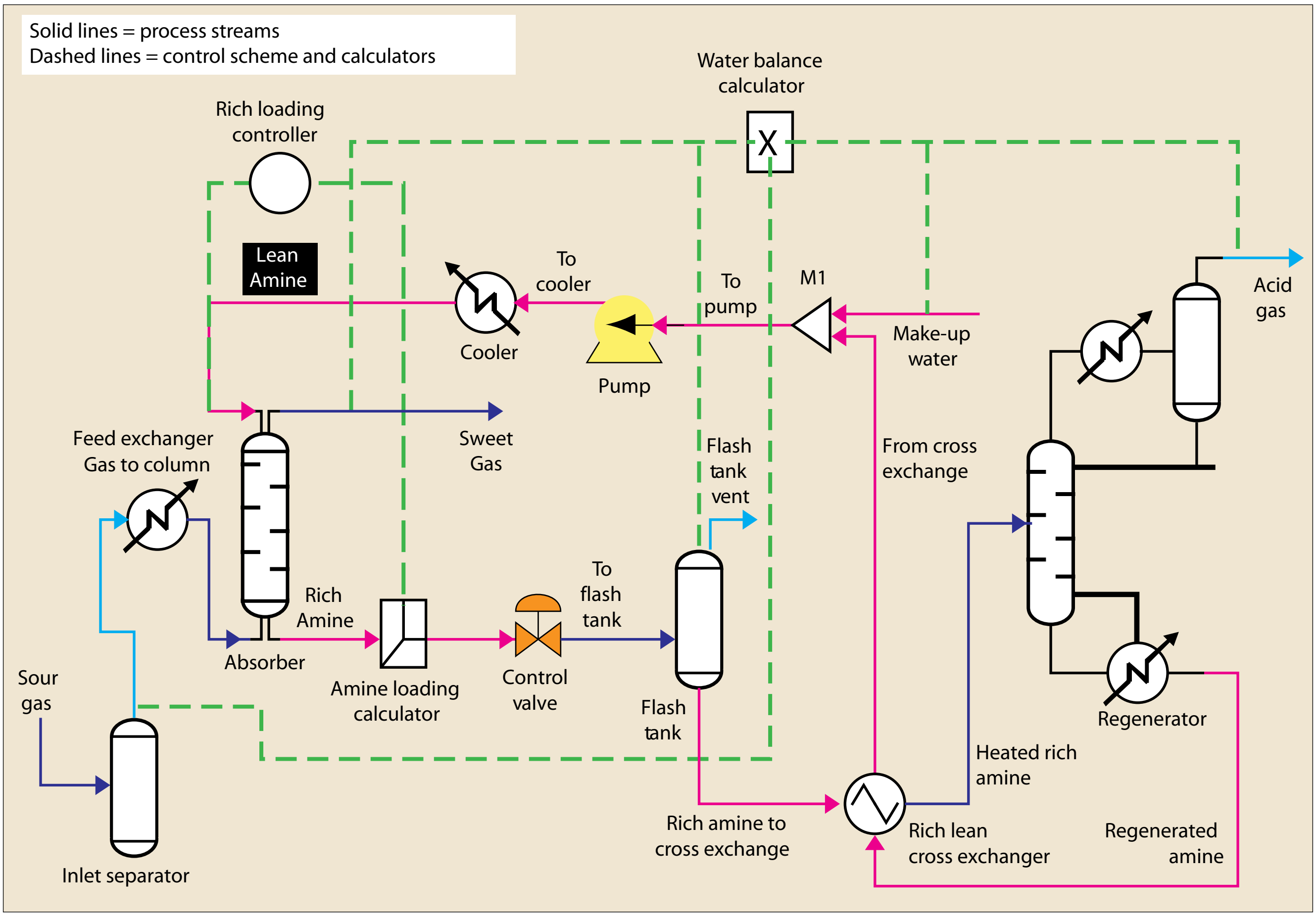

Figure 1 Primary simulation topology used

The simulation user needs to be sensitive to the fact that even the most sophisticated equilibrium-stage model uses only two of five elements employed in the rate-based model; namely, mass and energy balances around an entire ideal stage, plus thermodynamic-phase equilibrium. Programs that include reaction kinetics by empirical modelling via an adjustable parameter (H_2S and CO_2 tray efficiencies and/or liquid residence times) that forces the simulation to reproduce a conventionally operated column's treated gas composition can only be effective if comprehensive operating experience has been gained and validated. In addition, the equilibrium-based program should have a reliable feature to include tray efficiencies to convert ideal stages into actual trays so that the tray characteristics can be represented pre- and post-revamp. VMGSim[4] uses specific mass transfer multipliers that can be tuned to match plant data and provides the ability to use tray and component efficiencies in the model. As a result, VMGSim has been used successfully to model existing plants and to accurately predict tray revamps in this service.

Of note, the solvents used in amine absorbers are rarely pure solutions of water and amine. Contaminants entering with the feed gas or makeup water can change the chemistry of the solvent significantly. This can both worsen and, in some cases, enhance the absorption efficiency. To improve the accuracy of the simulation, the impact of heat-stable salts and other contaminants on the performance of the amine should be factored into the evaluation.

VMGSim results — increased flow through plant

Case (constant lean amine, %)	H_2S, ppm	H_2S/amine, mol/mol	Acid gas/amine, mol/mol	Lean amine, BPD
920 mscfh - plant data	5	0.49	0.573	10 500
980 mscfh - 5 ppm H_2S	4.88	0.49	0.569	11 200
980 mscfh - max H_2S in amine	22	0.527	0.605	10 500
1175 mscfh - 5 ppm H_2S	5.27	0.49	0.562	13 600
1175 mscfh - max H_2S in amine	17.7	0.523	0.6	12 700

Table 1

Process evaluation

A simulation using VMGSim (equilibrium-based model) with an appropriate amine thermodynamic package (validated with both Protreat and Ratefrac rate-based models) was developed based on plant data provided from January 2009. The fuel gas absorber was running at ~921 mscfh charge to the unit. Simulation cases were run at:

- 921 mscfh to match plant data
- 980 mscfh demonstrated sustainable limit of absorber column performance
- 1175 mscfh based on expected

acid gas loading limit of 0.6 (moles acid gas/moles amine).

Acid gas is primarily H_2S and CO_2. The hydraulic limit of a proposed tray change would be 1234 mscfh, which is 5% above the expected revamp design value of 1175 kscfh. The primary objective of the simulation work was to determine what maximum flow the absorber could handle within the existing 5ft (1.5m) shell diameter and the supporting equipment (coolers and pumps) while still meeting desired product specifications. The regenerator was included in the evaluation and simulation to provide a closer representation of the plant (see Figure 1) and to better extrapolate the performance of the unit at higher rates.

In addition to tray modifications, process modifications can be considered (see Figure 2) to increase further the capacity of the fuel gas absorber. An approximately 4% decrease in amine flows for the same outlet H_2S ppmv value can be realised by increasing the lean amine concentration from 23.5–25.5%.

Simulation results (possible increased charge rates)

Taking the base representative simulation (VMGSim) for the 921 mscfh plant data of January 2009, which was within 5% of the plant data, and adhering to the design criteria, the following cases were reviewed:

- Maintaining sweet gas H_2S at approximately 5 ppm(v)
- Minimising lean amine rate to a maximum of 0.6 (mol acid gas/mol amine) acid gas loading.

Feed rates of 980 and 1175 mscfh were used in the evaluation.

The reduced amine circulation was reviewed to determine how much more capacity the tower had by offloading liquid to allow more vapour while still meeting minimum product specifications. The cases used the identical thermodynamics and tuning developed to match the plant data.

The 980 mscfh simulation was developed to determine a baseline for the limit of the trays, because operational feedback indicated that amine carryover began to occur at this feed rate. The 1175 mscfh case simulation was developed to reflect the expected maximum feed rate that the absorber could handle hydraulically (after a revamp to higher capacity internals). For the 1175 mscfh case, the total acid gas load (mol acid gas/mol amine) of 0.6 was the limiting process variable when trying to keep amine flow to a minimum. Table 1 shows the simulation output results for the four cases evaluated. The sweet gas H_2S composition is below the specification of 50 ppm(v) for all cases. As noted previously, the limiting parameter was the acid gas loading of 0.6 for the existing case and the expected revamp case.

The impact of heat-stable salts and other contaminants on the performance of the amine should be factored into the evaluation

Tray hydraulics evaluation for 920 and 980 mscfh

Trays	Top	Top	Btm	Btm
Description	920 mscfh	980 mscfh	920 mscfh	980 mscfh
System factor	0.83	0.83	0.83	0.83
Hydraulic data				
Jet flood, %	85	93	89	100
Downcomer flood, %	41	44	41	44
Downcomer backup, in liq	9.2	10.0	9.6	10.7
Total tray, ΔP * in liq	5.9	6.7	6.4	7.5
Total tray, ΔP * mm Hg	11.3	12.3	12.1	13.7

Table 2

Evaluation of existing internals

Using the simulation output results for the 920 and 980 mscfh cases, the existing tray internals were evaluated. A system factor (foaming) of 0.83 was used in calculating the tray performance. From past experience, a typical system factor of 0.73–0.85 for heavy foaming systems such as amine absorbers is applied. Using 0.83 for the study was well within what is expected for this service and provided a representative match to the plant performance. Table 2 shows the tray evaluation results for the 920 and 980 mscfh cases. It appears that the primary limit on the trays was the active area, with a jet flood of 100% for the 980 mscfh case. Such a high jet flood value matches with the observation of amine carryover due to high froth heights on the trays. From the plant data at 980 kscfh and the hydraulic evaluation, trays may not still be at incipient point of flood, yet operation and evaluation indicates that entrainment may be the primary issue and thus this phenomenon needs to be

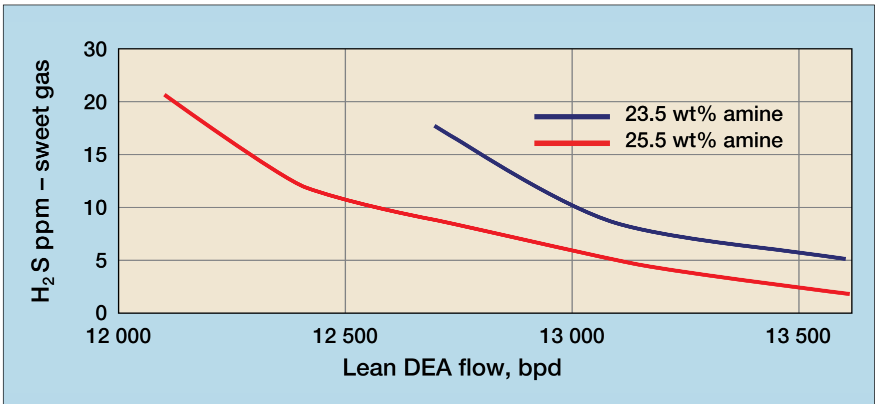

Figure 2 Amine concentration vs product H_2S purity @ 1175 mscfh plant feed rates

Debottleneck case (1175 and 1234 mscfh) high-performance tray hydraulic rating

Trays	Top	Top	Mid	Mid	Btm	Btm
Description	1175 mscfh	1175+ 5%	1175 mscfh	1175+ 5%	1175 mscfh	1175+ 5%
System factor	0.83	0.83	0.83	0.75	0.83	0.83
Hydraulic data						
Jet flood, %	75	79	75	78	81	85
Downcomer flood, %	79	83	76	80	81	85
Downcomer backup, in liq	6.7	6.9	6.6	6.8	6.9	7.2
Total tray, ΔP * in liq	3.5	3.6	3.4	3.6	3.6	3.8
Total tray, ΔP * mm Hg	6.6	6.8	6.5	6.7	6.7	7.0

Table 3

considered during the revamp design.

Revamp considerations

By using a high-performance tray device, the increase in capacity over the 980 mscfh current maximum was determined to be 1175 mscfh (an increase of 20% over current maximum sustainable rates). The revamp product type chosen maintained the overhead H_2S to below 50 ppm (v) and the acid gas loading on the amine below an acceptable maximum (0.6 mol acid gas/1.0 mol rich amine).

Using the information from Tables 1 (to set the column process performance) and 2 (to set the internals hydraulics performance), a debottleneck evaluation resulted in the recommendation that the column could favourably (that is, maintain H_2S on specification) support a process gas feed rate of up to 1175 mscfh.

Superfrac trays with valve push features and enhanced contact (for example, the Minivalve movable valve - MV-1) and enhanced downcomers were considered for this revamp. These trays, illustrated in Figure 3, reduce the dead space on trays to increase capacity yet still maintain the necessary contact time (with bubble promoters and other features) between the amine and gas to ensure optimum absorption occurs.

Superfrac trays reduce the dead space on trays to increase capacity yet still maintain the necessary contact time between the amine and gas

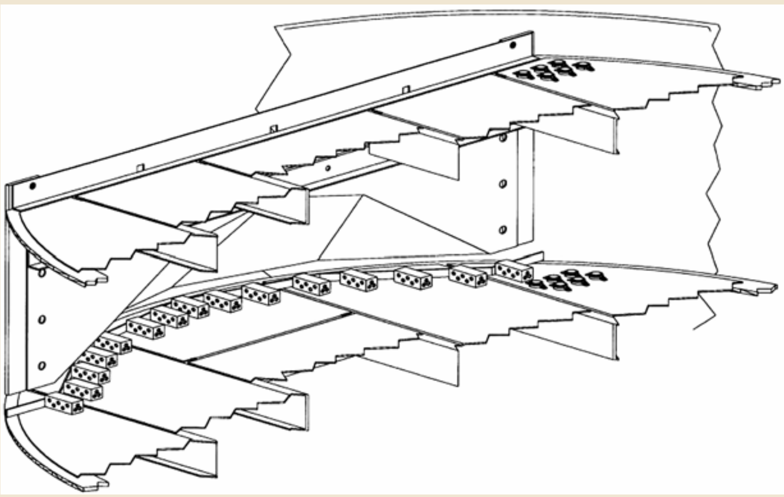

Figure 3 Sketch of Superfrac tray setup

Tray geometry

	Existing	Proposed
Net top DC area, ft^2	3.5	2.7
Active area, ft^2	12.7	15.8
Valve type	Sieve	MV-1

Table 4

Tracerco scan results[5] summary

Tray # (1-bottom)	Tray clear liquid height, in	Froth height, in
11–25	2–3	8–9
1–10	2	7–9

Table 5

Table 3 shows the results from the tower internals hydraulic analysis using high-performance trays. Using 85% for both downcomer and jet flood limits in a revamp, the hydraulic limit is at 5% above the 1175 mscfh revamp design feed rate, or 1234 mscfh. Factoring in inaccuracies in field measurements, fidelity of the simulation and hydraulic calculations, the tower limit should be expected to easily handle 1175 mscfh of feed and meet sweet gas product specification.

To meet the increased flows, the downcomer size and shape would need to be optimised, along with changes to the active area, with the use of Minivalve high-performance valves included in the active area changes. Table 4 shows a generic comparison of the characteristics of the existing and proposed tray designs.

The tray evaluation was based on reusing all existing tower attachments, with no welding required on the vessel shell or tower attachments to meet the shutdown schedule. Since the existing trays are one-pass, cross-flow trays, any modification to increase capacity preferably should be based on cross-flow trays so that the existing tower attachments can be reused. The foaming factor for the revamped tray evaluation will remain at 0.83 due to uncertainty in the level of foaming in the future. If the same conditions persist after the revamp, the Superfrac trays using movable valves could be evaluated

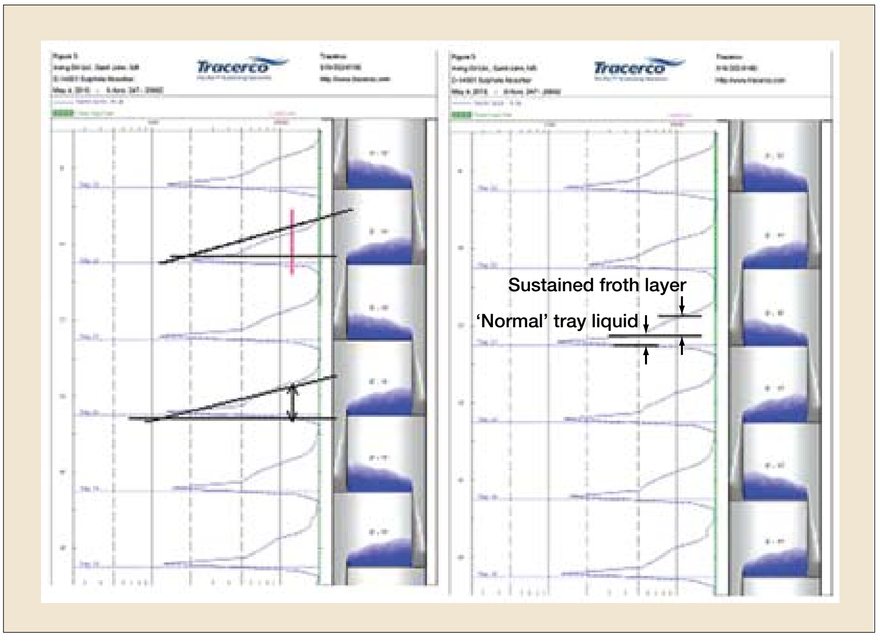

Figure 4 Excerpt of Tracerco[5] gamma scan of the tower

with a foaming factor of 0.9 (in other words, a further increase of capacity of around 8%, or up to 1460 mscfh feed rate). The features of the MV-1 valve's active area are configured in such a manner as to reduce the promotion of foam in this service. Since a definitive analysis of foaming tendencies was not performed, the foaming benefit was not included in the revamp's design expectations.

Post-revamp test results

A test run and tower scan were performed in May 2010, to validate the performance of the column post-revamp. Since startup post-revamp, the column feed had reached up to 1160 mscfh at 20 wppm H_2S with no operational issues. Using a material balance with sulphur, the column flow rate for the test run was calculated/confirmed to be in the range 1150–1170 mscfh, with no indication of amine carryover and a sweet gas H_2S concentration of 18–20 wpmw. The VMGSim simulation was updated and corroborated the post-revamp plant data. The tower scan indicated that, at these rates, there was still ample room on the trays to handle flows of up to 1340 mscfh. Table 5 shows the calculated activity on the trays in the form of clear liquid height on the tray and froth height. Adding these two values together gives the total height occupied by the liquid (clear and aerated) on the tray deck, which is in the 9–12in (22.5–30cm) range across the tower. Using the same process data from the test run in the simulation to generate the internal loads, the KG-Design hydraulic rating program from Koch-Glitsch provided 70% jet flood results. Both values, the froth height and the jet flood, would tend to indicate that the trays still have room to process more material.

Figure 4 shows an excerpt from the gamma scan of the top section of trays, performed during the test run, capturing the level of activity on the high-performance trays and providing an indication of how much room is left hydraulically on the tray. Tracerco's mid-peak calculation is shown on the left, and the tray and froth height calculation is shown on the right of Figure 4. These tools help to convey how the high-performance tray functions at such high rates. Even factoring in the potential high foam generation, there appears to be approximately 45–50% disengaging space still available for further processing of gas above the test run rates.

The plant test run values, post-revamp simulation, tower scan and hydraulics evaluation appear to be in line with each other, giving similar results. Using the scan and plant data, and calculating the trays at 80% jet flood, the flow to the column can safely be 15% more than the test run, which is approximately 1340 mscfh.

The expected design flow rate post-revamp was set to 1234 mscfh at 20 wppm H_2S (85% jet and downcomer flood), with reasonable expectations of reaching up to 1351 mscfh at the amine carryover point. If foaming/froth is still proportional as the rates increase further, based on the test run evaluation, an upper rate of 1460 mscfh through the tower is possible.

Performance likely better than expected

A plausible reason for why the performance of the revamp trays is currently better than expected with the test run rates was that the full benefit of the Minivalve valve to mitigate foaming (over large sieve and large valve trays) in the column was not factored into the revamp

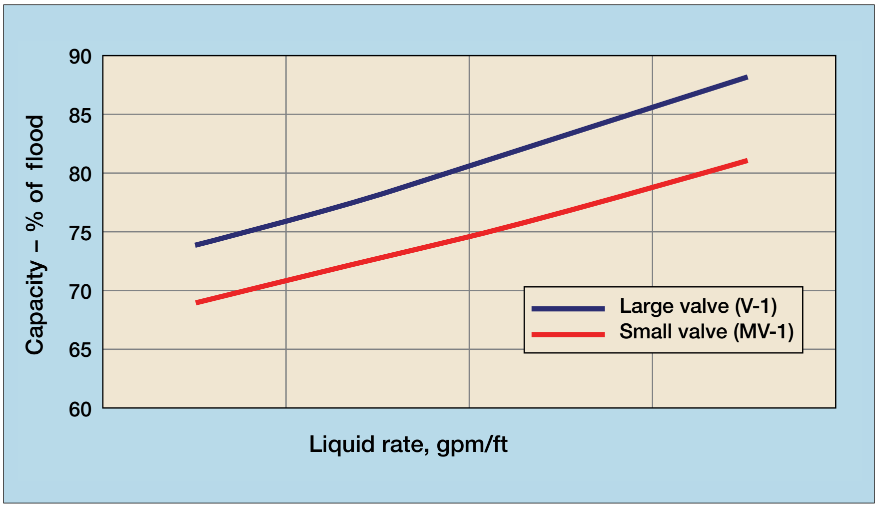

Figure 5 Capacity impact from different valve types

Source: KG-Tower rating software

design. As was noted previously, a foaming factor of 0.83 was used for the conventional trays because it resulted in a good match of the plant data and pre-revamp gamma scan results. For the revamp study, the foaming factor was kept at 0.83, not accounting for the benefit of the Minivalve, which can reduce tendency to foam.

Considering the tower scan results post-revamp, a foaming factor of 0.9 could be used for the Superfrac trays with MV-1 movable valves. With the tower exhibiting an improvement over design expectations, the difference could be attributed to the reduced foam generated by the valve type or simply that the added capacity of the valve's active arrangement on the tray provides even more capacity in this service than is normally anticipated. For a set open area, when the hole/valve size decreases, the capacity of the tray increases (see Figure 5). The increase in capacity comes from a reduction in froth height. With reduced froth height, there is more disengaging room to deal with foam, and thus more capacity. This phenomenon, arising from the different valve size, helps to deal with and/or address foaming issues in the column and thus further increase capacity in the column.

Conclusions

The revamped fuel gas absorber has met and exceeded the design objectives to enable Irving Oil Refining to increase overall refinery performance while maintaining strict environmental objectives. The absorber has been able to operate consistently above pre-revamp rates, and with expected post-revamp rates at the same product quality levels as before the revamp. Collaboration between the operating company and the tower internal company enabled a low-cost and effective tower revamp.[6]

References

1 Nieuwoudt I, Penciak J, Best of both, *Hydrocarbon Engineering*, July 2007, 85–89.

2 Nieuwoudt I, *et al*, Revamp & retune, *Hydrocarbon Engineering*, Jul 2009, 14, 7, 56–60.

3 Remesat D, Improving performance through low-cost modification of tower internals, *PTQ*, Q3 2010, 37–42.

4 VMGSim website, www.virtualmaterials.com

5 Mak R, Tracerco Internal report for Irving Oil Refining GP, Tru-Scan of the Sulphide Absorber, May 2010.

6 Remesat D, Inside-out design approach, *Hydrocarbon Processing*, August 2006.

Darius Remesat is a Chemical Engineer working in process and business development for Koch-Glitsch LP, Calgary, Canada. He holds a BS in engineering and management from McMaster University, Ontario, Canada, an MBA from Heriot-Watt University, Scotland, UK, and a MS and PhD in chemical engineering from the University of Calgary, Canada, where he is also an Associate Adjunct Professor.
Email: Darius.Remesat@kochglitsch.com

Michael Beshara is an Engineer working in the development, assessment and execution of profitability improvement projects for Irving Oil Refining, New Brunswick, Canada. He holds a BS in chemical engineering from the University of New Brunswick.
Email: michael.beshara@irvingoil.com