Debottlenecking a refinery fuel gas absorber

The purpose of a fuel gas absorber is to selectively remove components, primarily H$_2$S 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$_2$S 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 retaining 60% turndown capability (maximum throughput with given constraints is desired)

Numerous programs are available to assist in representing a column that uses amines to remove H$_2$S and CO$_2$ from fuel gas streams

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, Irving Oil Refining commissioned Koch-Glitsch to:

1. 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
2. Recommend and model internal changes to increase column capacity while retaining 60% turndown capability (maximum throughput with given constraints is desired)
3. 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
4. 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
5. Revamp work to fit within the set turnaround schedule.

Methods and tools
The first and most important step in any revamp study is to generate an accurate characterisation of the process. 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.

Numerous programs are available to assist in representing a column that uses amines to remove H$_2$S 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.
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\textsubscript{2}S and CO\textsubscript{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\textsuperscript{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.

### 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 cases

#### VMGSim results — increased flow through plant

<table>
<thead>
<tr>
<th>Case (constant lean amine, %)</th>
<th>H\textsubscript{2}S, ppm</th>
<th>H\textsubscript{2}S/amine, mol/mol</th>
<th>Acid gas/amine, mol/mol</th>
<th>Lean amine, BPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>920 mscfh - plant data</td>
<td>5</td>
<td>0.49</td>
<td>0.573</td>
<td>10 500</td>
</tr>
<tr>
<td>980 mscfh - 5 ppm H\textsubscript{2}S</td>
<td>4.88</td>
<td>0.49</td>
<td>0.569</td>
<td>11 200</td>
</tr>
<tr>
<td>980 mscfh - max H\textsubscript{2}S in amine</td>
<td>22</td>
<td>0.527</td>
<td>0.605</td>
<td>10 500</td>
</tr>
<tr>
<td>1175 mscfh - 5 ppm H\textsubscript{2}S</td>
<td>5.27</td>
<td>0.49</td>
<td>0.562</td>
<td>13 600</td>
</tr>
<tr>
<td>1175 mscfh - max H\textsubscript{2}S in amine</td>
<td>17.7</td>
<td>0.523</td>
<td>0.6</td>
<td>12 700</td>
</tr>
</tbody>
</table>

Table 1
Acid gas loading limit of 0.6 (moles acid gas/moles amine).

Acid gas is primarily \( \text{H}_2\text{S} \) and \( \text{CO}_2 \). 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 \( \text{H}_2\text{S} \) 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 \( \text{H}_2\text{S} \) 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 \( \text{H}_2\text{S} \) composition is below the specification of 50 ppm(v) for all cases.

<table>
<thead>
<tr>
<th>Trays</th>
<th>Description</th>
<th>Top 920 mscfh</th>
<th>Top 980 mscfh</th>
<th>Btm 920 mscfh</th>
<th>Btm 980 mscfh</th>
</tr>
</thead>
<tbody>
<tr>
<td>System factor</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Hydraulic data</td>
<td>Jet flood, %</td>
<td>85</td>
<td>93</td>
<td>89</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Downcomer flood, %</td>
<td>41</td>
<td>44</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Downcomer backup, in liq</td>
<td>9.2</td>
<td>10.0</td>
<td>9.6</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Total tray, ( \Delta P * ) in liq</td>
<td>5.9</td>
<td>6.7</td>
<td>6.4</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Total tray, ( \Delta P * ) mm Hg</td>
<td>11.3</td>
<td>12.3</td>
<td>12.1</td>
<td>13.7</td>
</tr>
</tbody>
</table>

| Table 2 |

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

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 considered.
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 H₂S 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 H₂S 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 between the amine and gas.

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.

Table 3

<table>
<thead>
<tr>
<th>Description</th>
<th>Top system factor</th>
<th>Top Mid system factor</th>
<th>Mid system factor</th>
<th>Btm system factor</th>
<th>Btm system factor</th>
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</thead>
<tbody>
<tr>
<td>Net top DC area, ft²</td>
<td>Existing</td>
<td>3.5</td>
<td>Proposed</td>
<td>2.7</td>
<td></td>
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<tr>
<td>Active area, ft²</td>
<td>12.7</td>
<td>15.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve type</td>
<td>Sieve</td>
<td>MV-1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Tray # (1-bottom)</th>
<th>Tray clear liquid height, in</th>
<th>Froth height, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–10</td>
<td>2</td>
<td>8–9</td>
</tr>
</tbody>
</table>

Tracerco scan results

<table>
<thead>
<tr>
<th>Tray #</th>
<th>Top m id Btm Btm</th>
<th>Top m id Btm Btm</th>
<th>Top m id Btm Btm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Top m id Btm Btm</td>
<td>Top m id Btm Btm</td>
<td>Top m id Btm Btm</td>
</tr>
<tr>
<td>11–25</td>
<td>11–25</td>
<td>11–25</td>
<td></td>
</tr>
<tr>
<td>1–10</td>
<td>1–10</td>
<td>1–10</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 Sketch of Superfrac tray setup
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 H₂S 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 H₂S concentration of 18–20 wppm. 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 H₂S (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.
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 Mini-valve, 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
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