Increasing vacuum tower performance

Advantages of using gravity flow liquid distributors in services where, historically, spray nozzles have been used, specifically in refinery vacuum tower wash sections where liquid entrainment must be avoided if capacity is to be increased

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Spray nozzle distributors are commonly used in heat transfer services and wash sections, but have the inherent disadvantage of generating small liquid droplets that tend to be entrained upward with the tower vapour. In vacuum tower wash sections, where vapour velocities are high and entrainment is critical, this can create serious process problems. Compared to spray nozzles, gravity flow distributors have better distribution characteristics and generate little, if any, liquid entrainment. Because of this, replacing vacuum tower spray nozzle distributors with gravity flow distributors can achieve capacity increases of over 25% while maintaining existing product yield and quality. Testing data highlight the distinctly different operating characteristics of spray nozzle and gravity flow distributors.

Since the introduction of structured packings and grid into refinery towers, the most commonly used liquid distributor for refinery vacuum tower wash sections has been the spray nozzle distributor. However, for several years gravity flow distributors have been successfully used to achieve significant performance increases in vacuum tower wash sections with no loss in column performance or run length.

When evaluating equipment for replacement, it is a good idea to compare the important characteristics and capabilities of each type of equipment. Spray nozzle distributors are widely used with packed beds. Obviously, there are advantages in their use. The major advantages include:

—High open area producing very little vapour-side pressure drop
—Some degree of heat transfer from the interfacial area generated from the droplet formation
—Relatively insensitive to out-of-levelness
—Low residence time.

However, spray nozzle distributors also have several inherent disadvantages, including relatively small orifices that are often susceptible to fouling, relatively poor distribution quality and lower turndown range.

Accordingly, there are several benefits in using gravity distributors in most services, particularly with regard to less entrainment, high quality distribution and fouling resistance.

The vapour-side pressure drop across a distributor is often an important consideration in vacuum towers. A spray nozzle distributor has a typical open area of 85-90%. A narrow trough gravity flow distributor (Figure 1) used in vacuum service will have an open area of about 70-75%. Both distributors have high open areas.

Using a simple orifice equation, the vapour-side pressure drop for both devices is calculated to be less than 0.1 in of water (0.15mm Hg). This is similar to the pressure drop taken by 1ft (305mm) of grid packing. Vapour-side pressure drops of this magnitude are quite low and should not adversely affect tower operations or economics.

**Distribution quality**

Spray nozzle distributors have a poorer distribution quality than gravity flow distributors due to their geometric layout and also from flow variances within the spray pattern itself. The nozzle pattern for a spray nozzle distributor header is arranged to create concentric rings of nozzles. The number of rings varies with column diameter, nozzle spray angle, and nozzle elevation above the packed bed. The conical spray patterns from the individual nozzles then overlap on the top of the packed bed.

Typical designs use anywhere from 150 to 200% coverage for the spray patterns in order to ensure the complete bed coverage. The problem that arises with this design is that the overlap patterns are never uniform across the bed. In order to get a more uniform overlap pattern, arrangements with more nozzles must be used. As more nozzles are used, the nozzle orifices must get smaller, creating a potential for fouling. Also, as more nozzles are used, the complexity and cost of the distributor increase.

Levelling of distributors should also be an important consideration. As stated earlier, spray nozzle distributors are not especially sensitive to out-of-levelness. This is due to the fact that the pressure drop taken across the nozzle itself is much larger than any typical level differences that may be seen. Therefore, liquid head deviations from out-of-levelness are generally negligible.

Most gravity flow distributors require a levelling tolerance of ±1/8in (3mm). This tolerance is generally not difficult to achieve. In some very large towers (>30ft or 9.1m), levelling can be a challenge, but is achievable with proper design and installation techniques.

Regarding turndown, distribution quality for all distributors suffers when the effective turndown range is exceeded. In wash section service, spray nozzles generally operate in the range of 10 to 15psi (0.7 to 1.0 bar) pressure drop with a maximum pressure drop of 20psi (1.4 bar). Above this range, the nozzles create larger amounts of small droplets that are susceptible to entrainment.
Below this range, nozzle spray angles tend to decrease. There is also a possibility that the spray header pressure drop may become a significant portion of the overall distributor pressure drop and maldistribution may occur within the header itself. The pressure drop range of 10 to 20psi (0.7 to 1.4 bar) limits the allowable turndown, which will be the square root of 10/20, or 71%. A gravity flow distributor can easily be designed to allow for a 35% turndown or twice that of a spray nozzle.

The gravity flow distributor is clearly superior with respect to distribution quality and turndown. This is very important in the case of the vacuum tower wash section where improved distribution increases the packing efficiency and lowers the asphaltene and heavy metals concentration in the (HVG0) product drawn from above the wash section.

Fouling resistance
A spray nozzle generally takes a significant pressure drop on the liquid side due to its relatively small orifice. Because many refinery services are fouling or coking, spray nozzle distributors are typically installed with a filtering system to remove fouling material. A gravity flow distributor in a fouling service should be designed with an overflowing pre-distributor box and with flow orifices that are located in the vertical plane and elevated above the floor of the distributor. This design creates a primary settling zone in the pre-distributor box and a secondary settling zone in the channels and troughs for the particulate matter that may be in the liquid.

Narrow trough distributors equipped with splash baffles can also be used to improve fouling resistance because this design has fewer flow orifices than typical gravity flow distributors. This is possible when the orifices discharge the liquid horizontally from the troughs onto an external vertical wall, or splash baffle, that serves to further distribute the liquid streams.

Figure 2 shows a common design. With this arrangement, the lower number of flow orifices allows the orifice diameter to be larger for a given liquid flow. Larger orifices increase the fouling resistance.

A well-designed gravity flow distributor is more fouling resistant than a spray nozzle distributor. Specifically, a narrow trough distributor with a vertical splash baffle minimises fouling by maximising orifice size and separating potential fouling material from the orifices. These distributors may be used without a filtering system in low to moderately fouling services. In critical and/or severely fouling services, an external filtering system is generally recommended.

Entrainment
Spray nozzles generate small liquid droplets and are much more susceptible to liquid entrainment at moderate to high vapour rates. This is especially critical in vacuum services where volumetric vapour rates are quite high. Test data presented in Figures 3–5 show the significant difference in entrainment rates between spray nozzles and gravity flow distributors. This is discussed in greater detail in the following simulator test section.

Testing conducted with spray nozzles in heat transfer services has shown that a spray nozzle itself will produce a portion of a heat transfer stage without any packing beneath it. This is due to the large amount of interfacial area that is created with the spray from the nozzles. A gravity flow distributor will also generate heat transfer, but typically not as much as a spray nozzle. However, due to the significantly better liquid distribution quality of the gravity flow distributor, the improved efficiency within the packed bed should compensate for any heat transfer differential between a spray nozzle and a gravity flow distributor. Because of this, both types of distributors should perform equally well in most heat transfer applications.

Residence time
Liquid velocities and the flow path length can be used to determine the residence time for liquid distributors. Assuming that the average flow path length will be similar between a spray nozzle distributor and a gravity flow distributor, the relative residence time will be inversely proportional to the average velocity of the liquid in each device. For a spray nozzle distributor, an average velocity will be around 4ft/sec (1.2m/s). In a trough distributor, an average velocity will be 0.5ft/sec (0.15 m/s).

The residence time of a spray nozzle distributor can be roughly calculated as 10–15% of that of a conventional gravity flow distributor. For example, an 18ft (5.5m) column with a spray nozzle header has a typical residence time of four seconds versus a gravity flow distributor residence time of 30 seconds. An alternative calculation for a 20ft (6.1m) diameter narrow trough distributor showed a residence time of 15 seconds at turndown and 40 seconds at the maximum rates.
Preventing coking in packing

Coking in the vacuum tower wash section is prevented primarily by ensuring that the packing is completely wetted at all times. Spray nozzles entrain feed liquids at high vapour rates and, by definition, whatever portion is entrained does not reach the bed to wet the packing. A well-designed gravity flow distributor will ensure that the proper amount of feed liquid will be evenly distributed to the bed below.

Gravity flow distributors can also be designed to help prevent coking of the packing in the case of a pump failure. This is done by installing overflow piping from the HVGO chimney tray to the wash section distributor. In towers with spray nozzle distributors, if there is a pump malfunction in the wash oil circuit, the only option is to shut off the HVGO product draw and let the HVGO chimney tray overflow unevenly onto the wash section bed.

In towers with gravity flow distributors, overflow piping from the HVGO chimney tray can minimise or prevent coke formation during a pump failure by the following method: in the event of a pump failure, the product draw can once again be blocked in, but the chimney tray will overflow via the overflow piping directly into the pre-distributor box of the distributor and then will be distributed evenly across the wash section bed. This will maximise the wetting of the packing until the pump can be brought back on line.

The cost of a spray nozzle distributor and a narrow trough gravity flow distributor should be similar. A review for a current inhouse project showed the costs to be within 5% between the two distributor types. In most cases, costs should not be a deciding factor and are expected to be within 10%.

Simulator testing programme

A test programme was conducted in an Air-Isopar test column in order to evaluate the operating characteristics of four types of grid structured packings with various liquid feed arrangements. The tests included a standard packed bed with a top liquid feed via a spray nozzle for one test configuration and a top liquid feed via a gravity flow distributor for the second test configuration. A conventional grid was tested as a baseline and compared with three new corrugated type grids with geometry designations of 40Y, 64Y, and 64X.

Corrugated grid packing is similar in design to conventional structured packing but has larger crimps to create a higher open area. The sheet thickness of the corrugated grid is thicker than typical structured packing. The designations of 40 and 64 represent the surface area in m²/m³ of packing. The conventional grid has a more conventional vertical structure with a surface area of approximately 40m²/m³ and is also made from a thicker material.

Table 1 shows which tests were performed on each type of grid.

The simulator is a 48in (1.2m) tower with once-through vapour flow and recirculating liquid flow. The vapour used for this testing was ambient air and the liquid was a proprietary product that contains isoparaffins in the range of C₄ through C₆. This test system is a good approximation of a low-pressure hydrocarbon distillation. Entrainment was collected with a double-pocketed vane collector and measured with a graduated tank.

Testing configurations details

The first of the two test configurations is described as follows:

- Standard bed test with top liquid feed from spray nozzle:
  - Liquid feed rates: 1.5, 2 and 2.5 gpmft² (2.5, 3.8, 5.0, 6.2 m³/m²) of column cross-sectional area.
  - Vapour rates: Varying to a maximum of 45000 lb/hr.
  - Spray nozzle: ½/4in, 90° for rates of 1 and 1.5 gpm/ft² (2.5 and 3.8 m³/m²); 1.5in, 90° for rates of 2 and 2.5 gpm/ft² (5.0 and 6.2 m³/m²).
  - Packing bed depth:
    - Conventional grid = 33.25 in (845 mm)
    - G40Y = 32.3 in (820 mm)
    - G64X = 35.1 in (892 mm)
    - G64Y = 36.5 in (927 mm)

The second of the two test configurations is described as follows:

- Standard bed test with top liquid feed from gravity flow distributor:

  All conditions in the second test configuration are similar to the first of the two test configurations with only one exception pertaining to liquid feed – where a liquid gravity distributor is used instead of spray nozzles. More specifically, a narrow trough distributor used for all liquid flow rates.

Simulator test results

The results are shown graphically in Figures 3–5 and are summarised as follows:

- Figure 3: Entrainment graph for 1 gpm/ft² (2.5 m³/m²). As with all of the entrainment graphs, the data show that the spray nozzle feed generates much more entrainment than the gravity flow distributor. With a spray nozzle, all packings had an entrainment level of greater than 20% at an F-factor of 2.5 (C-factor of 0.36). With the gravity flow distributor, all packings had an entrainment level below 5% up to an F-factor of 3.0 (C-factor of 0.43).

- Figure 4: Entrainment graph for 1.5 gpm/ft² (3.8 m³/m²). Data appear similar to previous graph showing a clear distinction between the entrainment levels with a spray nozzle versus a VEP.

- Figure 5: Entrainment graph for 2.5 gpm/ft² (6.2 m³/m²). Similar trend as other entrainment graphs. Entrainment percentage rates appear to diminish as liquid rates increase. As is true throughout the entrainment testing, the MG64X shows less entrainment than all other types of packing when fed with a VEP distributor, while the other packings show very similar entrainment characteristics.

Spray nozzles entrain at much higher levels than the VEP gravity flow distributor. This generally does not come as a surprise, but the clarity of the results is
impressive. If limiting the maximum allowable entrainment rate to 10%, the spray nozzle distributor is limited to an F-factor of roughly 2.0 (C-factor of 0.29) while the VEP can accommodate F-factors of 3.0 to 3.5 without exceeding 10% entrainment. This represents a capacity gain of 50% for a VEP distributor over a spray nozzle distributor in this system.

Different grid types react differently to the feed arrangement. This was not expected. The results show throughout the testing that MG64X has the lowest entrainment level of any grid when fed with a VEP. The entrainment characteristics of the other grids are nearly indistinguishable when fed with a VEP. However, when a spray nozzle is used, the lower pressure drop grids (MG64X and Nutter Grid 3 (conventional grid)) have higher entrainment levels than the higher-pressure drop grids. A likely explanation is that this is due to the predominantly vertical momentum of the vapour leaving the lower pressure drop devices is more likely to entrain the spray nozzle droplets.

**Additional testing**

The combination of a gravity flow distributor and MG64X grid packing was selected by the Fractionation Research, Inc (FRI) membership for testing in their Category 1 test programme. This testing was completed in the summer this year. In the 5psia (333 mbar) test system using cyclohexane/normal heptane, the preliminary results show excellent performance up to a Cs value of approximately 0.6ft/s (0.18m/s). This matches well with the simulator testing which showed good performance up to a Cs of approximately 0.5ft/s (0.15m/s).

**Refinery plant results**

Data for revamps using VEP distributors in three vacuum tower wash sections are shown in Figures 6-9.

The first two cases for the vacuum tower revamps are in the Petrogal-Sines refinery. In the past, Sulzer
Spray nozzle pressure drops in psi and bar

<table>
<thead>
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<th>Flow Rate</th>
<th>1.0gpm/ft² (2.5m³/m²)</th>
<th>1.5gpm/ft² (3.8m³/m²)</th>
<th>2.0gpm/ft² (5.0m³/m²)</th>
<th>2.5gpm/ft² (6.2m³/m²)</th>
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<tr>
<td>Nozzle type:</td>
<td></td>
<td></td>
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<tr>
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<td>13 (0.83)</td>
<td>32 (2.2)</td>
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<tr>
<td>1.5 in, 90°</td>
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<td>–</td>
<td>11 (0.76)</td>
<td>17 (1.2)</td>
</tr>
</tbody>
</table>

Table 2

Chemtech had revamped the atmospheric crude column with structured packing and VEP liquid distributor in the wash section. Due to its performance, Petrogal decided to revamp the two vacuum towers (V-V1 and C-V9) downstream of the atmospheric tower. The main goal was to increase the capacity of the vacuum towers by 25% in order to produce more gas oil feed for the FCC unit. Both vacuum columns had packing in the wash sections with spray nozzle distributors. In order to increase the capacity of these sections, the packing size was changed and the spray nozzle distributor was replaced with a VEP distributor. Both of these columns went in operation in October 1996. The VEP distributors have performed well and are still in operation.

The third case presented is one of the first installations of a VEP distributor in a vacuum tower wash section. This installation is in a major refinery in Europe. The data shown in Figure 9 are somewhat limited but the main point for this case is that this VEP distributor has been in operation since 1992. This revamp was performed in order to reduce the amount of asphaltenes in the HVGO feed to the hydrocracker unit. This was accomplished by installing a different packed bed and replacing the existing spray nozzle distributor with a VEP distributor.

This service is especially prone to coking and fouling. The VEP pre-distributor box design has worked extremely well and insured trouble free operation throughout the normal turnaround cycle.

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