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Packed Bed Performance Analytics Based on Gamma Scans

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Refinery and chemical plant operations depend heavily on distillation and separation towers. Tower gamma scanning is well established in the process industries as a qualitative tool to help troubleshoot towers. Advancements in data analysis have led to a quantitative approach in expressing gamma scan data in numerical terms easily understood by process and operations engineers.
For packed towers, a grid-scan of 3 or 4 equal-distant scans crossing through the beds of packing would typically be used to investigate the quality of liquid distribution. The conventional approach to "analyzing" a gamma scan has been to visualize how well the scan data from the individual scans matched each other or how well they "overlaid" with each other. This is a totally subjective analysis lacking consistency, open to varying interpretation and does not translate well from tower-to-tower. Therefore, the resulting conclusions from this approach can be very ambiguous regarding the magnitude of any detected liquid mal-distribution.
An alternative analytical approach, termed PackView™, has been developed whereby a relative density scale is calculated from data that the grid-scan provides. The density scale begins at the density of the dry or non-operating packing. The density scale displays the calculated density of liquid retained in the bed of packing based on the scan data results.
Another calculation by which to put the liquid distribution into perspective and to get a measure on the useful capacity of the packing is to calculate the liquid holdup fraction or liquid volume fraction. If the measured liquid retention density is divided by the process liquid density at bed conditions (the liquid density at the actual operating temperature and pressure), liquid holdup or liquid volume fraction can be established. A comparison of the liquid holdup fraction to the packing operating capacity curves provides an objective appraisal of current operating capacity.
It is always easier to understand and discuss technical issues when quantitative information can be used to compare operational parameters with engineering design. This advanced analysis provides a new method of extracting quantitative information from gamma scan data to diagnose and characterize the operation of distillation and separation towers. It is our goal that using the advanced analytics presented will improve the value of gamma scan data and facilitate improvements in the operation of mass transfer equipment.

Introduction

Figure 1 shows the most typical orientations for conducting a gamma scan on a packed tower. These scans are conventionally called grid-scans.
Some of the process information that can be learned for a gamma scan of a packed tower is:

- Condition of packed beds – elevation of packing, depth of packing elements, uniformity of packing elements, etc.
- Collector and distributor liquid levels – Damaged? Overflowing?
- Base or bottoms liquid level.
- Flooding present?
- Foaming present?
- Excess liquid retained in packing?
- Liquid maldistribution?

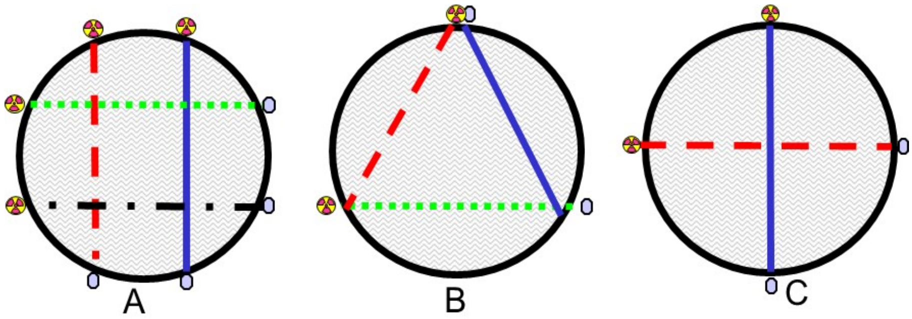

Figure 1. Typical Gamma Scanline Orientations: A for diameters 1.5 m and larger, B for diameters 0.5 – 1.5 m; C for diameters less than 0.5 m.

The purpose for doing multiple scans of a packed tower as shown in Figure 1 is to determine the state of the liquid distribution. The foundation for this analysis is the Beer-Lambert law as expressed here:

$I=I_o\, e^{-\rho\mu\chi}$, where
I_o is the initial gamma ray intensity measured at a given distance with no material interfering with the radiation transmission
I is the radiation intensity (counts) measurement taken through the tower
μ is the absorption coefficient of the material the radiation is passing through (material physical property)
ρ is the density of the material the radiation is passing through
χ is the thickness of the material the radiation is passing through.

Beyond questions concerning damage to internals and flooding within a packed tower the next biggest concern is the state of liquid distribution through the beds. Historically gamma scan analysis has relied upon performing two sets of parallel scanlines (given the tower diameter is sufficiently large) through the packing as shown in Figure 1A, commonly referred to as a grid scan. When gamma scanning a tower I_o remains fixed and μ is essentially a constant. For a grid scan the multiple paths of radiation through the tower must be kept equal so χ remains a constant. With I being measured the equation is solved for ρ, the material density.

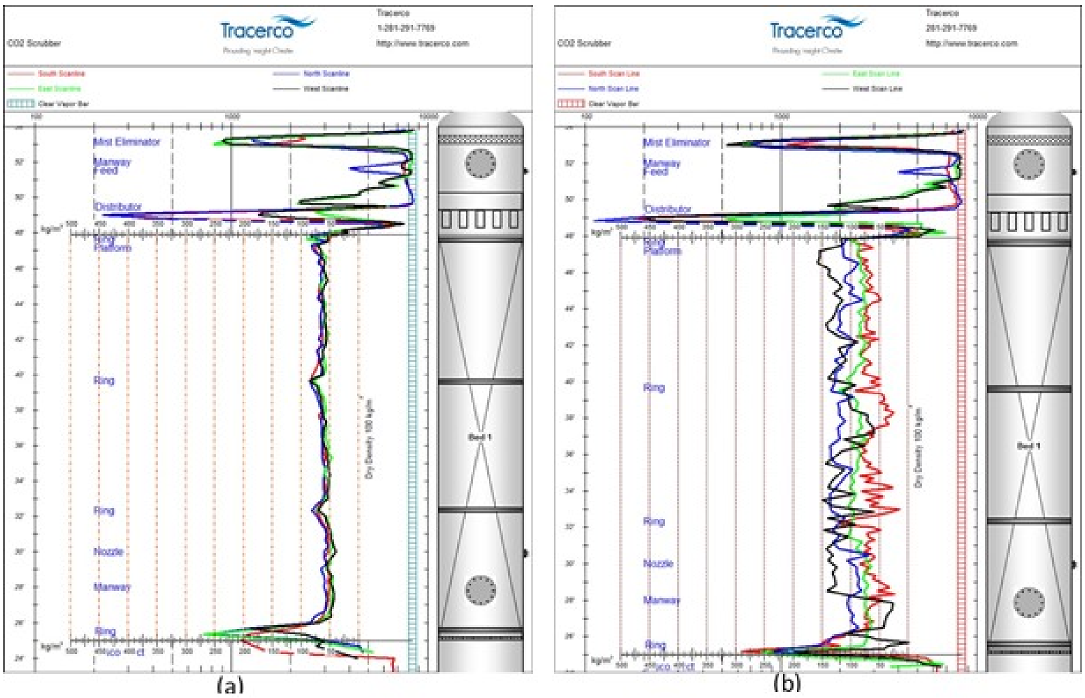

Figure 2 (a) Gamma scan results showing good liquid distribution due to the uniform response. (b) Gamma scan results showing liquid maldistribution since there was no uniform response among the scanlines.

On the basis that χ was indeed kept equal, then the multiple sets of scan data from a packed column grid scan could be simply visually compared to each other. The reasoning since all scan parameters were constant, particularly the length or path of radiation through the column (χ), uniform liquid distribution would be confirmed by all four scans detecting identical radiation. Figure 2a is a typical example of a grid scan showing all four scanlines matching, implying good liquid distribution.

However, when there was some variance in the radiation measurement and the sets of scan data do not seem to match very well then the liquid maldistribution would be blamed. Comparing the sets of scan data, lower radiation counts (higher density) indicated more liquid and higher counts (less density) indicated less liquid, therefore liquid maldistribution. An example of this type of conclusion is demonstrated in Figure 2b.

This is a totally subjective analysis lacking consistency, open to varying interpretation and does not translate from tower-to-tower. Additionally, this quantitative analysis does not give any insight into the severity or quantity of liquid maldistribution. Therefore**,** the resulting conclusions from this purely qualitative approach can be very ambiguous regarding the presence and magnitude of any liquid mal-distribution.

Advanced Analytics – PackView™

An advanced analytical analysis for gamma scan data from packed columns was developed to consistently analyse gamma scan data and reach a conclusive result. Densities are calculated based on tower dimensions, scan path length (variable χ) and the gamma scan data through the packing. The calculation results are used to superimpose a density scale onto the scan data. The basis of the density scale is the dry bulk or non-operating packing density. Calculated densities greater than the dry packing density represent liquid and/or solids retained in the bed of packing. Figures 3b, 4b and 6b show examples of this liquid retention density scale. As with the qualitative gamma scan analysis if the multiple scanlines have matching liquid retention densities then the implication is the liquid distribution is good. However, if there is a difference between the scanlines, the retention density gives a numerical comparison from which to gauge the extent or severity of any liquid maldistribution, in terms of liquid density.

PackView™ Example 1

Figure 3a shows the gamma scan results from a small-diameter packed tower (only two scanlines performed due to the small diameter). The tower diagram on the right side of Figure 3a shows where the bed of packing is supposed to be per the reference tower drawing. There is a reduction in radiation counts from the Clear Vapor region at the expected elevation for the top of the bed. After a short distance into the bed the radiation counts decrease. The question is, what is the operating condition of the bed? Are the lower counts (higher density) liquid holdup (flooding) at the bottom of the bed? Or is the radiation counts at the bottom of the bed "normal" and something has happened to the packing in the top of the bed? A visual or qualitative evaluation of the radiation counts cannot answer these questions with confidence.

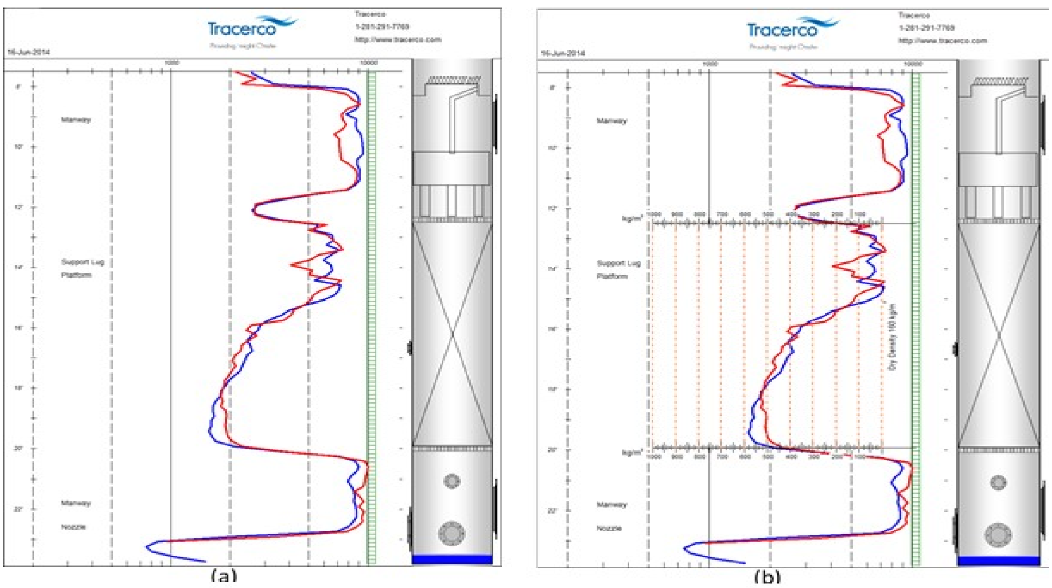

Figure 3. (a) Initial gamma scan results from small diameter column. (b) Gamma scan results, enhanced with liquid retention scale, showing missing packing at top of bed.

Figure 3b shows the gamma scan results from Figure 3a with the liquid retention scale added. Note that the density of the dry packing is 160 kg/m^3 and the top of the bed has a density essentially equal to this. However, the tower was operating and there was liquid traveling down through the packing. Where is the additional density from the retained liquid? The overall density at the top of the packing should be the combination of retained liquid and packing densities. Since the scan results show the overall density to be nearly equal to the dry packing, either there was no liquid (obviously not the case) or packing was missing. This was a bed of random packing. The PackView™ analysis made it conclusive that portions of the packing were missing. The high density in the bottom of the bed was likely crushed packing retaining an excess of liquid. Eventually entry into the tower confirmed these results.

PackView™ Example 2

Figure 4a shows the gamma scan results from a crude vacuum tower (the fourth scanline was not performed due to limited access). One of the biggest problems with crude vacuum tower operation is managing the coking (fouling) of the wash bed. In this example plant operations suspected the wash bed had coked up so the gamma scan was done to assess the situation. As shown on the tower diagram on the right side of Figure 4a this wash bed consisted of two different types of packing. The top section was typical structured packing while the bottom section was grid packing. The scan results showed the bottom section to be very dense, as the radiation intensity was less than 5 counts, essentially background (no radiation passing through the tower). Based on this result the diagnosis was that the grid section was coked and/or flooding with liquid, but plant management was not convinced. Grid packing is dense packing so what if the radiation source was too small? In other words, some radiation would pass through the packing from using a larger radiation source and then perhaps the tower would not appear to be flooding.

Figure 4b shows the gamma scan results from Figure 4a with the liquid retention scale added. The dry density of the grid packing is 255 kg/m^3. The density of the process material inside the grid packing, based on the scan results, was calculated to be approximately 300 kg/m^3. Grid packing is very open packing and the typical liquid rate on a vacuum wash bed is very low. A typical liquid retention density for grid packing in this service is 80 – 100 kg/m^3. The density calculated from the scan data is far above this so the grid was coked and/or flooding. Therefore, the scan radiation source used on this tower was more than adequate. The advanced analysis proved that if this wash bed had not been fouled with coke and flooding there should have been 30 – 50 radiation counts passing through the tower, rather than less than 5.

An additional computation confirmed this diagnosis. The liquid volume fraction was calculated by dividing the liquid retention density of 300 kg/m^3 by the process liquid density (800 kg/m^3). The resulting liquid volume fraction was 0.38. Figure 5 shows typical capacity curves from studies of packing capacities. Note that usually packings reach flood stage with liquid volume fractions greater than 0.12. Therefore, the grid packing far exceeded its maximum useful capacity.

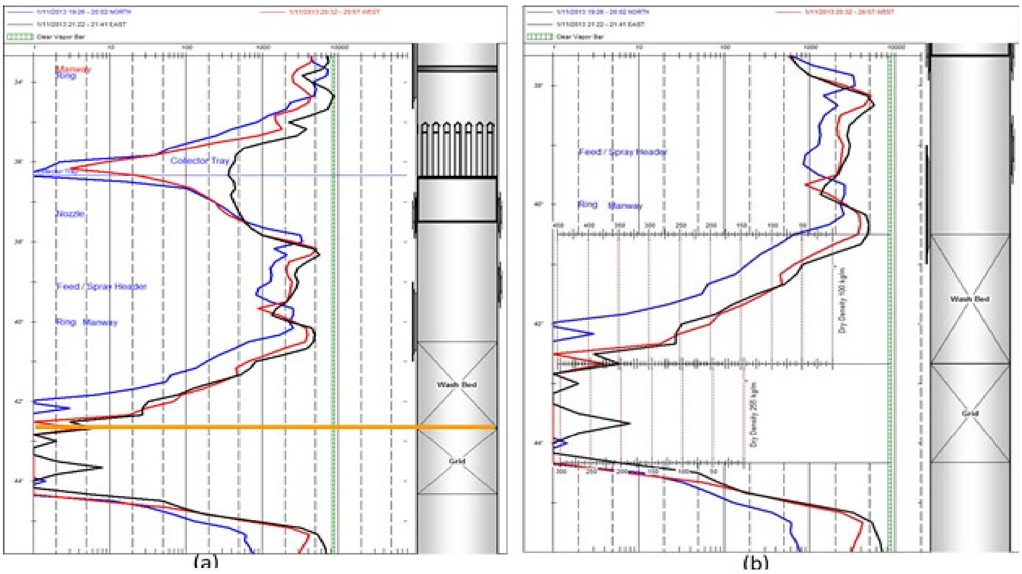

Figure 4. (a) Initial gamma scan results of crude vacuum column showing bed placements and high density (very low radiation intensity) through the wash bed grid. (b) Gamma scan results, enhanced with liquid retention scale, showing wash bed grid either completely coked or flooding with retained liquid. Excess liquid backing up into wash bed packing.

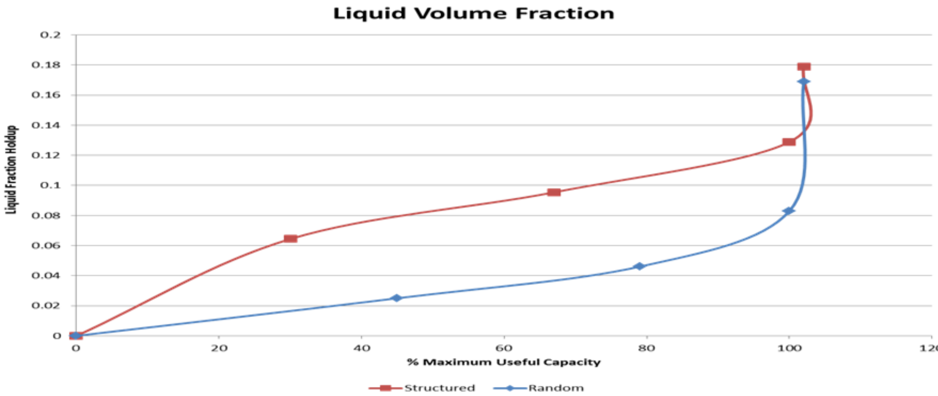

Figure 5. Typical curves showing maximum capacity for general types of packing as a function of liquid holdup.

PackView™ Example 3

Figure 6a shows the gamma scan results of a packed bed in a CO_2 scrubber where the resulting product gas was out of specification on CO_2. The gamma scan showed no major problems with the scrubber internals other than the possibility of liquid maldistribution. The typical qualitative evaluation seems to show there is a problem in the bed of packing. The four scanlines do not match each other very well indicating that the overall density between the four sets of data are different from each other. The radiation intensity counts vary from 1800 – 3600 as read from the horizontal scale of Figure 6a. But what is the severity of the liquid maldistribution? The radiation intensity or counts gives no perspective or evaluation of the actual liquid distribution quality.

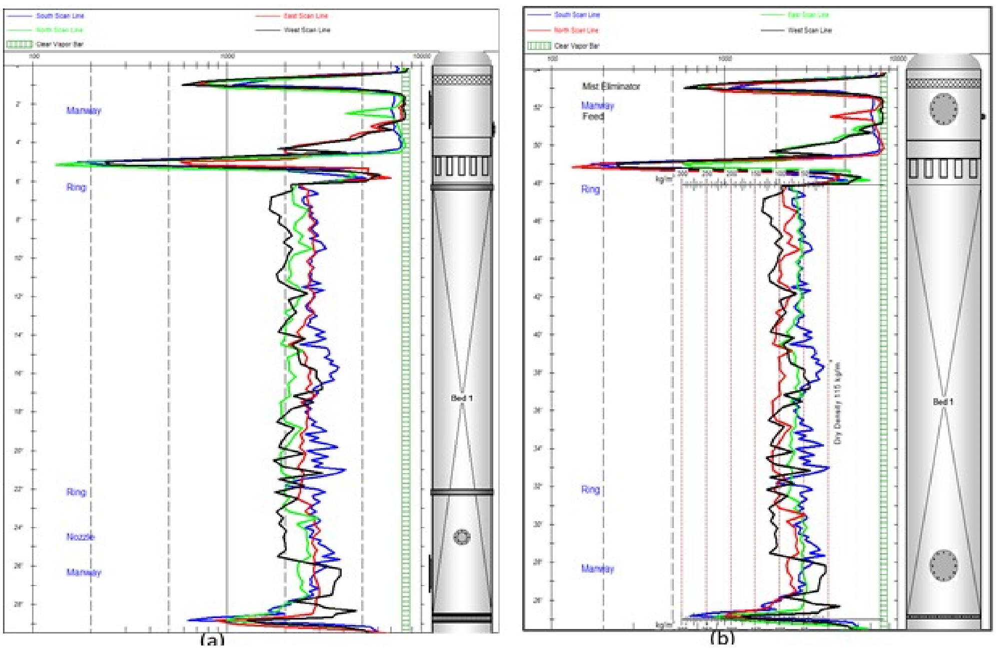

Figure 6. (a) Initial gamma scan results showing what appears to be liquid maldistribution as no uniformity of the scanlines through the bed. (b) Gamma scan results, enhanced with liquid retention scale, showing large density differences among the scanlines. One side of tower (blue scanline) shows almost dry packing as liquid retention density is almost the same as the dry packing density.

Figure 6b shows the same gamma scan results from figure 6a with the liquid retention density scale added. The dry packing density is 115 kg/m^3. The PackView™ analysis shows the liquid retention ranged from 10 – 130 kg/m^3. In terms of liquid density across a bed of packing this was a large density difference.

Reinforcing the liquid maldistribution diagnosis was the fact that one scanline (the blue data curve in Figure 6b) had almost the same overall density as dry packing alone. Thus, this scanline was nearly dry or very little liquid on that side of the scrubber. Furthermore, the liquid volume fraction calculated, based on a process liquid density of 800 kg/m^3, ranged from 0.01 (very low liquid fraction) to 0.16 (bordering on flooding).

Therefore, the advanced analysis conclusively proved that the bed of packing was suffering from very poor liquid distribution.

Figure 7 shows general guidelines for the magnitude of liquid retention density differences seen across packed beds from gamma scans and the relative quality of liquid distribution. Please note that these are only general guidelines and may differ based on the specific service the tower performs and the overall liquid operating rate.

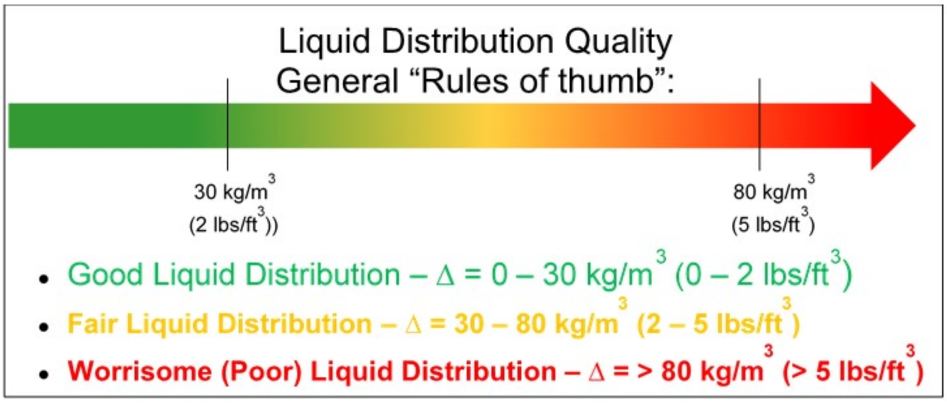

Figure 7. General guidelines for evaluating liquid distribution quality based on gamma scan results using the advanced analytics of the liquid retention scale.

Conclusions

Properly applied advanced analysis of gamma scan data can be used to quantify liquid maldistribution through a packed bed in terms of liquid density differences. The liquid retention density calculated from gamma scan data can indicate areas of excess liquid holdup caused by fouling or flooding within packing. If the actual operating liquid density is known, a simple calculation can determine the % liquid fraction, a measure of the Maximum Useful Capacity of the packing.

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