Radioisotope Technology - Benefits & Limitations in Troubleshooting Packed Beds in Vacuum Distillation

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Introduction

The use of radioisotope technology in Chemical, Petrochemical and Refinery Process Plant mass transfer vessels has continuously been developed over the past 50 years to assist engineers in troubleshooting process problems, optimize production and plan shutdown schedules to minimize plant down time. Many advances in data acquisition and processing ability now allow critical information to be provided quickly to ensure the most efficient use of plant equipment.

With the advancement of data gathering and handling it is important to note that fundamental physics behind each and every measurement involving radioisotopes has never changed. As with any technology there are many advantages in its use. However there are also limitations that a process engineer must fully understand so that a possible problem is not overlooked or simply discounted based upon results generated.

Mass transfer design can typically be split into two main categories; trayed and packed beds. Packed beds are becoming increasingly popular. In the case of a trayed tower, the open area is typically less than 10% whereas the open area in a packed bed is greater than 50%. Additionally, packing tends to have a lower liquid holdup than trays. These characteristics combine to result in pressure drop for a theoretical stage being lower in packing than in trayed systems. This reduction in pressure drop can have a significant impact on tower and plant economics.

As with all situations, packed towers bring their own particular challenges. As an example, the same open area and reduced liquid holdup that benefits pressure drop may result in lower liquid and vapor velocities, and therefore, an increased susceptibility of packed beds to accumulate solids in systems prone to polymerization or precipitation. Another common issue surrounds mechanical integrity. Packed bed towers are more susceptible to damage as a result of pressure surges as compared to trayed vessels. Finally, a critical consideration in the effective operation of a packed tower is the mechanism for fluid distribution. Poor vapor or liquid distribution can result in a significant efficiency reduction. In fact, the necessity of uniform distribution increases with the number of theoretical stages in a bed. This results in tower internal designers limiting bed length and redistributing process materials at specific and regular intervals.

With the increased use of packed beds the application of radioisotope technology to troubleshoot problems has become popular. This paper, with the aid of case studies, describes the general principles of the radioisotope diagnostic technologies used in both trayed and packed bed towers that allow operating characteristics to be measured. It shows the benefits that can be gained by using the technologies as well as limitations and in some cases the necessary strategy of radioisotope technology integration to successfully determine the source of a particular mass transfer problem.

Outline of Radioisotope Technologies Used in Vacuum Tower Diagnostics

Gamma Ray Transmission Scanning

The intensity of detection of a source of gamma emitting radiation is dependent upon several factors including the source type used, the distance between the source and detector and the density through which the source has to pass to reach the detector. If the source and detector are positioned at a fixed distance apart the detector response is proportional to the density it encounters in-between. This physical parameter can be used to determine the density profile through a vessel. Relating the density profile to expected materials within the vessel allows diagnostics to be performed on the vessel contents.

In the case of a tower, a source can be positioned on one side and a radiation detector positioned horizontally opposite, on the other side. In the case of a trayed tower the radiation beam is normally passed across the active area of the trays (avoiding the downcomers) to determine the liquid level on the tray and the quality of the liquid/vapor disengagement above the tray. The source and detector are then moved vertically downward and the intensity of the radiation transmitted through the tower is recorded at each measurement position.

As the source and detector move downwards through a normal vapor space within a tower, a transmission peak (high intensity) is observed, and when the scan line intersects liquid on a tray, a packed bed, or other dense material, an absorption peak (low intensity) is observed.

In practice the changes in scan response between regions of low intensity to high intensity, or vice versa, are not perfectly sharp because wide beam instead of narrow beam radiation is used. It is necessary to use wide beam radiation because the shielding required to produce narrow beam radiation would make the source container too heavy and unwieldy for practical use. Consequently, there is a contribution to the radiation field at any point due to radiation scattered indirectly from the internal structure of the tower toward the detector.

A graph of radiation transmission measurements as a calculated relative density versus tower elevation generates a density profile of the operating tower. Interpretation of the density profile can identify a variety of operational and mechanical problems, such as flooding, entrainment, foaming and damaged internals. The density profile is normalized for diameter changes and wall thickness variations.

All quoted density values are calculated relative to the highest observed radiation transmission, which is assigned a vapor density of zero pounds per cubic foot. The quoted vapor density represents the minimum observed density in the vapor disengagement zones, and indicates the quality of the liquid/vapor disengagement.

Several factor limit the effectiveness of the Gamma Scanning Technique as it pertains to vacuum distillation. Three basic factors limits it’s effectiveness: column diameter, internal configurations in relation to radiation absorption, and statistical limitations of radiation counting. All three factors are interrelated and will be discussed in detail below.

The largest challenge is overcoming the large column diameters used in vacuum distillation in relation to radiation penetration through the tower. The graphic below dictates the column width as it relates to radiation source sizing typically used in these types of studies. These value represent the activity needed to penetrate through the column only and not internals such a packing or distributors.

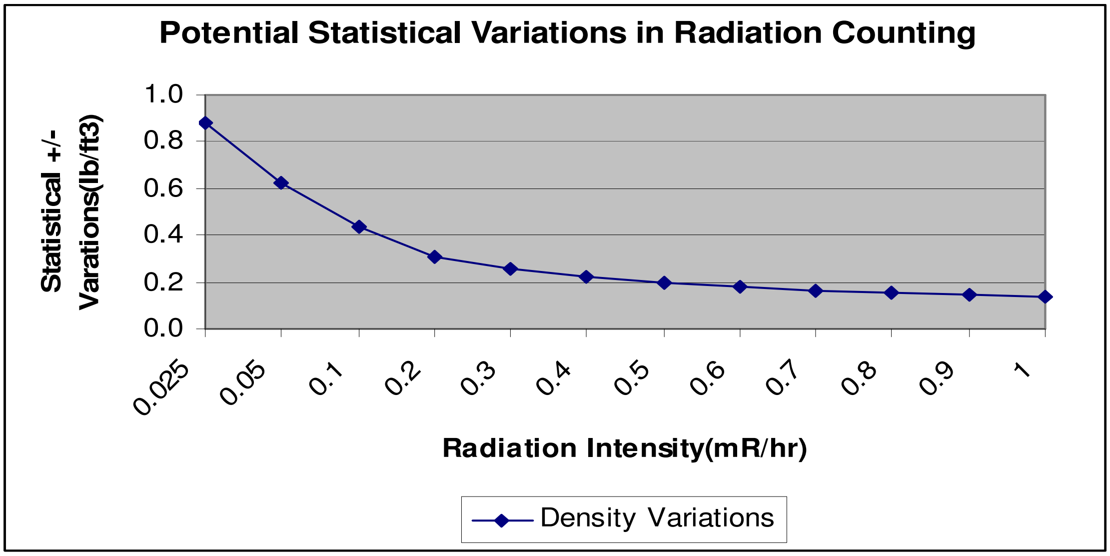
Tower	**Minimum Activity Needed(mCi)**	**Ideal Activity(mCi)**
48”	1	7.4
96”	3.5	26.6
144”	8.0	60.1
192”	14.0	107.0
240”	22.3	167.3
360”	50.2	376.9

Theoretically, the values above are within reason, but the vacuum column will have internals such as packing that will be of interest in a typical tower study. Penetrating the internals requires a separate calculation relating the diameter of the tower to the internals bulk density. If we assume that standard structured packing is used in a vacuum tower with a density of 12 lb/ft3 then the corresponding source sizes will be needed to get statistically correct data.

Tower	**Minimum Activity Needed(mCi)**	**Ideal Activity(mCi)**
4’	2.2	16.4
8’	17.5	131.2
12’	90.7	904.4
16’	346.0	2,594.7
20’	12429.0	9,321.9
30’	19,497.0	146,234.5

With these source sizes in mind, it is important to understand the statistics of radiation counting and how they relate to radiation intensity. The typical NaI radiation detector used in the industry has a high and low limit for effective radiation counting. The upper limit of radiation refers to the NaI crystal and photomultiplier tube ability to process the gamma particles as the crystal becomes saturated with gamma particles. This upper limit is called “dead time” and has a sliding scale as to the effects to the count rates or radiation intensity increases on a detector. Naturally, the more intense the radiation the larger the effect on the ratio of “lost” counts. The effects of dead time can begin to be seen at approximately 1.8 mR/hr and above. The lower limit is self-explanatory as the few particles that contact the crystal are lost in the background noise of natural radiation and electronic noise.

The natural statistical variations that occur in radiation counting also become an issue as the radiation intensity increases or decreases. The substantial variations occur in the lower detectable limits of radiation counting. The graph below shows the effects of statistical variations as a function of radiation intensity and the concurrent density relation.



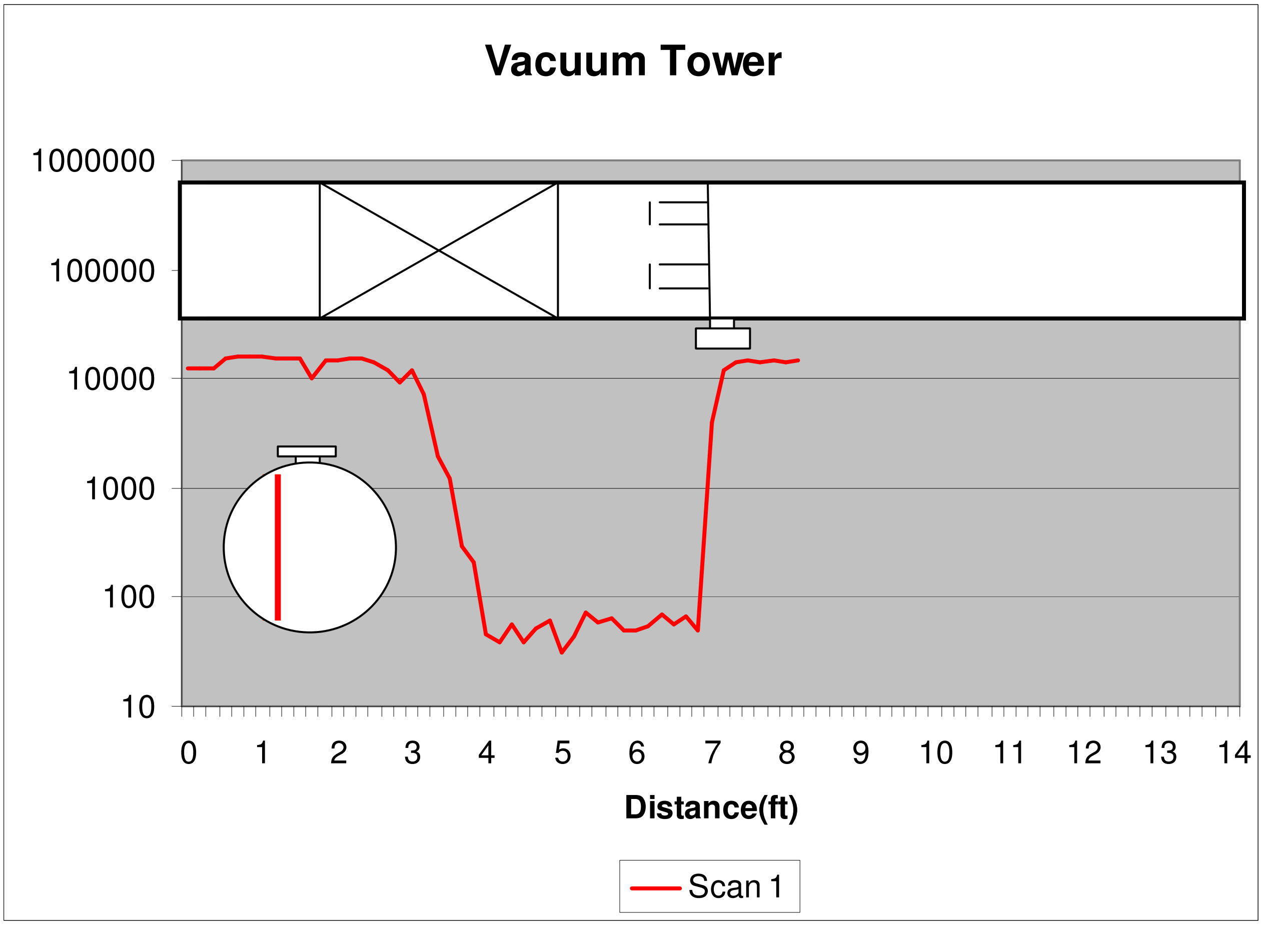
Case Study – Gamma Transmission Scanning

PROBLEM

A major oil refiner was experiencing a high differential pressure in the vacuum column limiting production. A tower scan was needed to identify the cause and location of the issue.

RESULTS

Within hours of job scope discussions with the refiner, a team of two engineers performed an initial tower scan and located the problem. A packed bed had collapsed on to the chimney tray below (Red Solid Line). The fallen packing was limiting the pump-around draw.



Radiotracer Residence Time & Distribution Measurement

Injecting a compatible radiotracer into an appropriate inlet upstream of a vessel and monitoring its passage through the vessel allows a residence time and fluid distribution to be measured. Sensitive radiation detectors are placed at strategic elevations / locations on the vessel. The detectors are relatively small and easy to mount at each position. Each one is connected by a cable to a central data logging device that records radiotracer concentration versus time information.

When the radiotracer passes each detector a response is registered and recorded. Prior to the test each detector is assessed and its response normalized such that each detector responds identically to a given unit of radiotracer. Analysis of each detector response allows significant information to be obtained including time of flight, pulse duration, Inverse Peclet Number, Stirred Tank Equivalent, individual detector response area and the individual percentage from each detector response area relative to the total of response areas for each distribution ring of detectors. This in turn allows maldistribution to be determined.

In the case of a packed bed tower detectors are usually placed towards each of the individual packed beds as well as the inlet and outlet pipe work. In the case of liquid flow the upper detector ring allows determination of any maldistribution due to the liquid distributor. The lower ring of detectors allows the detection of maldistribution from within the packed bed. In the case of gas this is reversed with the lower ring detecting any distributor mal distribution issues and the upper ring any packed bed distribution effects. The outlet and inlet detectors allow residence time to be measured and compared to calculated values. They also allow the presence of channeling to be further verified by the mean residence time determination and the presence of concentration versus time “fingering” effects that show flow channels within each bed.

Vacuum towers pose a unique set of issues to fully document each phase of the flow. The vapor portion of the flow regime is very easy to tag and monitor as it would flow through the tower. The typical gas phase trace material used is an Argon-41 or Krypton-79 gas. Each is radioisotope gas not affected by the temperature or pressure within the tower. The liquid phase on the other hand is a much more susceptible to the conditions of temperature and pressure. The typical liquid phase tracer used in the industry to tag a hydrocarbon flow is a Br-82 compound. In general, the typical vacuum tower operating conditions have a higher than allowable operating temperature for this compound to be used causing the carrier fluid for the bromine compound to flash. This will cause the bromine to drop out of solution and “plate” or stick to the local mechanical hardware in the area. Tracing the liquid portion of the flow patterns within the tower is critical to help determine the root cause of the maldistribution, fouling, or mechanical damage. The vapor phase testing cannot be injected into the individual bed areas to test just it’s distribution. The vapor has to be injected with the feed to the lower and can be affected by each internal structure it passes while the liquid phase typically has it local distributor for each packed bed.

I association with a major refiner, a solution to this issue was prioritized. A number of compounds were trialed for compatibility with similar temperature and pressure regimes. A Manganese-56 compound was found that fit the needed considerations. A series of tests were performed in lab scale models and again in pilot plant operations to test the true limits of the compound with favorable results. A full scale test was performed and the following case studies show the results of the study

Case study – Maldistribution within a Packed Bed Tower

PROBLEM

A major oil refiner was experiencing poor performance from a newly installed packed bed in a vacuum Tower. A radioisotope distribution study was agreed to offer the best information to identify the cause of the poor performance.

RESULTS

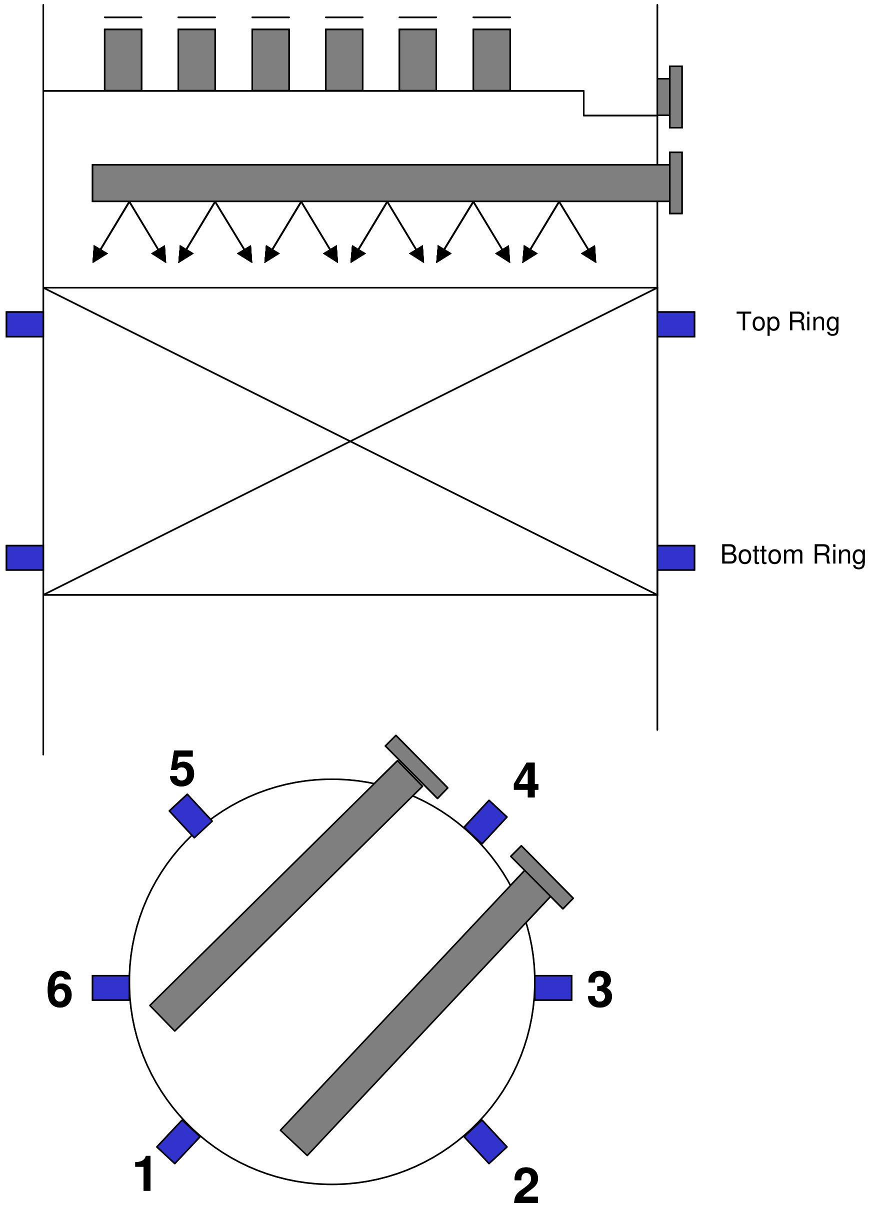
A total of 20 detectors were mounted on the tower. Four detectors were used to monitor the inlets and outlets of the tower for timing. The remaining 16 detectors were mounted in two rings of six and one ring of four. The detectors were equally spaced every 60 degrees around the circumference of the tower. The top ring of detectors was mounted 1ft into the packed bed and the bottom ring of detectors was mounted 1ft above the bottom of the packed bed.

There locations started at 0 degrees (above the vapor inlet) and were positioned every 60 degrees. For simplicity, the detector locations will be referred to as 1, 2, 3, 4, 5, and 6.

Where detectors were used to monitor flow distribution, a comparison of the detector response curve areas was obtained, with the total observed at the elevation by all detectors representing 100 percent. The expected distribution percentage per quadrant was **16.6** percent for equal distribution.

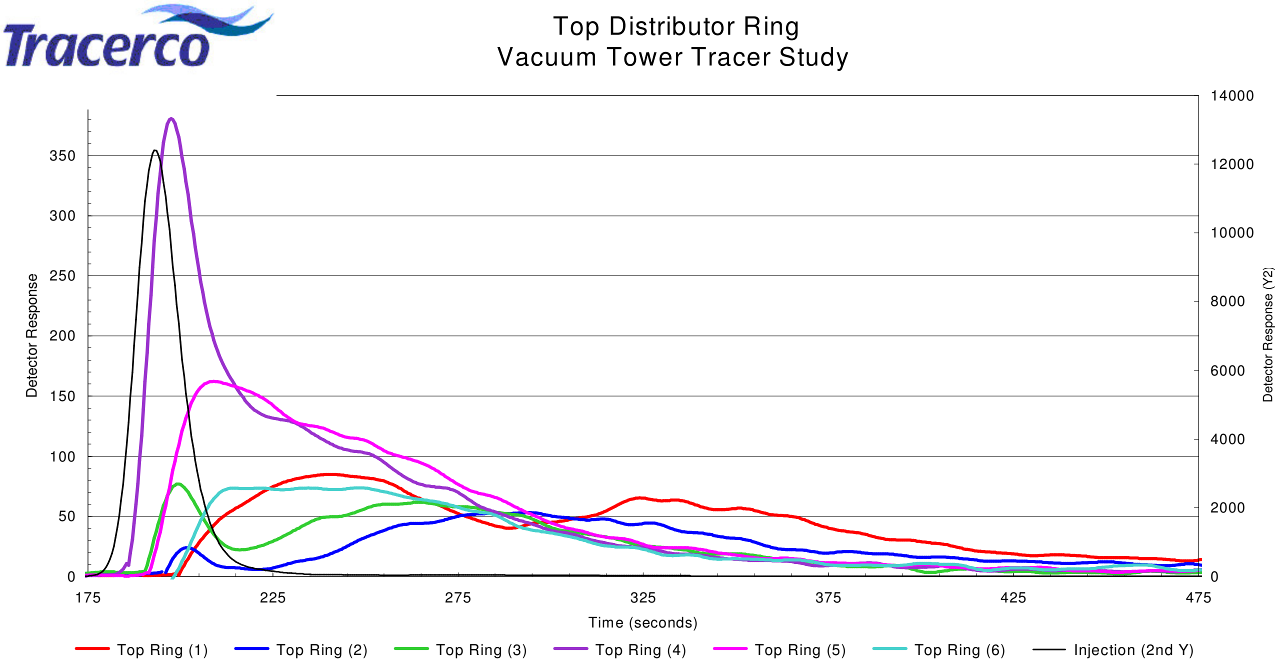
The graphic below shows the detector orientation and elevation.

Detector Location and Orientation

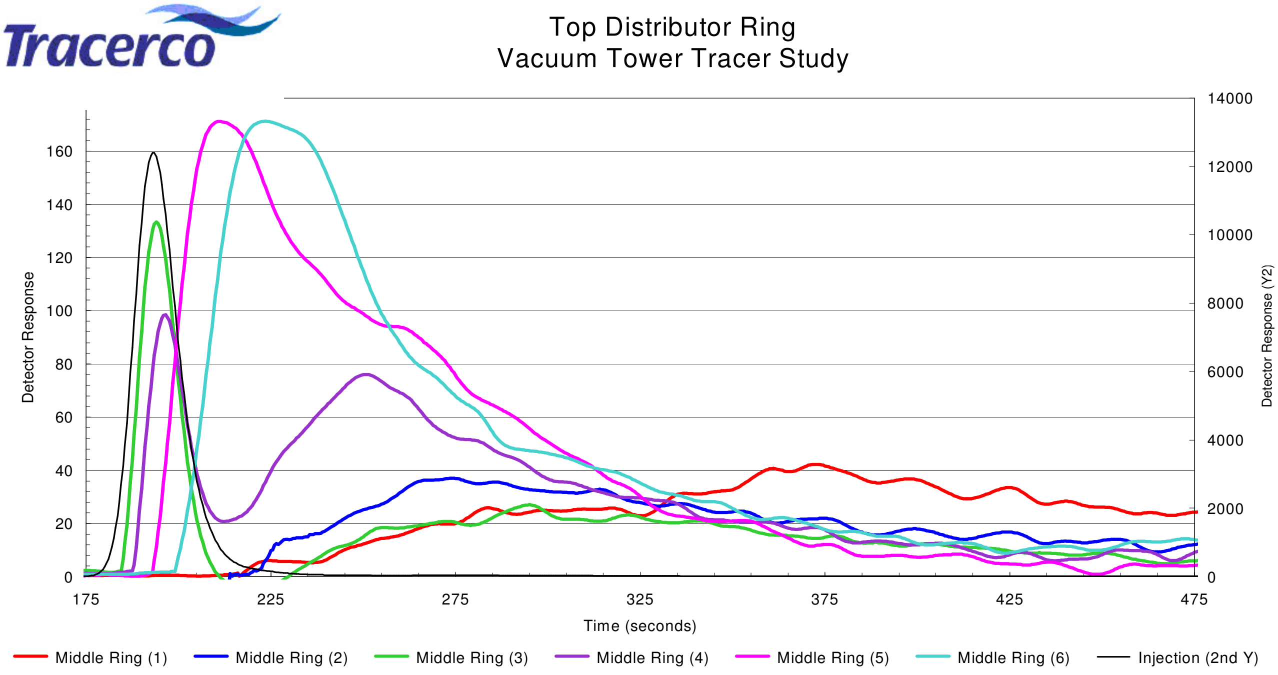


Liquid Distribution

The analysis of the liquid distribution in the bottom ring of detectors showed preferential flow to the 4 and 5 quadrants with 31.2% and 21.1% of the flow, respectively. The 1, 2, 3 and 6 quadrants showed 14.4%, 9.4%, 11.5% and 12.4%, respectively. See below for graphical representation of the response curves.



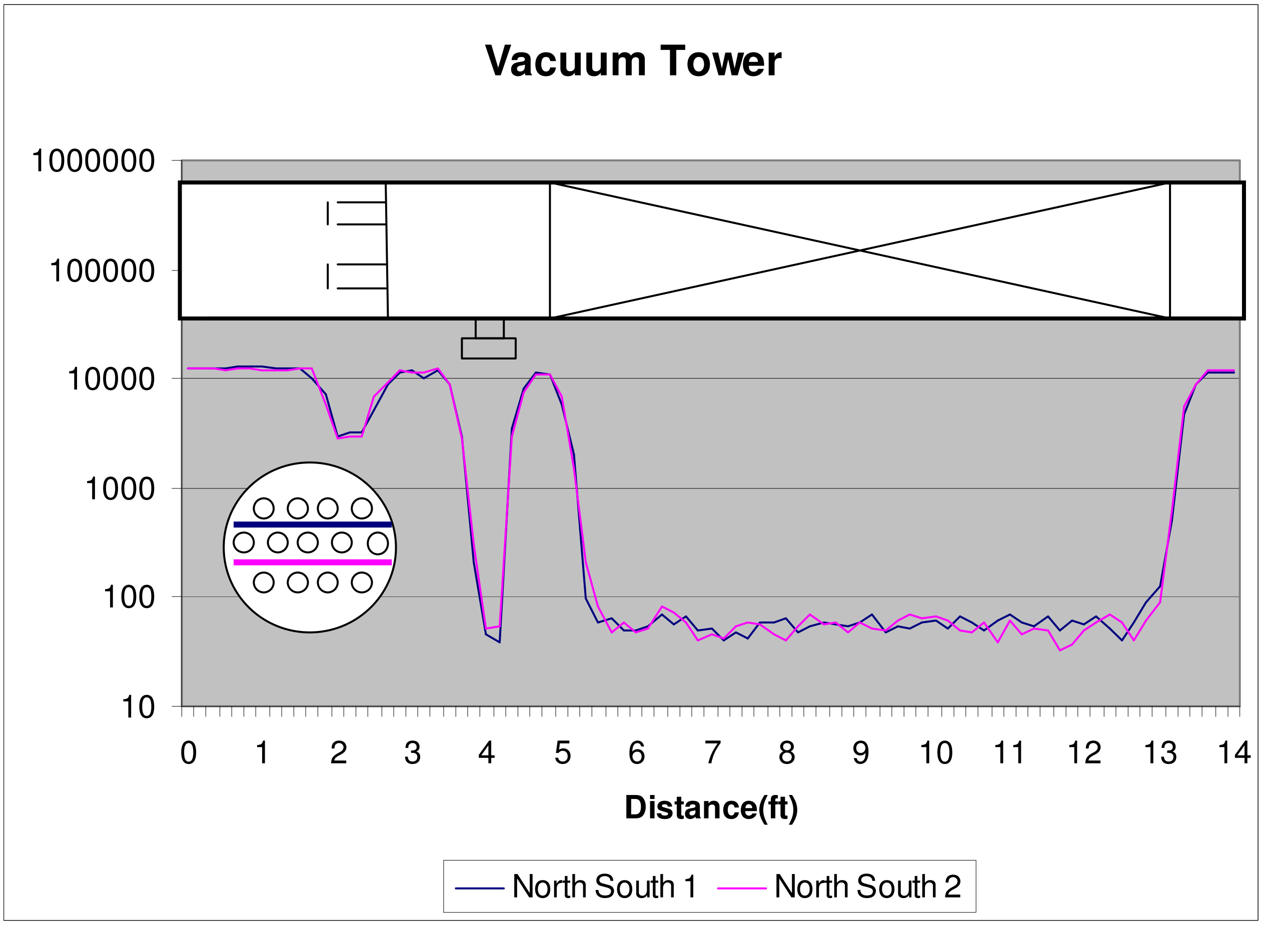
The analysis of the liquid distribution in the middle ring of detectors showed preferential flow to the 5 and 6 quadrants with 29.2% and 27.1% of the flow, respectively. The 1, 2, 3 and 4 quadrants showed 10.9%, 9.4%, 7.5% and 16.9%, respectively. See below for graphical representation of the response curves.



Theoretically, the vapor and liquid should behave the same in all quadrants, meaning the pulse profiles and timing should be identical for all. The data collected showed some preferential liquid flow to the 4, 5, and 6 quadrants within the tower. The information gained for this study aided in the evaluation of the liquid distributor used in the tower.

The application of gamma ray transmission technology is very effective in many situations. In the case of trayed towers a number of operational problems can be detected. However the technology must be used with caution in the case of packed bed systems. Usually in these vessels a gamma ray grid scan is performed using four equal length chords. The chords are selected to run through the bed such that two intersect the other two at an angle of 90 degrees. This arrangement allows the measurement of the presence and location of the distributor system, liquid height within the distributor and hence determines if the hardware is working correctly, is overflowing or is angled causing maldistribution of the liquids. In addition, this strategy is normally able to detect position of the bed and significant blockages within as the density difference is large between vapor and solids. However, when the actual problem is one of liquid or gas maldistribution the limitations of the technology must be understood by all involved in order that measurements obtained are interpreted in an appropriate manner and additional technologies are used to further explore possible sources of the problem.

A gamma scan was performed on the tower as well as the distribution study to help determine the position of the liquid distributor and associated liquid height. The graph below shows the results of the gamma scan.



The gamma scan showed the draw tray above the liquid distributor to be damaged and causing the maldistribution observed in the distribution study. No useable information was gained in the packed bed as the count rates were a background levels, but showed the packed bed to be intact.

Due to the physical and mechanical constraints of the modern vacuum tower, typical radioisotope techniques have to be combined to in order to solve the sometimes complex issues that arise in the distillation process.

Conclusion

Therefore when applying radioisotope technologies to a vacuum tower with packed beds it is recommended that the following strategy is used:-

1. Gamma Ray Transmission Scan Using One Chord of a Grid Scan Set. This will allow very obvious problems to be detected with minimal costs such as a missing distributor, missing or partially missing packed bed or flooded tower.

2. Gamma ray Transmission Gamma Grid Scan to assess the presence of distributor problems or localized significant blockages within the packed bed (if diameter allows).
3. Injection of a compatible liquid and gaseous radiotracers into the process with rings of detectors located at critical positions around the bed to detect the presence and extent of liquid or gas maldistribution.

It is therefore concluded that radioisotope technologies can be very useful tools in diagnosing operating characteristics of process vessels including both trayed and packed bed towers. However, limitations of gamma ray transmission must be fully understood in order that flow distribution problems are not missed and discounted as the source of tower malfunction.

Gamma ray transmission scanning is relatively inexpensive, and excellent at verifying the mechanical integrity and gross operational characteristics of a packed bed tower and distribution system. However, it faces severe limitations as a flow distribution measurement tool with as much as 50% flow maldistribution not being detectable.

Radiotracer distribution and residence time technology offers significant improvements in flow distribution measurement sensitivity, provides a measurement of traffic residence time, and allows distribution measurement of both liquid and vapor traffic to be determined.

In all packed bed diagnostic studies careful planning must be undertaken that uses gamma ray transmission as well as neutron backscatter to detect gross mechanical problems within the tower. Radiotracer use must be addressed as the second stage of the study if no obvious problems are determined using the scanning techniques. This approach ensures that all possible fluid flow distribution issues are covered as part of the tower performance investigation.