Paper 8g

Converting a Commercial Column Into a Research Tower

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New Frontiers in Distillation Tower Operations

Abstract

Koch Hydrocarbon Company owns and operates a large natural-gas-liquids plant at Medford, Oklahoma. One of the towers in this facility is a 5-ft diameter depropanizing column containing 60 trays, designated the *Swing Depropanizer*, or *4P*. This column is currently being converted into a research tower and will be used to collect research-quality efficiency and capacity data in a truly commercial environment.

The Swing Depropanizer is being refurbished and augmented by Koch-Glitsch, Inc., (KGI) in collaboration with Koch Specialty Plant Service, Inc. and Koch Hydrocarbons Company. It is to be equipped with multiple, new feed and reflux nozzles, new platforms, numerous sampling and pressure taps, abundant thermocouples and several high-precision flow meters. When completed, this column will be able to be switched back and forth between functioning as a production tower and as a tray and packing research column. In research mode, the setup will permit accurate determination of tray and packing capacity, pressure drop, and especially efficiency. This paper describes the work that has been done and the column's augmented capabilities.

Introduction

The approach to evaluating the hydraulic performance of trays and packing has invariably been to simulate as closely as possible the performance in some target chemical or hydrocarbon system by using an innocuous model system, principally one of those discussed by Cipa et al. (2000). Overwhelmingly, the main test system has been air-water, although air-isopar, and more recently air-ester and air-surfactant, have been used, too. The results of tests using such model systems have provided the basis for the hydraulic design of some 40,000 distillation columns in the United States alone. However, the importance of further tests in a production tower using the exact fluids of interest should not be overlooked. For example, Bennett and Ludwig (1994) pointed out the limitations of air-water tests, and concluded, "Such testing of distillation column internals can provide useful insights in some cases but, in others, can be misleading." Perhaps one of the best-known illustrations of this fact is the disparity between packing performance measured using air-water, and the performance of the same packing in high pressure distillation applications. The issue in this instance is not merely one of efficiency—hydraulic performance is also discrepant. Clearly, the Holy Grail of distillation tests is found only in a production setting. In fact, when discussing ULTRA-FRAC® trays Bravo and Kusters (2000) stated, "Efficiencies appear to be in the range of those achievable with normal trays, but this still is subject to confirmation." It is this need to confirm the efficiency for the ULTRA-FRAC tray and other KGI mass transfer devices that have led to the project that is the subject of this paper.

Objectives

The goal of this effort was to develop the swing depropanizer in the west plant of Koch Hydrocarbon Company's Medford Oklahoma facility into a resource for the gathering of efficiency data on trays and packing in order to validate new tower internals products in a hydrocarbon distillation environment. The facility also has the potential to be highly visible to KGI customers and, with the realization of such potential, it would likely be subject to frequent visits.

At the beginning of the project it was clear that several options existed for developing a new commercial-size research tower. At least 5 different options were seriously considered, including a new grass roots facility as well as several revamp options. The Medford site quickly became the obvious choice, not only for the wealth of columns that it offered and the fact that it is an extremely well-run facility, but also for the very pragmatic reason that KHC Medford went out of its way to make us feel very welcome—they wanted us there. The fact that a research facility was being welcomed into a production plant was enormously important, especially for the long-term and on-going success of the project. The 4P tower, in particular, admirably satisfied all project objectives and represented the greatest reward for the investment.

The desirable attributes of the revamped tower included:

- Industrial-sized tower used in light hydrocarbon service
- Usable in both production and research modes with the ability to switch readily from one mode to the other
- During operation in research mode, tower must still produce on-specification products, for the most part
- Must have full-function research-tower instrumentation to allow collection of accurate efficiency data
- Multiple sample taps for sample acquisition to support efficiency calculation
- Tower must retain all pre-revamp (production) control features to minimize change to normal operations
- Must have augmented safety features and procedures to ensure incident-free operation in both research and production modes. Because of wide-ranging operating conditions, research-mode safety considerations go well beyond the normal safety issues of a purely production facility
- Capable of several turnarounds per year

These attributes reflect the guiding revamp considerations of safety, flexibility, accuracy and simplicity. The paramount consideration was, and continues to be, safety.

4P Tower Before Modification

Figures 1 and 2 are photographs of the Medford West Plant showing Tower 4P and the West Plant Control Building, respectively. The original tower was equipped with 61 dual flow trays. In the early 1990's it was retrofitted on a one-for-one basis with ULTRA-FRAC trays. The resulting tower configuration has the top tray (61) functioning as a liquid distributor, and the remaining 60 ULTRA-FRAC trays arranged with 32 trays below the feed and 28 trays above the feed. This tray count provides far more separation power than normally required in depropanizer service; consequently, the tower usually runs pinched and the effective number of theoretical trays is in considerable doubt when operating data are used to extract tray efficiency estimates. This can be seen by examining the plot of the number of theoretical stages (NTT) vs reflux ratio (R/D) shown in Figure 3 and the plot of separation factor vs tray number shown in Figure 4. Figure 4 shows a relatively flat region where the separation factor is not changing, thus demonstrating a severe pinch. This figure also shows that the middle part of the tower (about 20 trays) is not contributing to the separation of the key components.

Figure 3 is based on July 2000 operating data; it reflects normal feed composition and typical purity specifications. From this plot it can be clearly seen that a more sensitive, but still efficient, number of theoretical trays with which to operate is about 24. A 32-theoretical-tray point-of-operation was selected in deference to the plant's concerns for production efficiency and the need to assure that the modified tower could make on-specification product *even during operation in research mode*.

The original column configuration included orifice meters (used for process control) and an on-line process analyzer for control of overhead- and bottom-product composition. These instruments are tied to the plant's DCS process control computer and allow very satisfactory control of the tower. The roughly 10% to 15% errors in metering do not affect the ability of the DCS to control the tower. However, such metering errors certainly do not permit a researcher to complete accurately either a mass or an energy balance. To apply process simulation to operating data taken in the plant's production mode configuration, it was necessary to resort to the usual practice of back-calculating the composition and feed rate from the measured compositions and the rates of distillate and bottoms products. (In other words, energy and material balances could not be closed closely enough to do otherwise.) This approach, when applied to the analysis of data collected in the period 1992 – 1995 (immediately after ULTRA-FRAC was installed), yielded results that showed the ULTRA-FRAC trays were operating in the approximately 70% – 90% efficiency range. Although encouraging, these results were considered insufficiently accurate for R&D work. The same metering errors were encountered with the July, 2000 data (already referenced in the foregoing), collected to assess the need for new, more-accurate instrumentation. Despite the care taken in collecting these data (see Table 1), lack of agreement between the measured and calculated flows is evident. Similarly, the reflux rate and reboiler duty differed from the calculated values by as much as 40%.

Table 1 Operating Data—Medford Swing Depropanizer Before Revamp†

Stream or Variable	Metered Rate	Calculated Rate	Ratio of Metered to Calculated (%)
Feed (bbl/hr)	215.2	237.7	90.5
Overhead Product (bbl/hr)	85.4	-	100
Bottom Product (bbl/hr)	129.1	-	100
R/D	2.481	1.838	135.0

† Feed = Overhead + Bottoms

These data were computer simulated using the number of theoretical trays previously determined, together with the raw-feed flow rate and composition values, and calculating the corresponding overhead product, bottom product, and heat duty. This analysis yielded flow rates and differences ranging from 5% to 50%. Collectively, the analytical work of 1992 – 1995 and the more recent work of July, 2000 demanded the tower changes itemized in the following.

Tower Modifications

Tower additions consisted of several significant cost items, summarized in Table 2. Not shown as additions, but items that must be considered during such a revamp, are the significant work required to remove old and add new insulation, testing for lead paint and its removal, heat treating where new nozzles are added, crane rental, scaffolding, and so on. The purpose of each addition listed in Table 2 is obvious with the exception of the Bottoms Cooler. The Cooler is a natural convection industrial air cooler, having a finned-tube surface area of approximately 1500 ft^2. Its purpose is to remove sufficient enthalpy from the bottoms stream to assure a subcooled liquid. Of the streams to be equipped with precision meters, only the bottoms is not pumped at or near its bubble point. Pumping bubble-point liquids represents a potential problem for metering. The metering technology selected utilizes Coriolis meters for mass measurement and, although highly accurate, they are sensitive to second phase formation. In fact these meters will not yield any useful readings at all if slug flow is present.

Table 2 Revamp Tower Additions

Number	Description
5	Fisher-Rosemount Micro Motion® mass flow meters
9	Fisher-Rosemount temperature RTDs
2	Fisher-Rosemount differential pressure cells; 1 for each tray section
2	Sets of 20 ULTRA-FRAC trays; 1 set above feed, 1 set below
1	Koch Industrial Coolers bottom-product cooler
8	Spectacle blinds for major tower nozzles
2	Feed nozzles, reflux nozzles & valves for changing configuration
4	On-tower sample points, piping & manifold
5	Pressure nozzles and transmitters
1	Set of platforms and ladders
2	Set of 20" Manholes and Blind Flanges
1	Set of redesigned ladders and platforms
1	Set of sample piping plus at-ground manifold for sample collection

To give experimenters all the features normally found in any well-equipped research tower, it is intended to install a pair of sight ports (windows) at two key tray locations, each equipped with a 6-inch port for illumination and a companion 8-inch port for viewing. The windows are Safety Sight Glasses supplied by Cyclops Industries, Inc., South Charleston, WV.

To accommodate potential viewing as well as the various safety-related activities associated with tower isolation at the start and end of each turnaround, it was necessary to redesign completely the ladder and platform system. Modification of the existing structures would have been an aesthetically ugly solution. At the recommendation of Koch-Glitsch Field Services, the entire system was redesigned and fabricated. The addition of spectacle blinds for all major tower lines is done for the convenience of multiple switches of the tower from production to research mode and *vice versa*.

As shown in Figures 5 and 6, the reduction in active-tray count from 60 in production mode to 40 in research mode is effected quite readily by switching feed locations from the original feed tray (32) (bottom-up tray numbering) to tray 21, and by redirecting the reflux from tray 61 to tray 41. In both production and research configurations, the first tray in each section functions as a distributor. The revamp not only produces two new zones of 20 mass transfer trays each, but in research mode it forces the uppermost 20 trays in the tower to run completely dry. After each series of tests is completed, the tower then can be switched back to its original production configuration to utilize the full complement of 57 trays in the revamped tower. This means that the Operations Department still has use of the tower with the maximum number of trays for most efficient production. R&D, on the other hand, has use of the tower in both 57-tray mode and in the generally-more-useful, 40-mass-transfer-tray mode.

The testing strategy calls for evaluating a different tray type in the rectifying and stripping sections. This is made possible by the addition of (i) new DP cells and temperature RTDs in each 20-tray section, and (ii) sample collection nozzles, both liquid and vapor, at the critical feed location, for the precise matching of simulation results with operating data. These new data, augmented with data collected from the highly accurate Micro Motion mass flow meters on each of the feed, distillate, bottoms and hot oil streams, allows the closure of the unusually accurate heat and material balances that are so necessary for accurate tray and packing efficiency calculations. Additionally, this same information allows more precise determination of the onset of flood.

For the first set of test runs, additional changes are being made to the tower internals. ULTRA-FRAC is a very high capacity tray. In the 1992 revamp to ULTRA-FRAC trays, the tower was equipped with six elements per tray. The column's reboiler is incapable of flooding this tower (and the condenser is incapable of condensing the vapor, if it could be flooded). To flood the tower within the established battery limits of the unit, it was necessary to blank off two elements on each tray (see Figure 7) above the new feed location (trays 21 – 40), and to blank off one ULTRA-FRAC element on the trays below the feed (trays 1 – 20). These modifications make it possible fully to explore the normal operating range of the tower with the new trays within the battery limits of the plant.

To facilitate addition and removal of trays or packing for both this and future revamps, two new manholes are being added to the tower. The addition of these manholes results in the loss of two trays at each location. Thus, the revamped tower contains four fewer trays of somewhat reduced capacity, but still capable of allowing the column to process all the feed that can be fed to it and with the greatest possible efficiency. Indeed, ULTRA-FRAC performs best from a mass transfer efficiency standpoint when operated at maximum rates per contact element, so the reduced number of elements per tray should result in improved efficiency at production rates.

Special Challenges

By far the most time consuming and challenging issues have been safety related, as embodied in the added equipment and the procedures required to run research equipment. The most notable of these are the Cyclops sight ports. Although a number of research towers, including towers at KGI and FRI, are routinely equipped with sight ports, they are an obvious (and undesirable) deviation from the ideal in a production facility. Processors of light hydrocarbons do not like glass and KHC personnel rightfully emphasized the significant difference between operation of a research tower and the heavily regulated operation of a NGL production facility. Both, of course, must comply with the same regulations.

The revamp team studied all the issues associated with collecting, transporting and analyzing samples. Staffing, safety, logistics, timing and execution of the tests led KGI to design a collection system at ground level, to be equipped with a manifold of valves and piping for sample collection and the (environmentally) safe return of purge fluids to the system.

Besides KGI, KHC and the Koch-Glitsch Field Services, Inc. (a division of KSPS, Inc.) already mentioned, this project has involved Optimized Process Designs, Inc., an engineering company subsidiary of KII. Diversified Projects, Inc., a provider of engineering and design services for the oil and gas industry, was used to assist in crafting the required changes to the P&IDs and PFDs, as well as to generate the necessary piping isometric drawings describing the changes to the plant piping system. All these players effected operational, business and procedural benefits.

Summary

A commercial column that can be operated in research mode is unquestionably the best test vehicle for developing mass transfer performance data for tower trays and packings. The conversion of the KHC Medford Swing Depropanizer into such a research tower will give Koch-Glitsch, Inc. a powerful new facility for demonstrating the capabilities of its newest mass transfer devices, such as ULTRA-FRAC trays and FLEXIPAC® HC™ structured packing. The revamp is scheduled for mid 2001.

Literature Cited

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Bravo, J. L.; K. A. Kusters; Chem. Eng. Prog., *96(12)*, p. 33, December (2000).

Cipa,T.; J.A.Garcia; M. Resitarits; R.. H. Weiland; *Fluids for Evaluating the hydraulic Performance of Trays and Packings*, paper presented at the AIChE Los Angeles 2000 Symposium on Distillation.

Figure 1 View of Koch Hydrocarbon Company's Medford OK Gas Processing Plant Facility, West Plant, Site of Conversion of Commercial Process Column Into a Research Tower

Figure 2 West Plant Control Room—KHC Medford OK Hydrocarbon Processing Plant

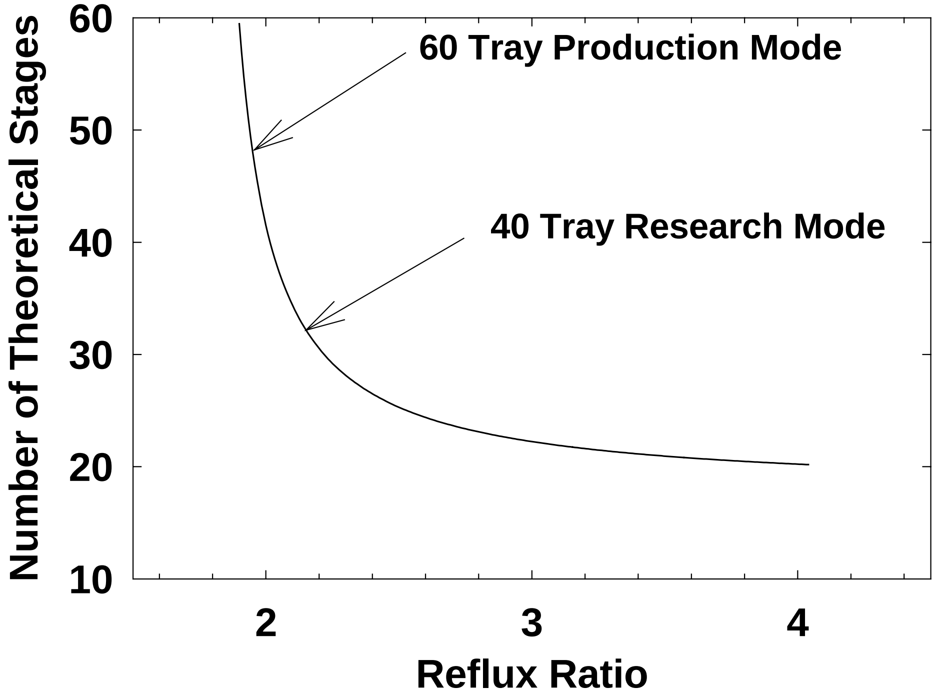


Figure 3 Number of Theoretical Stages vs Reflux Ratio for 4P Depropanizer Column

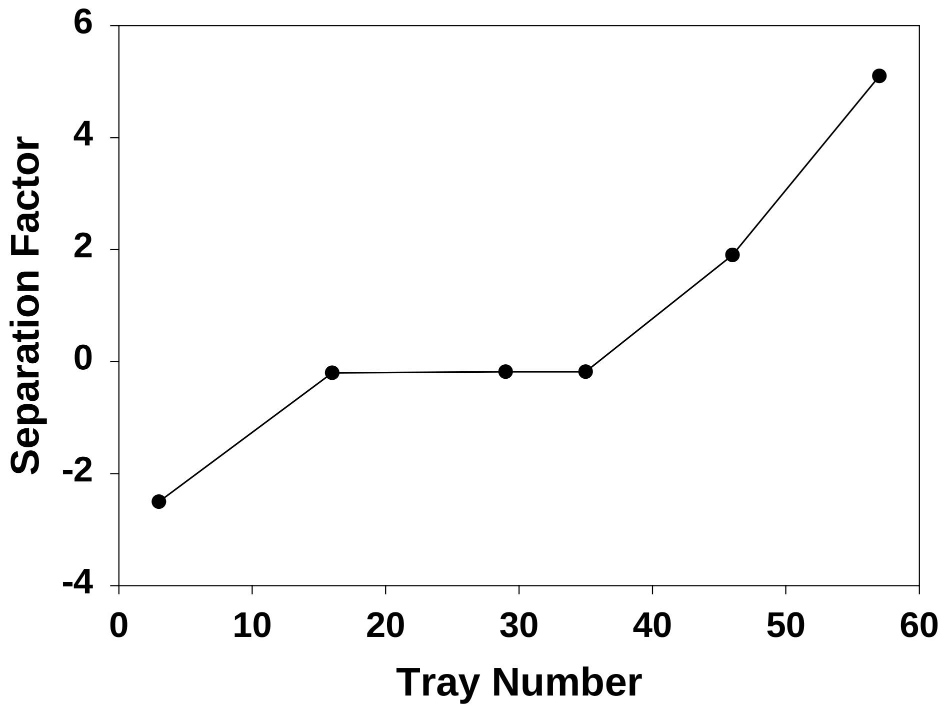


Figure 4 Separation Factor vs Tray Number From Bottom Showing Ineffectiveness of Middle 20 Trays (Pinch)

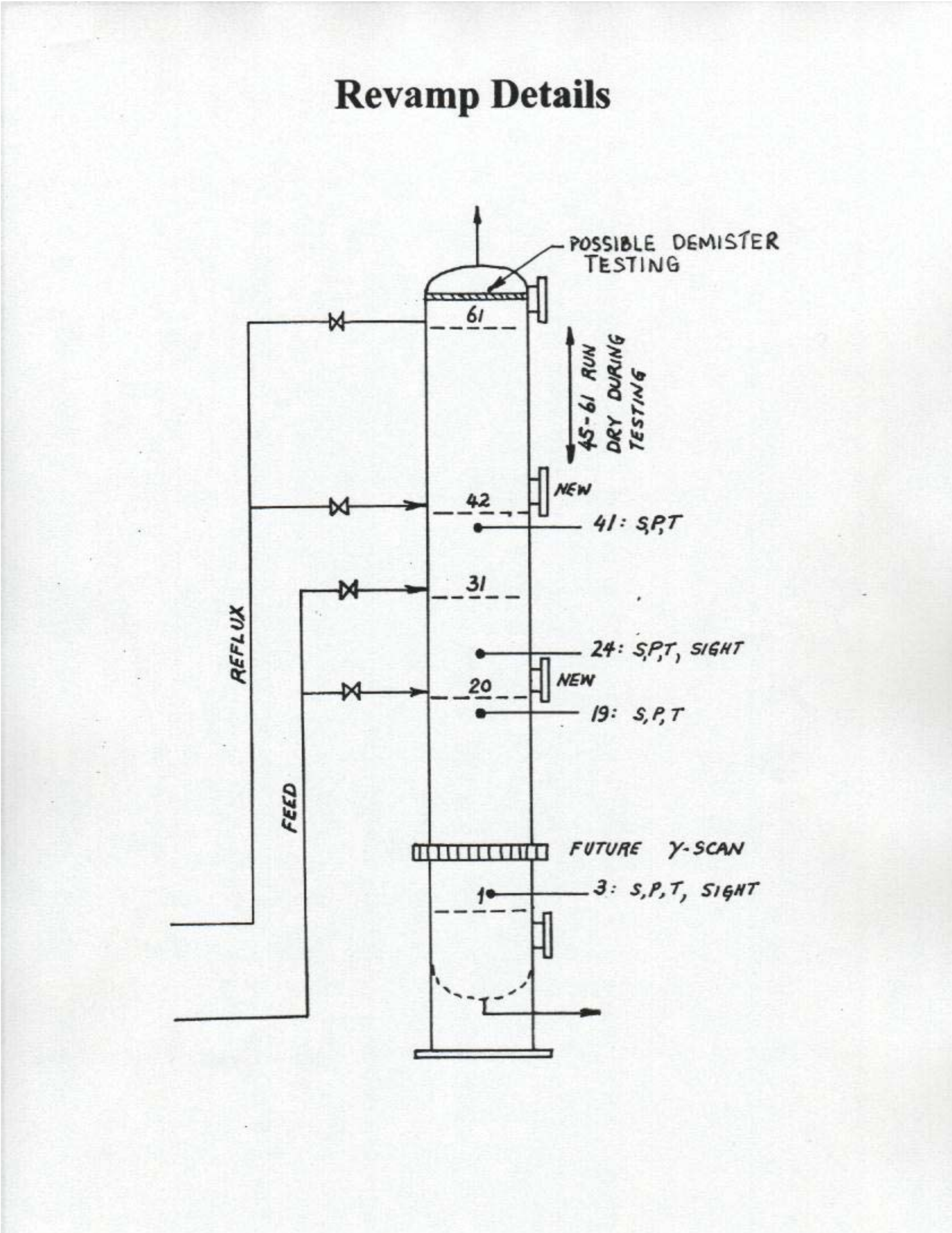


Figure 5 Detail of Column Revamp Showing Alternate Feed and Reflux Points, Positions of Sample Points (S), Pressure (P) and Temperature (T) Taps, Sight Glass Locations, and Position of Future One-Tray Detailed Gamma Scan

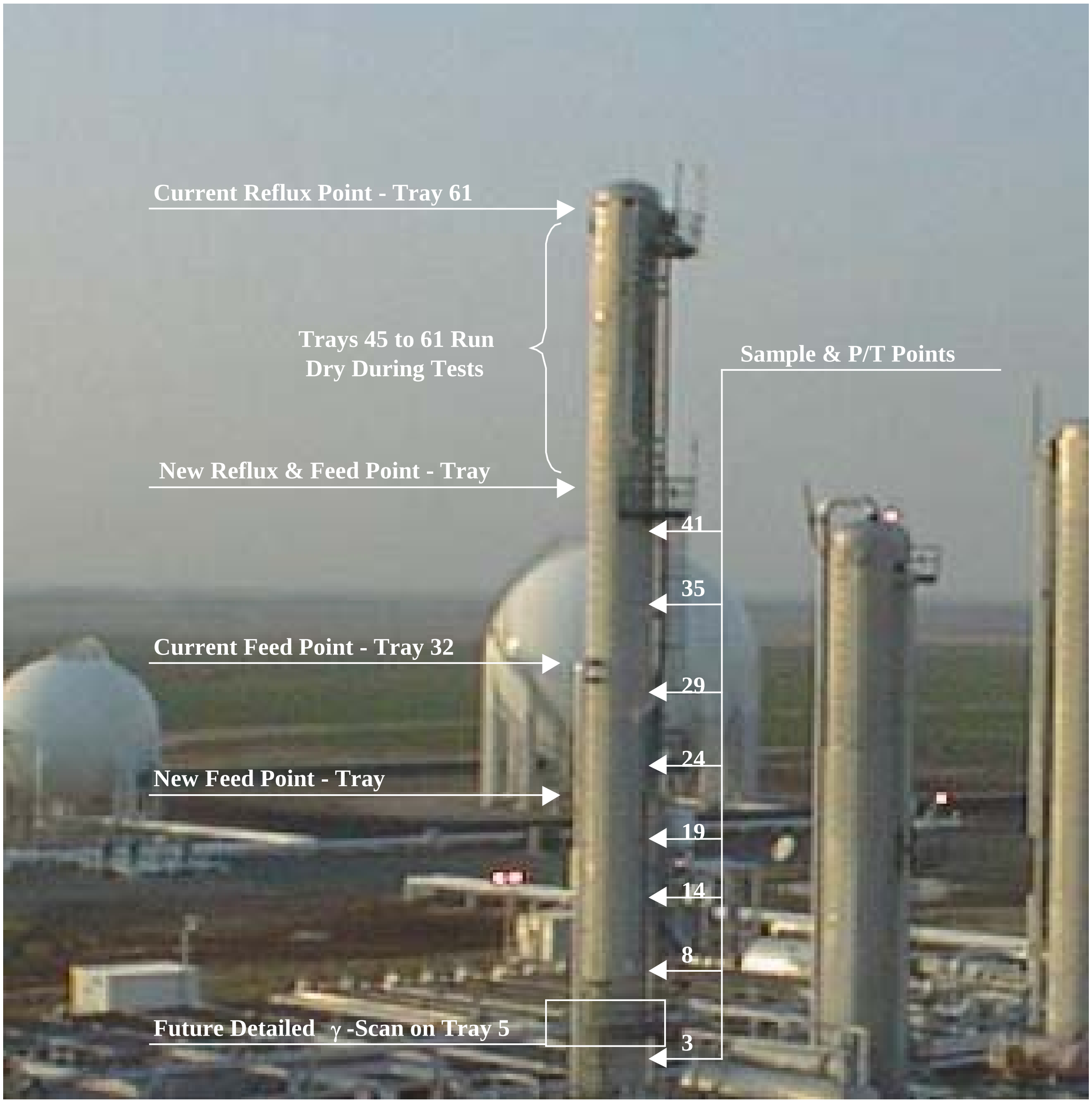
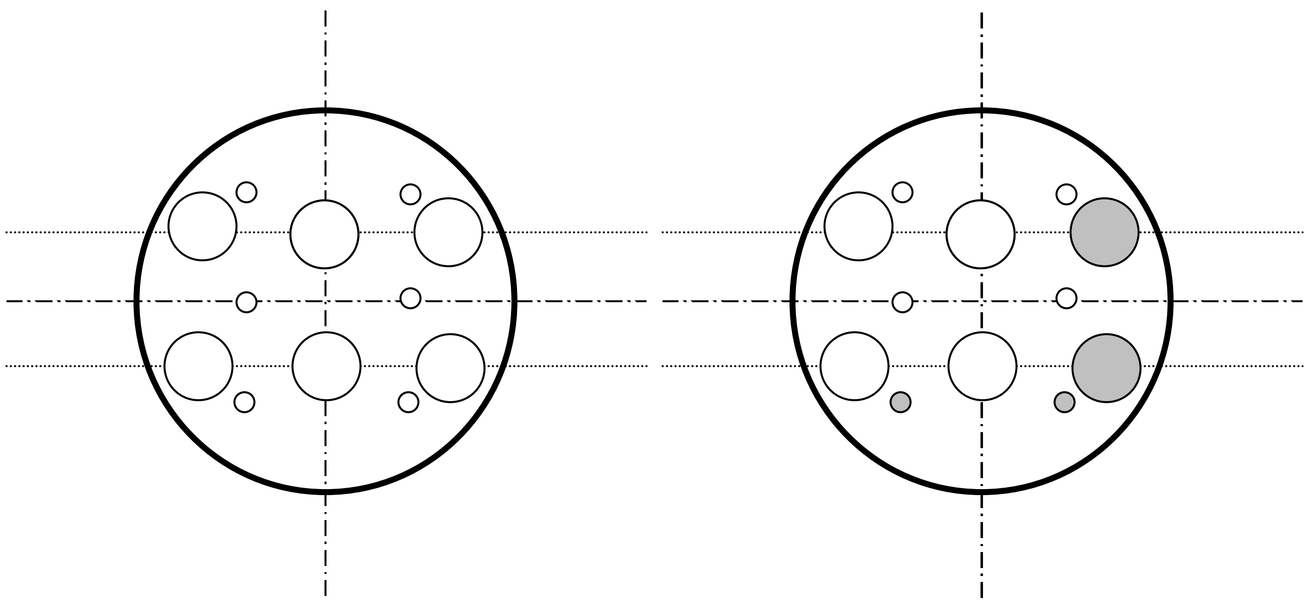


Figure 6 Photograph of 4P Tower Showing Additional Features



Original ULTRA-FRAC Trays—6 Elements Per Tray

Trays After Revamp (Grayed Elements Blanked—4 & 5 Active Elements Per Tray)

Figure 7 Typical ULTRA-FRAC Tray Before and After Revamp