HOW TO PROPERLY EVALUATE and DOCUMENT TOWER PERFORMANCE

By

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Abstract

Obtaining good tower performance information is a difficult and tedious task that requires special attention to many details. The end result of such an endeavor can lead to a wealth of knowledge that can be invaluable for the operation of that particular tower and numerous others. How to generate a good performance evaluation with proper sensitivity analysis and documentation will be the topic of this paper. Special attention will be given towards model choice, Heat and Material balancing, data acquisition, data evaluation, hydraulics evaluation, performance diagram generation, sensitivity analysis and final documentation.

The author has had the opportunity to evaluate numerous towers to examine both good and poor operation. Many of these evaluations have been the topics of prior papers(1,2,3,4,6,7,13,14,16). The wealth of his experience will be placed in this one document to help establish a standard for future tower evaluations.

Design Information

One of the simplest tasks in evaluating the performance of a tower is finding the original design basis, rating sheets and drawings. Oftentimes this basic information is lost, overlooked or simply ignored especially in those situations when an urgent troubleshooting is in progress. Efforts need to be made to determine the original design basis and it is highly suggested to duplicate the original design calculations with available (or different) hydraulic tools at hand. This effort is advised to ensure that the original design was not plagued by the (unfortunately) common typographical error that many times is made in the transposition of the original design loads and physical properties. In addition, rating sheet geometry information should be assembled based on drawing information, not the original design information, to ensure that the drawings were made to the expectations of the designer.

Basic information needed from the original design are;

Name of the Unit and Purpose of the Separation
Tower Diameter
Number of Trays or Packed beds
Tray Spacing or Bed Depth
Reflux and Feed Piping information
Distributor Types (Trough, Pipe Lateral or Pan)
Distributor hole type, count and size
No. of Tray Passes and Downcomer Widths
Internal Loads and physical properties
Design Operating Range (turnup and turndown)
Tower Attachment Drawings
Tower Internal Assembly Drawings
P&ID (Process and Instrumentation Diagram)
PFD (Process Flow Diagram)
Original Design Rating/Specification Sheets
Original Heat and Material Balance (if available)

Background

It is assumed that the reader of this paper is interested in determining how best to acquire and evaluate a single tower's performance information. It is presumed that the reader will be attempting to determine the number of theoretical stages that a particular tower is generating. To do this, there must be available to the reader, a VLE model that best represents the separation that is being investigated. This model can be as simple as an equilibrium curve on a McCabe-Thiele diagram or as complex as a multicomponent computer simulation that incorporates enthalpy effects. It is extremely important that the chosen model represent the real world as best as computationally possible. If the system being investigated is a common separation, there are typically several choices of VLE model to choose from. For example, a hydrocarbon separation will typically be best represented by a Peng-Robinson or Soave Redlich-Kwong Equation of State model with default interaction parameters that most commercial simulation providers supply. The same will apply to most common aqueous systems with alcohol except the VLE model is best represented by an activity coefficient model such as NRTL or UNIQUAC with default interaction parameters. However, difficult separations (those with relative volatilities of 1.5 or less) will typically need interaction parameters that are modified to represent the users past experience. For separations that a user is not familiar with, a thorough investigation of available VLE data and pure component physical property data (and even mixture physical property data if available) should be undertaken. Most commercial simulation packages have features that can fit interaction parameters to available manually input data. It is the author's most sincere hope that once a user establishes a simulation model, that the very next step they take is to reproduce the model prediction in direct comparison to the accumulated VLE and physical property data. There is nothing like the warm feeling one gets when they can physically see how well the model matches the pure component data and the relative volatility data. It is the recommendation of the author that once a model has been assembled, that it be documented thoroughly on how well it was fit to the available data and the documentation show the charts that reproduce the provided data. Charts such as the binary relative volatility vs. composition at isobaric or isothermal conditions against real data are especially useful. In addition, pure component model predictions vs. actual data for physical properties such as liquid and vapor density, liquid viscosity, surface tension, heat of vaporization and liquid heat capacity are especially useful when plotted against temperature. It is also the author's recommendation that once this model is established in this manner that it be documented thoroughly and NEVER be changed or adjusted in the future.

It is assumed at this point that a verified VLE and enthalpy model has been established for the major compounds and pressure range of the tower of interest. It is also assumed that original design information has been gathered as described above. Now the task is to assemble sufficient information regarding tower operation to determine both the tower's hydraulic and efficient performance. Efficient performance for the sake of this paper with respect to a trayed tower is defined as number of theoretical stages generated by the tower internals divided by the number of actual trays and is typically expressed as a percent tray efficiency. For a packed tower, efficient performance is defined as the packed height divided by the number of theoretical stages and usually expressed as an HETP (Height Equivalent to a Theoretical Plate). This definition of tray efficiency and HETP subsequently excludes rate based models(8,9) from any evaluation of a tower, and for the sake of this paper, an equilibrium based model must be used.

Tower Evaluation

Steady State

The first task in an evaluation of a tower is establishing an overall material balance. By establishing a material balance, you ensure that the tower is operating at steady state and the flow meters are correct. It is important that the evaluation of a tower be performed at steady state (or as near to steady state as reasonably possible). Steady state will ensure that there is the highest probability that a material balance can be established, that the tower is not in a transient flooded condition and the tower internals will achieve their highest potential efficiency. For optimum determination of efficient performance, the tower should be operated (during the evaluation) at the highest possible internal loadings that can be maintained at a steady state. Tower evaluations are often operated at conditions other than normal operation. Therefore, steady state needs to be maintained for a sufficient amount of time after the last adjustment tower operation to ensure that all composition profiles are reestablished throughout the entire volume of the tower. A good rule of thumb on the time it takes to establish and maintain steady state for a proper evaluation of a tower is take the tower liquid holdup using units of weight including the sump and reflux drum holdup, multiply this total holdup by the reflux ratio and divide this by the mass rate of the feed. This will provide units of time and establish the minimum time that it takes for the tower to reestablish steady state after an operational change has been made to the tower.

Material Balance

An overall material balance of Sufficient Quality is typically not easily or readily established for a tower under evaluation. Sufficient Quality for the sake of this paper is defined as +/- 10%. To some this is a large number, but even though the author has observed numerous towers with material balances better than this value, for most towers a material balance within 10% is difficult to achieve and maintain. In addition to the overall material balance, the major components in the tower also need to have a material balance that is of Sufficient Quality. Obviously for refining towers, without individual identifiable components, this is impossible, but most chemical and natural gas units should also be able to establish individual component balances as well as an overall material balance.

An overall material balance is considered established when the summation of all the feed flow rates minus the summation of all the product flow rates divided by the summation of all the feed flow rates is of Sufficient Quality as defined above.

When a material balance is not of sufficient quality, the flow rates need to be examined very closely. The most common reason for a poor material balance is that one or more of the flow rates (to or from a tower) are incorrect. The most common reason why a flow rate is incorrect is because current operation of the flow metering device is very different from when it was designed. Most flow meters are simply pressure drop measuring devices. Instrument technicians can easily check that a flow metering device is "zeroed" and spanned correctly, but when they are finished all you really know is that the pressure drop being transmitted by the device is accurate. When the physical properties are different than what the flow measuring device was designed with, then the translation of the pressure drop into a flow rate will be incorrect. In addition, if a flow meter that was initially setup to measure a purely liquid or vapor stream, encounters some flow of the other phase, the resulting average density is vastly different than the original design. The author has used Equation 1 below, which is a standard Orifice Equation for gases or liquids from Perry's Handbook found on page 5-11 in the 5th edition.

The pressure drop can be obtained from any commercially available flow controlling computer. Most readings from a flow element are transmitted to the flow controlling computer as a milli-amp (mA) value where a 4 mA value represents zero pressure drop and 20 mA represents the highest pressure drop that the flow element is currently spanned for. The mA reading has a linear relationship with the pressure drop across the metering device. The author commonly will check the flow rate recorded against the mA reading to see if the flow rate is accurate. The way this is done is to first zero the flow meter and check the span with an instrument technician. Then while the flow rate is relatively stable, get a mA reading from the flow transmitter and make note of the flow currently being recorded by the computer. With correct physical properties for the flowing fluid and the orifice specification sheet, equation 1 can be solved for the flow rate and checked for accuracy.

$$\mathbf{Rate = 3600\ C\ Y\ A_T\ (2\ g\ \rho\ \Delta P/(1-\beta^{4.0}))^{0.5} \qquad (Eq.\ 1)}$$

Where,

Rate = lb/hr
C = Orifice Coefficient (typically = 0.61)
Y = Expansion Factor (1.0 for liquids)
A_T = Area of Throat, ft2
g = Gravitational Acceleration, 32.174 ft/sec^2
ρ = Density of the Fluid, lb/ft^3
ΔP = Pressure Drop, lb/ft^2
β = Throat to Pipe Diameter Ratio

This equation can be used for several different types of metering elements including (but not limited to) orifices, venturis and flow tubes as long as a pressure drop is the measured value. Coriolis devices will not be commented on in this paper. The author has frequently found erroneous flow measurements with this simple check. Liquid flow measurements are very simple with this method since the expansion factor is always a value of 1.0. Vapors are a little more difficult. It is very important to know if the flow being measured is a single phase. If two phases are present, the percentage of each phase is never known accurately because it changes as it passes through the flow element, therefore the true density of the fluid is unknown.

For component balances it is highly important to know the composition of the feed and product streams around the tower. Samples are taken daily on most towers and analyzed in the plant's local laboratory. However, these laboratories are typically setup to measure for certain key compounds that can contaminate the final product and do not have the capability of measuring the full spectrum of a multicomponent column's feed. Therefore, unless the tower of interest has only a few components in the feed, a full component balance will typically need special laboratory assistance which more than likely will come from outside the local plant. Be very careful with compositions and understand the units of measurements that are provided by the laboratories. Frequently they will NOT provide the units such as molar, volume or weight percentages. In addition, it has been the author's experience that some components are measured by different methods and can subsequently be recorded with different units of measure.

Temperatures and Pressures

These important parameters are typically found in abundance around a tower. Make sure they make sense such that the highest temperature and pressure should be at the bottom of the tower with lessening values as you go up the tower. If you see a temperature inversion, check it carefully. It may be the result of a bad thermocouple. However, it could very well be a sign that there is maldistribution in the tower. Since most towers operate at the bubble point, you should be able to get a rough check of composition in a tower if given a pressure and temperature reading at the same point in the vessel. On the other hand you can also check if a thermocouple or pressure measurement is trustworthy if they do not accurately reflect bubble point conditions in the part of the tower where you are sure of the composition. It is the author's experience that thermocouples are typically more accurate than pressure measurements. Therefore, it is wise to check the pressure measuring instruments first if there is a discrepancy, or to trust a temperature over a pressure. Temperature can usually be checked with a hand held TI (Temperature Indicator) at the thermowell if a faulty reading is suspected. In addition, a Temperature Gun or Pyrometer can be useful at other locations (except for heavily insulated cryogenic units). These pyrometers don't actually check the process temperature but the heat radiating from the skin of a process vessel or pipe and they translate that into a temperature. It is best to "shoot" the equipment with the Pyrometer as close to the vessel as possible and pick a place that is near insulation and is dark in color. Pyrometers tend to pick up thermal radiation more accurately from a dark colored surface than from a painted or shiny surface. Skin temperature can be 10 to 15 degrees F different than the process temperature because of the temperature gradient between the process temperature and ambient temperature and the heat transfer coefficient of the whole layout.

Heat Exchangers

These unit operations need to be understood to establish a Heat Balance around the tower. The reboiler(s) on a tower are typically instrumented sufficiently to determine the valuable energy consumed by them. Steam or process flows to the individual reboiler are typically measured as well as the inlet and outlet temperatures. The most difficult part of determining the heat duty of a reboiler is truly understanding the condition of the steam that is coming to the reboiler or the fuel flow to the fired heater that is used as a reboiler. Knowing the pressure of the steam and understanding if it is superheated is extremely important to determine the overall duty. If the steam is close to saturation (dew point) there may actually be some liquid water carried with the steam which then adjusts the average density of the fluid and can give erroneous flow measurements. Typically the steam condensate flow rate is not measured, only the steam supply. Again special efforts should be made to check the steam flow meter with the procedures outlined above. Once the steam flow rate is known as well as the inlet and outlet conditions, the heat duty can be determined by the difference in enthalpy. Again make sure that the observations make sense, such as the bottom temperature of the tower should not be hotter than the reboiler return temperature. Condensers, especially water cooled condensers, are notoriously devoid of instrumentation. They lack both water flow meters as well as outlet water temperatures. Typically the cooling water supply temperature is the only reliable (or know) measurement around a water cooled condenser. This is understandable because there is no energy "price" for the use of cooling water. Cooling water is typically abundant and free. Air cooled condensers also typically lack instrumentation to determine their operating duty.

Heat Balance

A heat balance is typically achieved by checking the reflux rate (which is measured) against the reboiler duty with a simulation. The simulation should account for all the enthalpy differences with the feeds and products as well as the reflux and reboiler duties. It is extremely important to know the reflux temperature when determining a heat balance because subcooling of the reflux (which is very common) can be a very large. The author has seen towers refluxes with more than 100 degrees F subcooling. An overall heat balance of Sufficient Quality is hardly ever measured much less established. Reflux meters have nothing to balance them directly against to see if they are even in the "ballpark" with accuracy. Reflux meters are typically set at startup and then never adjusted again. The reflux flow (or ratio) is watched by the operators to gauge if the plant is close to design performance but the absolute value of the flow rate is typically never checked. Therefore, the reflux flow is typically not well established or reliable for a tower under evaluation. Heat balances of Sufficient Quality for the sake of this paper is defined as +/- 10%. However, to accurately determine the tray efficiency or packing HETP, a heat balance better than 5% is typically needed.

For heat pumped systems, the overall heat balance is also difficult to obtain because the cooling water flow rate to the trim cooler (condenser) is almost never measured. However the reboiler duty can be determined by the heating fluid's flow rate (which is typically measured) to the reboiler/condenser and checked against the reflux flow rate in a simulation of the tower. This will not reveal the overall heatpump heat balance, but the column heat balance.

Heat integrated systems pose some interesting dilemmas. For these systems the reboiler of one tower may be the condenser of another. When this is the case, there typically is insufficient information to be able to isolate data for a single tower. Therefore, these systems add complexities to the evaluation in that all of the heat integrated towers need to be evaluated to simply determine the performance of one individual tower. This is very typical of today's modern fuels ethanol plants(10) where a high pressure rectifier's condenser is the reboiler of the Beer Still.

Data Assembly and Enumeration

An important aspect of recording and documenting a tower's performance is identifying all the important flows, temperatures, pressures and compositions in one place, preferably on a single sheet of paper for an individual column. The author has demonstrated this several times in his previous work(1,2,3,4,6,7,13,14,16). An example of this can be seen in the attached Table 1 which is from a Heat Pumped C3 Splitter(7). Note that in this Raw Operating Data Summary there is a data column for the tag number or source of the information tabulated here and a data column for the accuracy. It is extremely important to note the source or tag number of the instrument providing the information. This table makes it easy to reference where the information came from and can be used as a template for future evaluations of the particular tower. The accuracy data column tells the evaluator how good a particular measurement is. The accuracy is determined by recording (or observing) operation during the steady state period and noting the average high and low values of the various instruments during this period of time. This is very important when trying to establish a material balance, for example. Small streams, such as product steams which are typically much smaller flows than feed streams, can have a higher inaccuracy than larger streams and not severely affect the material balance. Therefore it is good to know which streams have the highest reliability when determining the material or heat balance. It is also important to record the date and the time period that the data was taken for future reference. A ready reference of what data is needed in a typical tower evaluation can be seen here:

Feed Flows, Temperatures and Pressures
Product Flows, Temperatures and Pressures
Compositions of all feeds and products
Tower Top and Bottom Pressure
Reflux Drum Pressure
Intermediate Pressures (if available)
Tower Top and Bottom Temperature
Reflux Temperature
Intermediate Temperatures (if available)
Steam Pressure at Reboiler
Steam Supply Temperature (superheated?)
Steam Condensate Temperature
Cooling water flow rate to condensers
Cooling water temperature change (if available)
Heat Pump compressor compression ratio (if applicable)
Compressor Suction and Discharge Temperatures (if applicable)
Pump-around flow rates and temperatures (if applicable)
Side Exchanger withdraw/return rates and temperatures

Simulation

With this tabulated data and a heat and material balance of Sufficient Quality, a simulation of the tower can be made. Commercial quality simulation software have distillation unit operations built into them and the data in Table 1 can be readily and easily accommodated. A detailed feed analysis should be used for the feed composition. If this is not available, then the products can all be added together to represent the feed (assuming there is only one feed). The simulation software will need some specifications. Preferred specifications are product compositions as opposed to reflux rate (or ratio) and a heat duty. The later may be simpler to converge the simulation but will not be helpful in the sensitivity evaluation of the determined performance.

The feed point needs to be determined early in the simulation process. Typically there is insufficient information to accurately place a feed point within a simulation. The ONLY true way is to have a side sample taken from the tower one or two trays away from the feed tray. With this information, the feed point will be one theoretical stage from the simulation's internal composition that most closely matches that side sample. Taking the side sample at the feed tray will provide a sample that is highly influenced by the feed and not represent the tower composition. It is not recommended to take a tower sample at the feed tray.

In a packed tower this is a little more difficult. Typically the packed bed above the feed point will have a liquid collector immediately below the bed. If a sample nozzle exists at this collector, then a liquid sample of the bed can be taken and its composition analyzed. The feed point will then be one theoretical stage below the simulation's internal composition that most closely matches that side sample.

An alternative (and less accurate method) is to match the feed temperature to the tower simulated internal temperature. This only works if the feed is at the bubble point and at the same pressure as the tower. It will not work for subcooled or superheated feeds. Without sufficient feed point information, the best that can be done to place the feed point in a simulation of tower operating data is to assume that the performance of the trays or packing is proportionately distributed to all the trays/packed beds equally. This gets a little difficult when, for example, there are trays below the feed and packing above.

Tray or packing performance is determined by simulating the tower numerous times with various theoretical stages while applying the feed point(s) as established above. It is highly recommended that a theoretical stages vs. reflux ratio curve be generated for a wide range of theoretical stages. Alternatives to reflux ratio for this curve could be reflux rate, condenser duty, reboiler duty or any other parameter indicative of the heat balance. An alternative to theoretical stages can be tray efficiency. However, simulations using various forms of tray efficiency will give erroneous results at low efficiency values. It is highly recommended by the author to conduct simulations, especially for a detailed evaluation, using theoretical stages. The author does realize that running simulations are a lot easier to set up using real trays and then applying a tray efficiency factor to determine the desired results.

A typical theoretical stages vs. reflux ratio curve is shown as Figure 1 attached. The observed reflux rate is shown and represents 79 theoretical stages. By examining this plot carefully, one can easily see that the number of theoretical trays are somewhat sensitive to the reflux rate. For example, the error in the heat balance that this example came from was 2.5%. A 2.5% change in reflux rate translates into a reflux rate change of only 21,000 lb/hr. The resulting change in theoretical trays is from 79 to 74 or a 6.3% loss in theoretical stages. An error of less than 10% on theoretical stages is very good. If the heat balance from this example had an error potential of 5% (which is still quite low), the change in theoretical stages would have been well in excess of 10% and the tray efficiency validity would have come into question. It is the author's opinion that curves of this nature are an invaluable part of a tower's performance evaluation.

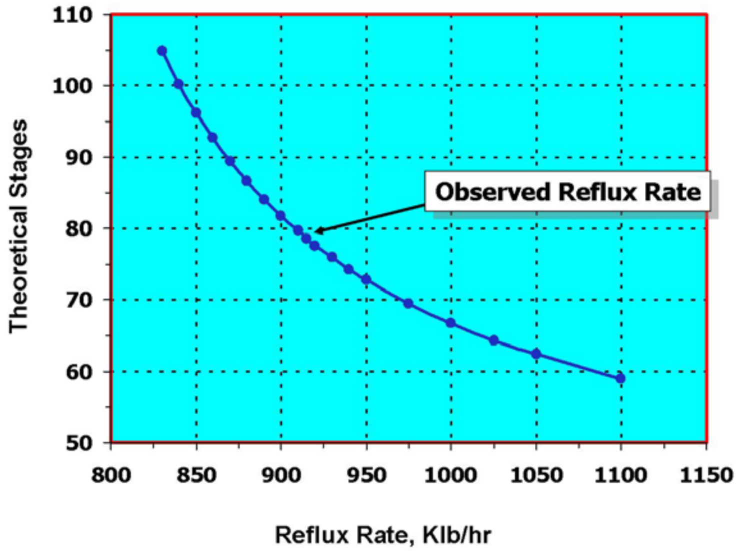

Figure 1 – Efficiency Sensitivity

Hydraulics

Once the observed operating point simulation is determined using the curve in Figure 1 above, internal loads and physical properties can be generated from that Heat and Material Balance simulation. The Heat and Material Balance needs to be summarized and documented at the observed operating conditions. An example of such a summary is shown in Table 2 (which was Table 4 in reference 1). The loads and properties from this Heat and Material Balance can then be used to evaluate the performance of the tower internals including the trays, packings, distributors, withdraw devices and chimney trays. Commercial software to perform these calculations are available(12) unless the equipment is proprietary, then you need to see the vendor of the particular equipment. Hydraulics documentation on the performance of trays should include values that indicate the vapor maximum capacity, liquid maximum capacity, froth/spray transition determination(11), pressure drop, dry tray pressure drop, downcomer velocity and weir loading. For packed tower sections the documentation should include vapor maximum capacity, overall pressure drop of each bed, pressure drop per unit depth, and liquid load divided by tower cross sectional area. In addition, a comparison of the liquid load to the original design liquid operating range of the bed's distributor should be included.

A proper evaluation of a tower does NOT end with a simple evaluation of the trays or packings. It also MUST include an evaluation of all the distributors, withdraws, chimney trays and nozzles to be considered complete. In addition for trays, performance diagrams can be generated with today's hydraulics software and is an invaluable part of the documentation process(5). Performance diagrams, once generated and if plotted with liquid volume units and vapor v-load units, can represent tray performance independent of operating pressure and composition.

Pressure Drop

The observed pressure drop across columns today can come from two sources. One is the typical Pressure Differential or DP Cell. A DP Cell measures the pressure differential between two elevations of the tower. The DP Cell itself is typically elevated above both pressure taps and is free draining back to the tower with (typically) ½" tubing. The other method to obtain pressure drop is to take two localized pressure measurements from two tower pressure taps and then subtract them in the control room. For short low pressure towers the pressure drop determined by both methods is nearly identical. However, for tall high pressure towers, the difference in the two methods can be very significant. Any time a tower's pressure drop is evaluated, the method of recording should be established and the elevations between the two pressure taps recorded. The reason for this is that most pressure drop calculations for either trays or packings do NOT account for the vapor head in the tower. Historically there is a reason for this. When tower pressure drops were measured exclusively with DP Cells, the vapor head was inherently subtracted in the long vapor leg from the lower pressure tap. To make the pressure drop predictions for tall towers in high pressure applications match the observed tower pressure drop, the vapor head was eliminated from most tray and packing pressure drop calculations. Today, numerous towers do not have DP Cells or are in the process of removing them. As a result, observed pressure drops are sometimes 30 to 50% higher than the original predictions. An example of this phenomenon (1) showed an observed tower pressure drop of 10.6 psi. The predicted pressure drop was only 7.41 psi. The elevation between the two tower pressure taps was approximately 185' of height which has a gas head of 83.6 inches of water. Assuming a vapor density of 2.35 lb/ft^3 this equals 3.02 psi. When added to 7.41 the total pressure drop is 10.4 psi which was within 2% of the observed value.

It needs to be noted that tower pressure taps can be found located in a variety of places such as the overhead vapor line, the condenser receiver or the opposite wall from a highly energetic reboiler return. Be sure to note exactly where the pressure taps are located (in addition to elevation) because the pressure drop results can be highly influence by what is happening near by or include other head losses.

An important side note is that the predictive pressure drop for high pressure towers will always be lower than the real world as long as the vapor head is not accounted for. Normally this has no affect on tower operation because the magnitude of the tower pressure drop is so small in comparison to the overall pressure of the tower. The pressure drop is not large enough to need to be accounted for in the tray or packing design because the physical properties (e.g. vapor density) is not affected to any significant extent as it is in vacuum applications. There is one area however, where it is important to understand the true pressure drop in high pressure operation. That important area is tall Heat Pumped towers. For these towers, it is extremely important to know the tower's true pressure drop because the reboiler ΔT and compressor capacity and compression ratio are highly dependent on this value.

Gamma Survey

Radioisotopes can be used to diagnose shortfalls in tower capacity and performance(15). When compositional and pressure drop analyses fail to determine the root cause and/or the location of a shortfall in tower performance, gamma scans, radioisotope injection, X-rays and neutron backscatter tools can be employed. It is not part of the scope of this paper to discuss this topic (there are plenty of references listed in reference 15) but it is important to mention that "dry" gamma surveys of a packed or trayed tower needs to be included in the documentation of tower as well as any radioisotopic diagnosis that was performed during the evaluation of the tower's performance.

Documentation

This is an often overlooked aspect of Tower Performance yet is the most valuable for retention of valuable experience. The author has witnessed numerous detailed studies of tower operation become trash because either a system was not in place to retain the information or the information was not placed in a usable format. How many engineers have collected data and written reports on a particular topic and then need to focus on another project before they have had a chance to weed out their files and assemble a summary report?

Evaluation and/or troubleshooting a tower takes a lot of work as outlined above. This work needs to be summarized and documented for posterity. Even if the tower is taken out of service and the plant demolished, the information from the performance of any tower is an invaluable piece of information that needs to be retained. It is very rare that distillation towers are evaluated thoroughly. When this evaluation does occur it needs to be summarized and documented well. Below is a list of information that is of particular interest and needs to be retained so that future generations may benefit from this knowledge. The information that is recommended to be retained is found below and should be tabulated in this logical order:

Title and Description of the Evaluation
Vessel Sketch
Flow Diagram
Original Design Rating Sheets
Assembly Drawings
Tower Attachment Drawing
Raw Operating Data Summary Table(s)
Simulation Input Sheets and VLE Reference
Theoretical Stages vs. Reflux Ratio Curve
Observed Heat and Material Balance Summary Table
Hydraulics Performance Rating Sheets
Performance Diagram (Trays Only)
Distributor Design Sheets with Operating range (Packing Only)
Evaluation sheets for Nozzles, Distributors and Withdraws
Overall Tower Pressure Drop Analysis and Summary
Gamma Survey (if performed)
Applicable Photos of tower and Internals

Conclusions

Historically, there is a dearth of tower operational feedback. The main reason for this lack of information is that a proper evaluation of a tower is a tedious and multi-tasking operation. Not many people have the time and understanding to perform all the tasks needed for a proper operational study. Frankly, it is difficult to obtain good operating feedback from a distillation tower. The only time people will take the effort to do a tower study is when it is perceived to be operating erratically or there is a particular interest in determining the performance (e.g. new application). This paper hopefully will make this task understandable and simpler by illustrating how to best generate a good performance evaluation with proper sensitivity analysis and documentation. The goal and dream of the author is that this document can somehow, in a small way, help the industry to establish a standard for future tower evaluations and enable a significant increase in column performance feedback.

Table 1
Raw Operating Data Summary

Data	**Units**	**Tag No.**	**Value**	**Accuracy**
Feed Rate	BBL/D	FE-8854	4975	+/-50
Feed Temp.	Deg F	Pyrometer	87	
Top Pressure	Psig	PI-8831	100	
Delta-P	psi	PDI-8827	9.2	
Top Temp.	Deg F	TI-8774	53	
Bottom Temp	Deg F	Pyrometer	73	
Comp. Suction Temp.	Deg F	Pyrometer	55	
Comp. Discharge Press	Psig	PC-8832	230	
Comp. Discharge Temp.	Deg F	TI-8776	119	
Comp. Discharge Temp.	Deg F	Pyrometer	135	
Main Reflux Rate	MSCFD	FT-8858	34,550	Too Low
Main Reflux Temp.	Deg F	Pyrometer	74	
Trim Reflux Rate	BBL/D	FT-8857	600	
Trim Reflux Temp.	Deg F	Pyrometer	99.5	
Bottoms Flow	BBL/D	FT-8864	1060	+/-50
Propylene Product Temp	Deg F	Pyrometer	110	
Propylene flow rate	BBL/D	FT-8860	3840	+/-100
Overhead Composition	vol% C3=	AR 869-3	92.1	+/-0.5
Bottoms Composition	vol% C3-	AR 869-2	97.1	+/-0.1

TABLE 2

Heat and Material Balance

October 19, 2006 Operation Simulation Results

C_2 Splitter and Vent Condenser Tower

(Composition: wgt%)	**Feed**	**Vent**	**Ethylene Product**	**Dilute Ethylene Product**	**Ethane Bottoms**
Hydrogen	0.0016%	0.26%	0.21 ppm	0	0
CO_2	0.0001%	0.0006%	0.0002%	0.61 ppm	0
Methane	0.091%	14.45%	0.007%	0.007%	0
Ethylene	77.77%	85.28%	99.98%	80.44%	1.55%
Ethane	21.66%	0.0002%	0.0109%	19.56%	96.17%
Propylene	0.291%	0	0	0.002%	1.37%
Propane	0.0071%	0	0	0	0.033%
IsoButane and Heavier	0.187%	0	0	0	0.88%
Total	100,000*	588	71,853	6,292	21,265
Phase	Vapor	Vapor	Liquid	Liquid	Liquid
Temperature, °C	-13.0	-43.4	-29.8	-26.1	-7.0
Pressure, psig	340	250	270.5	276.2	279.7

DA-2410 Condenser Pressure	250	Psig
DA-2410 Top Pressure	251	Psig
DA-2404 Condenser Pressure	269.9	Psig
DA-2404 Top Pressure	269.9	Psig
Vent Condenser Duty**	0.73	MMBTU/hr
Condenser Duty**	49.87	MMBTU/hr
Reboiler Duty**	23.18	MMBTU/hr
Side Reboiler Duty**	13.17	MMBTU/hr
Reflux Rate to DA-2410*	4,730	lb/hr
DA-2410 Reflux Temperature	-43.4	°C
DA-2410 Top Temperature	-36.1	°C
Vapor Rate to DA-2410*	5,318	lb/hr
DA-2404 Reflux Rate*	349,370	lb/hr
DA-2404 Reflux Temperature	-33.7	°C
DA-2404 Top Temperature	-30.4	°C

*All Flows adjusted to a 100 Klb feed basis to mask the true capacity of the Unit
**All duties adjusted to a 100Klb feed basis

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