The Economic Advantage Added by Specialized Knowledge of Distillation Fundamentals

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01 October 2011

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1.0 Introduction

Knowledge is a familiarity with someone or something, which can include information, facts, descriptions, and/or skills acquired through experience or education. It can refer to the theoretical or practical understanding of a subject

Wisdom is a deep understanding of people, things, events or situations, resulting in the ability to choose or act to consistently produce the optimum results with a minimum of time, energy or thought. It is the ability to optimally apply perceptions and knowledge and so produce the desired results.

The Law of Comparative Advantage is the ability of an individual, company, or economy to conduct an activity better than another for some fixed and sometimes almost unchangeable reason. Comparative advantage is important in making decisions such as what products one should make or sell; if a company is unable to make a product as well as another and that is unlikely to change, the company might be well advised to make a different product.

Kolmetz Law of Specialized Knowledge Advantage is the ability of an individual, company, or economy to conduct an activity better than another, for a changeable reason such as specialized knowledge

2.0 Distillation Specialized Knowledge

In most chemical processing systems two main unit operations dominate; chemical reaction followed by separation. From the reactor the reactants are then sent to a separation unit. In the separation unit, the reactants are separated into desired products, unreacted products for recycle, and unwanted or by products.

It has been estimated that the capital investment in separation equipment is 40-50% of the total for a conventional hydrocarbon processing unit. Of the total energy consumption of an average plant, the separation process accounts for about 50% to 70% of the energy consumption of the plant.

There are many separation processes and each one has its best application. They include distillation, crystallization, membrane, and fixed bed adsorption systems. Occasionally the best system may be a combination of these systems fundamentals.

The choice of the best application should be based on the life cycle cost. The life cycle cost is the initial capital cost of the plant along with the first ten years operating and maintenance cost. The life cycle cost should include a reliability factor, which is very important in designing any process plant equipment, reactors or separation equipment. Improved reliability has a very large impact on return on investment (ROI). Many life cycle cost only review energy, but not solvent, adsorbent, or catalyst cost because of accounting rules and this can lead to skewed economic decisions.

Distillation may be the most economical and utilized when possible. Distillation is the separation of key components by the difference in their relative volatility, or boiling points. It can also be called fractional distillation or fractionation. Distillation is favored over other separation techniques such as crystallization, membranes or fixed bed systems when;

1. The relative volatility is greater that 1.2,
2. Products are thermally stable,
3. Large rates are desired,
4. No extreme corrosion, precipitation or sedimentation issues are present,
5. No explosion issues are present

3.0 Extend Unit Run Length (Reduce Maintenance Cost)

Hydrocarbon Producers are exploring avenues to extend the on-stream time between outages for maintenance. Key equipment that can determine the end of run includes: catalyst life, cyclone erosion, and compressor and tower fouling. Critical equipment that has been shown to be a limiting factor can be duplicated to extend run length: for example parallel pumps, reactors and reboilers.

This is a successful method to extend on-stream time, though it is expensive and in fact, at times cost prohibitive. Incorporating design guidelines that increase the on-stream time of the key pieces of equipment is a better economic decision for most plants.

Currently Refiners are planning four-year run lengths and Ethylene Producers are getting greater than five-year run lengths. These targets present challenges for distillation column design. Potential problem areas include refining vacuum wash oil beds, ethylene plant quench and saturator towers, and butadiene and other polymer producing distillation columns. Each of these applications has some common characteristics.

A review of successful and not so successful designs can help develop key design criteria. Design guidelines (best practices) developed from successful and not so successful applications can improve the on-stream time of each of the applications.

For distillation the most significant non-capital component to the life cycle cost would be energy, followed by maintenance losses. To minimize energy, a designer should focus on column sequence and optimizing individual tower performance, as well as considering the impact of tray and packing efficiencies. The designer should also review the reliability of the equipment and scrutinize the complexity of the process to achieve minimal downtime for maintenance.

3.1. The Correct Distillation Equipment for the Process Conditions

There are many types of processes that are grouped together and called distillation. Most have similarities, but some have noticeable differences. A partial list of the distillation grouping includes; (5)

1. Distillation
2. Absorption
3. Stripping
4. Extractive Distillation
5. Reactive Distillation
6. Azeotropic Distillation
7. Batch Distillation

There are several choices of distillation equipment for each of these operations. The choice of which to utilize depends on the 1) pressure, 2) fouling potential, 3) liquid to vapor density ratio, 4) liquid loading, and most important 5) life cycle cost. Distillation equipment includes many categories of equipment. The two major categories are trays and packing, but each of these categories has many divisions.

Tray divisions include;

1. Baffle Trays
2. Dual Flow Trays
3. Conventional Trays
4. High Capacity Trays
5. Multiple Downcomer Trays
6. System Limit Trays

Packing divisions include;

1. Grid Packing
2. Random Packing
3. Conventional Structured Packing
4. High Capacity Structured Packing

There are both process and economic arguments for the best choices in equipment selection. Typically structured packing is better than random packing for fouling service because it has no horizontal surfaces, but if the process has high maintenance concerns, random packing may be chosen to reduce the life cycle cost. An example of this is caustic towers in Ethylene Plants.

General Rules of Thumb

The first general rule of thumb is to review the common industry practice for your particular process. This will give you a guide in which to start your selection process, but in a competitive environment the lowest initial cost may be the most widely utilized, but may not be the best overall option. Rules of thumb will have exceptions and may only apply about 90% of the time.

Packing Rules of Thumb

Packing should be utilized when;

1. Compounds are temperature sensitive
2. Pressure drop is important (vacuum service)
3. Liquid loads are low
4. Towers are small in diameter
5. Highly corrosive service (use plastic or carbon)
6. The system is foaming
7. The ratio of tower diameter to random packing size is greater than 10.

Tray Rules of Thumb

Trays should be utilized when;

1. Compounds containing solids or foulants
2. Many internal transitions
3. Liquid loads are high
4. Lack of experience in the service
5. Vessel wall needs periodic inspection
6. Multiple liquid phases including water

Tower Rules of Thumb

1. Maintain 1.2 meters at the top for vapor disengagement,
2. Maintain 2 meters at the bottom for liquid level and reboiler return,
3. Limit tower heights to 60 meters because of wind load and foundation concerns,
4. The length to diameter ratio should be less than 30,
5. Reflux drums should be horizontal with a liquid residence time of 10 minutes,
6. Gas / liquid separators are vertical,
7. If the reflux drum has a second liquid phase, such as water, the second phase should have a linear velocity of 150 mm/sec and not smaller than 400 mm,
8. Utilize a water boot for small amounts of water accumulating in a reflux drum
9. Optimum pressure vessel length to diameter ratio is 3
10. Choose materials of construction to reduce corrosion issues,
11. Maximize operating flexibility for seasonal or market conditions.

Pressure

Pressure normally has a large effect on the parameters of surface tension and density ratios. Density ratio is the ratio difference between the vapor and the liquid densities. Structured packing can be utilized if the density ratios are large. If the density ratio is below 50, a back mixing effect can occur, where the liquid carries the vapor downward. The resultant stage efficiency (HETP) in a packed column is lower than expected and trays may be the most economical solution. Both packed and trayed columns have reduced capacity factors as the pressure increases.

Fouling Potential

Designing mass transfer equipment for fouling service requires first an understanding of the fouling mechanism, the process in which the fouling occurs, and behavior of the process when the fouling is present. An understanding of these items needs to be developed in advance of designing mass transfer equipment for fouling service.

The challenges of operating fouling columns can result in;

1. Increase energy consumption due to heat transfer and efficiency issues.
2. Reduced column capacity, which may lead to production loses.
3. Increased down time for cleaning and disposing of fouling wastes
4. Potential need for the use of chemical additives

Vapor to liquid density ratio

When structured packing was first introduced, the vapor to liquid density ratio was not understood, and structured packing was applied in areas of low vapor to liquid density with unexpected results. In one case an Alky Unit DeIsoButanizer was revamped from trays to rings with less performance, the original trays were then reinstalled. Several Propylene and Ethylene Splitters were revamped to structured packing, and then had trays re-installed.

Trayed column are also affected by the vapor to liquid density ratio. The down comer capacity is directly affected by the ability of the liquid vapor mixture ability to separate into their respective phases. At low vapor to liquid density ratios this can be difficult if the down comers are not sized properly.

Liquid loading

In low liquid loaded systems packing may be the best choice because of the mass transfer characteristics of packing. The mass transfer in packing applications takes place on a thin film of liquid that is spread over the surface area of the packing. If the liquid rate is high this boundary layer will increase, reducing the mass transfer. Trays should be considered by high liquid loaded applications.

In low liquid loaded systems trays can have high residence times leading to undesired affects such as fouling, discoloration, polymerization, and sedimentation. In addition trays in low liquid loaded systems have difficulty maintaining a good weir loading and distribution across the tray, resulting in lower than expected tray efficiencies.

Life cycle cost

Life cycle cost should include total operating cost for the first ten years of operation. Accounting rules which list some items as capital cost and other items as operating expense need to be totaled or a skewed life cycle cost can be generated. A partial list would include;

1. Capital
2. Catalyst
3. Solvents
4. Energy
5. Maintenance
6. Industry average on stream factor (95% - 20 days per year)

For distillation the largest life cycle cost would be energy and maintenance concerns. Distillation is typically the single largest consumer of utilities in a chemical plant or refinery, and also the largest producer of finished product in most facilities. For energy cost a review of tray and packing efficiencies is warranted. For maintenance cost a review of reliability and simplicity is warranted.

3.2 Correct equipment selection for expected run length

Hydrocarbon Producers are exploring avenues to extend the on-stream time between outages for maintenance. Key equipment that can determine the end of run includes: catalyst life, cyclone erosion, and compressor and tower fouling. Critical equipment that has been shown to be a limiting factor can be duplicated to extend run length: for example parallel pumps, reactors and reboilers. This is a successful method to extend on-stream time, though it is expensive and in fact, at times cost prohibitive. Incorporating design guidelines that increase the on-stream time of the key pieces of equipment is a better economic decision for most plants.

Currently Refiners are planning four-year run lengths and Ethylene Producers are getting greater than five-year run lengths. These targets present challenges for distillation column design. Potential problem areas include refining vacuum wash oil beds, ethylene plant quench and saturator towers, and butadiene and other polymer producing distillation columns. Each of these applications has some common characteristics. A review of successful and not so successful designs can help develop key design criteria. Design guidelines developed from successful and not so successful applications can improve the on-stream time of each of the applications.

Industry Review of Tower Incidents

One way to approach the expected run length issue is to review the tower incidents that have been reported in the industry. There are over 900 published cases of tower incidents in the literature. Attached is a list of tower incidents that was found in the literature. (2) Listed are the top five issues in distillation malfunctions.

1. Fouling, plugging and coking issues
2. Tower Bottoms and Reboiler Return issues
3. Packing Liquid Distributors issue
4. Intermediate Draws
5. Assembly Mishaps

Below is an explanation of each item.

1. Fouling, plugging and coking issues

    A. Coking
    B. Precipitation - salts
    C. Scale, corrosion products
    D. Solids in feeds

Fouling, plugging and coking issues are typically found

    A. Packing beds and Distributors
    B. Trays, active areas and down comers
    C. Draw lines
    D. Instrument lines
    E. Feed lines

2. Tower Bottoms and Reboiler Return issues

    A. High liquid levels
    B. Impingement by vapor inlets
    C. Vapor Mal-distribution
    D. Water induced pressure surges
    E. Leaking reboiler draw
    F. Gas entrainment in liquid bottoms

3. Packing Liquid Distributors issues

    A. Distributor Overflow
    B. Plugging
    C. Fabrication mishaps
    D. Feed entry problems
    E. Damage

F. Poor hole pattern
G. Poor irrigation quality

4. Intermediate Draws

A. Leakage at draw
B. Restriction of vapor - choking of draw line
C. Plugging

5. Assembly Mishaps

A. Packing Liquid Distributors
B. Packing assembly
C. Tray Panels
D. Internal mis-orientation at feeds and draws

Recent List of Refinery Fractionator Malfunctions

A recent list of refinery fractionator malfunctions was developed. (2) There are over 400 published cases of refinery tower incidents. They included;

1.	Vacuum Towers	86
2	Atmospheric Crude Towers	45
3.	Debutanizer Towers	37
4.	FCC Main Fractionators	33
5.	DeEthanizer Towers	23
6.	DePropanizer Towers	22
7.	Alky Main Fractionators	17
8	Coker Main Fractionators	15
9.	Naphtha Splitters	11

The main point here is there are plenty of published cases, and it is better to learn from others' mistakes. The largest number of cases is for the vacuum tower. The top causes of vacuum tower malfunctions include;

1.	Damage	27
2.	Coking	21
3.	Intermediate draws	17
4.	Misleading measurements	10
5.	Plugging	9
6.	Installation mishaps	9
7.	Abnormal operation (Start up, shut down)	9
8.	Mal-distribution	6
9.	Weeping	6
10.	Condenser	4

The top causes of damage in vacuum tower include

1.	Water induced pressure surges	9
2.	Insufficient mechanical strength	5
3.	Broken nozzles or headers of spray distributors	4
4.	High bottoms level	3
5.	Packing Fires	3

A lesson to be learned is that possibly one third of the causes of damage in vacuum towers can be prevented by design and operating procedure that adequately prevent water from entering the tower. A joint design / operations hazard and operability review (HAZOP) should focus on the listed potential problem areas.

3.3 Correct process control strategy to achieve stable operations

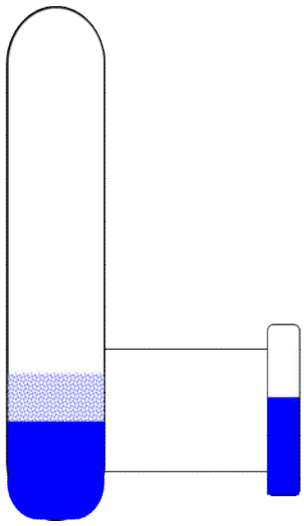
Pressure Control Challenges

Because humans are less sensitive to pressure than temperature, we measure pressure in large units. In the ideal gas law PV = nRT, pressure is measured in units of 1 bar and temperature in units of degrees Kelvin, therefore temperature measures will be much more accurate than pressure measurements. Control strategies that rely strongly on pressure will be less stable than those that rely on temperature.

Of the 37 listed DeButanizer malfunctions, the most common malfunctions are widely different from those in vacuum, crude and FCC fractionators. Ten of the thirty-seven were in process control, and five of them were with pressure and condenser controls. The challenge of DeButanizer condenser is with the non-condensables that the previous towers might not totally remove.

Level Instrumentation Challenges

Level instrumentation is much more difficult than many people perceive. Acceptable industry standard methods have greater than 10% inaccurateness. This is due to density differences in the tower bottoms and the level leg or sight glass. The tower bottoms will be frothy and at a higher temperate than the level leg. Because the principle of level measurement is Bernoulli's' Equation (density times gravitational force times height) the density has a direct effect on the measurement. The density is a function of the temperature and the froth aeration, both of which are reduced in the sight glass and level leg. For a hot system the level in the tower can be as much as 10% higher, and for a cycrogenic system the level can be lower than the sight glass due to the temperature effect.



Olefins Unit Application Example

An example of the phenomena by one of the authors was in an ethylene furnace steam drum. Because the steam drum has a low level shutdown, which also shut down the furnace, the operations group wanted to run the drum at a high liquid level to allow increased the operator response time. Operations decided to keep the drum level at 80%.

This drum operated at a 100 bar system pressure which has resulted in very high temperatures. Operations noted that there was a loss of efficiency in the steam turbines that utilized the high pressure steam. Tests were run to determine the carry over of the steam drums by measuring the sodium levels in the steam. It was determined by the sodium test, that the drums were full at 80% as verified by the photographs of the tide marks in the steam drums at the next down turn. The steam drum level was lowered to a measured 65% to reduce liquid carryover.

Picture of water mark on the steam drum

Steam Turbine Fouling

Refinery Unit Application Example

It is not unusual for operation to run a piece of equipment at higher levels if there is a low level shutdown, or if the process feeds a multistage pump. Caution needs to be taken and this phenomena need to be understood or a tower reboiler return can be blowing into the liquid level, resulting in entrainment to the first tray. If there is a steam sparger in the tower bottoms as found in refinery atmospheric crude towers, care must be taken to insure the sparger is above the liquid level.

In one example a refinery atmospheric crude tower was revamped and the steam sparger was lowered. During crude feed changes the tower bottoms level can be higher than normal resulting in the steam sparger being beneath the bottoms level. When this occurred, the diesel draw became dark, resulting in lost product.

3.4 Fouling / corrosion / polymerization potential

The most suitable mass transfer equipment for fouling service may also be the least efficient for mass transfer. Grid packing and shed decks can handle nearly every known fouling service, but they have low efficiencies when compared to sieve trays, random, and structured packings.

Packing

For packed towers the key fouling factors revolve around liquid distribution and packing residence time. The longer the residence times the less suitable. Low-pressure drop, smooth surface, low residence time packings perform best in fouling service. The order of preference is:

1. Grid
2. Structured packing
3. Random packing

Packing Distributor Concerns

In fouling service, distributors are areas where residence time is increased and fouling phenomena can occur. In high-fouling services trough v-notch or other type of trough distributors are recommended over pan type distributors.

Trays

The industry prefers trays in fouling service because of the long history of success trays have had in fouling service applications. The first continuous distillation column with bubble cap trays was developed in 1813 and structured packing was developed in 1964. The database and application know how is much larger with trays. The best trays to use in fouling services are dual flow trays and large fixed opening devices. Moveable valve trays are less resistant to fouling because the valves are areas where a polymer can seed and propagate. Solids can pack in small crevices around movable valves making them immovable.

Dual Flow Trays

Dual flow trays are the trays of preference for heavy fouling services, but have low stage efficiency. Dual flow trays have no down comers, where products of fouling phenomena can accumulate. Stagnation in a down comer, or even on a tray deck, due to back mixing, can result in polymer formation.

The vapor and liquid transfers up and down the column thru the holes on the tray deck. This is an advantage if the fouling is in the vapor state as the under side of the tray is continually washed. The continuous agitation of the liquid on the topside of the trays combined with continuous underside wetting/washing action makes this tray suitable for fouling services. The challenge of the dual flow tray is mal-distribution in larger diameter towers.

Two types of dual flow trays are available; standard deck and rippled deck. The standard deck has is a flat plate, and the rippled deck has sinusoidal waves. Levelness is of extreme importance to dual flow trays because the liquid will migrate to the low level on the tray and start channeling. Dual flow trays have a tendency for harmonic tray vibrations; rippled decks have an excellent record in fouling service except for one recent documented case.

Fixed Opening Trays

If mass transfer efficiency and fouling resistance are both needed, then a fixed opening tray is the preferred choice. This fixed opening device is a raised opening on the try deck that is sufficiently large to allow vapor to keep the tray deck non fouled, while providing higher stage efficiency.

Specially Chemical Application Example

Methyl-Meth-Acrylate (MMA) is polymerized into Poly MMA, which is sometime called acrylates; clear plastic sheets sometimes used a glass substitute, nail polish and floor wax. In the manufacture of MMA the towers normally require shutting down about every six months for cleaning.

In distillation service where there is a high probability of polymerization, like MMA, dual flow trays may be the trays of choice. The challenge of dual flow trays is mal-distribution, the vapor traveling up one side of the column and the liquid down the opposite side. In a windstorm the top of a column can move as much as 6 inches, and build a hydraulic instability within the column, which a dual flow tray cannot correct within itself.

3.5 Thermal stability, chemical stability and safety

There are several incident of thermal stability, chemical stability and safety incidents that need review

Thermal Stability

Thermal stability is an issue when dealing with many speciality chemicals. The need to reduce the tower bottoms temperature to reduce degradation or polymerization can shift

the process design toward packing, falling film reboilers and special over head condensers to reduce the tower pressure drop.

Chemical Stability

In several applications a small amount of the feed stream can accumulate in a distillation column and have chemical stability issues. In an ethylene plant propylene splitter tower, Methyl Acetylene and Propadiene can concentrate in a section of the distillation tower below the feed. At high concentrations, above 40%, this product can auto decompose resulting in large pressure increases with potential damage to the equipment.

In butadiene plants a small amount of vinyl acetylene is always present. Extractive distillation is typically used to recover the valuable 1, 3 butadiene. If not operated correctly, the vinyl acetylene can accumulated to an auto ignition level resulting in pressure vessel failure and consequential damages.

Column Safety

One issue for column safety is packing fires. Packing has been known to ignite and burn when the tower is opened for maintenance. FRI and others have produced guidelines for reducing the likelihood of tower packing fires.

3.6 Maintenance reliability, accessibility and simplicity of repair

Maintenance reliability, accessibility and simplicity of repair issues many times are developed in actual field experiences. The field experience is fed back to the tray designer to incorporate best practices. This is an area where an experienced team can bring huge value to a process.

Demister Pads

Demister pads are very easy to design and install, but tend to be high maintenance issue items. Typical entrainment removal of 99% can be obtained with 150 mm (6 inches) of mesh pads. There have been numerous failures in demister pad systems due to pressure surges. The pad may foul with material and fail due to pressure drop increases.

Typical Demister Pad Issues

3.7 Evaluation of the most cost effective solution for minimum life cycle cost

The best way to review profitability is the life cycle cost, which is the initial capital cost of plant along with the first ten years operations and maintenance cost. The life cycle cost includes a reliability factor, which is very important in designing any process plant equipment. Improved reliability has a very large impact on return on investment (ROI).

Life cycle cost should include total operating cost for the first ten years of operation. Accounting rules which list some items as capital cost and other items as operating expense need to be totaled or a skewed life cycle cost can be generated. A partial list would include;

1. Capital
2. Catalyst
3. Solvents
4. Energy
5. Maintenance
6. Industry average on stream factor (95% - 20 days per year)

For distillation the largest life cycle cost would be energy and maintenance concerns.

Factors that increase life cycle cost

Several factors that increase life cycle cost include;

1. The need for very high or very low temperatures, less that -40 C or greater than 250 C
2. Small concentrations of high boiling contaminants must be removed – high energy.
3. High operating flexibility for seasonal or market conditions
4. Low Stage Efficiency
5. Exotic Materials of Construction
6. Low instrumentation Reliability

In distillation the two large life cycle cost drivers are stage efficiency, which is actually energy usage and operational flexibility

Exotic Materials of Construction

The choice of materials of construction can have a profound effect on the performance of a unit if corrosion sets in. The engineer is constantly striving to produce an economical design with the least expensive materials. However, there are minimum specifications on the types of materials to be used in common services to ensure minimal corrosion or stress cracking. Some of these are:

Hydrocarbons (no H2S) Temp >40 Deg. C	Carbon Steel (A-569)
Hydrocarbons (no H2S) Temp –30 to 40 Deg. C	Killed Carbon Steel
Hydrocarbons (no H2S) Temp –100 to -30 Deg. C	3 ½ Nickel Steel (SA-203)
Hydrocarbons (no H2S) Temp <-100 Deg. C	304L Stainless Steel
Acetic Acid	316L Stainless Steel or Titanium
Chloride Service	Duplex 2205 or Hastelloy C-276
Chlorine & HCl Service	Nickel 200 or Tantalum
Ethanol	304L Stainless Steel
Methanol	Carbon Steel and 304L
Stainless Steel	

4.0 Verify Unit Capacity (Increase Total Product Capacity)

Each part of the plant has a guarantee of performance with an associated monetary penalty if the guarantee is not met. Therefore the process vendors design their portion of the plant with a safety margin, typically of 10%. Then the mechanical vendors add an additional 10% safety margin.

This means that the pumps, compressors, towers, and heat exchangers are all rated for 120%. The cooling tower is rated for 10% above the heat exchangers and should be designed for 130%.

Many times distillation columns are designated the unit limits. At one plant where I consulted the designated limit was deemed to be 107% of design. We ran a high load test on the tower and found the true limit to be 117%. The ROI for the test run cannot be calculated. An independent high load test needs to be conducted on each designated unit limit.

4.1 Determining Existing Distillation Equipment Capacities

There are many reasons to revise a distillation system. These include improved operability, improved reliability, reducing and or eliminating an environmental impact, improved system safety, better product purities, and the need for new products. The most common reason cited is to increase capacity. The incremental cost of producing a unit of product goes down with higher throughput. In addition profits are typically enhanced with higher throughput.

Increased profit is the fundamental driving force for most distillation unit revamps. Often small design or operating changes can result in capacity or energy improvements. The converse can also happen. To identify a tower to be retrayed, when it is not a limitation, wastes capital and results in the repair of false problems. It can also reduce unit reliability if the real problems are not found and corrected. This identification can be the difference between a revamp that has a high ROI or an expensive and unjustifiable project. High load test runs require forethought, planning and proper coordination to yield useful information.

4.2 Objectives of the High Load Test

Objectives of a high load test can include validation of a guarantee, capacity testing, trouble shooting, efficiency testing and benchmarking. Each of these requires a slightly different high load test, but the general principles remain the same.

The chosen objective will be the driving force to sustain the momentum of the exercise. The first step in a revamp is a plant load test. This test needs to be conducted to establish the baseline scenario as well as to test the available margins in the system. Accurate data will need to be collected from this data or the effort put into the load test will be in vain. A proper test run is not a random affair to be carried out on the spur of moment. Test runs require forethought, planning and proper coordination to yield useful data.

High Load Test Team

The success of most endeavors is based upon the quality of the team of individuals that are assembled for the project. A multidiscipline team needs to be established to plan and executed the high load test. The team should include people from operations, maintenance, laboratory, and process and should include experts in distillation.

It is important that, as a team, that all members listen carefully to each other. The operations and maintenance personnel have the most experience with the equipment and the most information about the unit. All members must learn the art of extracting detail from these vital sources. They will be truthful and helpful, even though many times they speak a different “jargon.”

The team must separate the observations from the conclusions. Most people want to tell you their conclusions first. The team must find out how the conclusion was made. Get an understanding of the observations that developed the conclusions. The old Cliché, “Patience is a Virtue” can and should be applied with vigor to this team because the benefits can be tremendous.

4.3 High Load Test Preparation

A high load test should begin with a study of the background of the process system, based upon a predefined system boundary. (3) Reviewing each of these items will assist the team in designing the high load test;

1. design manual,
2. physical property data
3. the process flow diagram,
4. the piping, instrument and control diagram,
5. equipment drawings,
6. operating procedures,
7. operating data taken during normal operations

The first group of items is from the original design basis, which may have been changed over time. A review of the current operating data is very important to record the changes from the original design basis. The amount of time required to study the background of the process system depends on your familiarity with the operation. A good step to take to familiarize yourself with the unit, is a P&ID walk down. There probably have been some field modifications that the drawings do not currently show. Try to find out why the modification were made, and think though the possible consequences of these changes.

The team must give a high level of importance to first-hand information. There is an old operator saying, “If you did not see it, it is not true.” What this means is - do not rely on second-hand information. It is easy for people who have been living with the same unit on a daily basis to develop tunnel vision. A person with no preconceptions and a fresh viewpoint may well find something that has been overlooked. Sometimes the obvious question is never asked because “We’ve always done it this way.” There are no stupid questions in preparation for a high load test.

Preparations for Data Collection

Based upon the system boundary, the team of process engineers, experts and plant engineers will establish what data needs to be collected during the test run. It is important to make sure the data you collect is valid. A list of instrumentation to be calibrated should be generated. It should include thermocouples, pressure transmitters, and flow transmitters. Make sure that the critical flow meters are ranged properly.

The largest source of error on most distillation columns is with the pressure. Where possible install a pressure gage at the pressure transmitter for verification. For vacuum system utilize a mercury manometer. Pressure is measured in much larger units than temperature. This is because the human body has the ability to detect temperature changes much better than pressure changes. In the standard PV=nRT equation, pressure is measured with units that typically have only 1 or 2 significant figures while temperature is measured with typically 3 or 4 significant figures.

When possible always double-check the data. Temperature can be confirmed with a pyrometer gun. Pressure can be confirmed with separate pressure gauges, and flows can be confirmed by heat and material balances. One way to confirm the heat and material balance is to measure the cooling water flow with a sonic meter, and the temperature with a heat gun...

Sample collection and analysis

It is necessary that the sample data collected and analyzed be representative of the stream that was sampled. Samples should be free of any contamination that would skew the result of the test run. Samples of the products should be taken where the process stream is in a single phase. Sampling of two-phase streams can not be performed accurately due to stratification of the liquid and vapor parts.

Samples should be taken in the well-mixed part of the process. For liquids, samples should be taken following pumps, control valves, or in bends. When obtaining vapor samples from a distillation column, it is essential that the vapor be free of entrained liquid.

Planning the Test Run

After deciding on the objective of the test run and setting up the system boundaries to identity all the measurements that are required, planning needs to commence for the actual test run. Items that need to be considered include;

Manpower / Staffing

The staffing of the test run needs to be identified and should include consultants, experts, operations, maintenance and laboratory. These personnel need to be available and contactable, with clear lines of authority. Manpower estimates need to be made to ensure that the test run is executed as fast and accurately as possible. Operating within a time window restraint will lessen the chance of a unit upset that will require repeating the test run.

Feedstock / Unit Stability

Operations during the test run need to be as stable as possible. Weather conditions need to be reviewed. A rouge rainstorm can skew test results of even the best-insulated plants. The person in charge of the operations need to be sure that the plant has sufficient storage (two days of feed is recommended) for the unit and enough storage for the product tanks if gauging is to be used as a cross check for the flow meters.

The performance of a separations unit can never be accurately determined if the feed, levels, product rates or pressures cannot be held reasonably steady. Steady operation

is paramount during a test run. Sufficient time needs to elapse during a test run to ensure all units are truly equilibrated.

Safety

Safety should be a concern during a test run. People are working together for the first time, and unit limits may be explored. Safety training should be included for all personnel and equipment should be inspected to insure that it is in safe working condition.

4.4 Test Run Execution

Tower Testing

Tower testing has two aspects. One can be categorized as hydraulic capacity, and the second as separation capacity or efficiency.

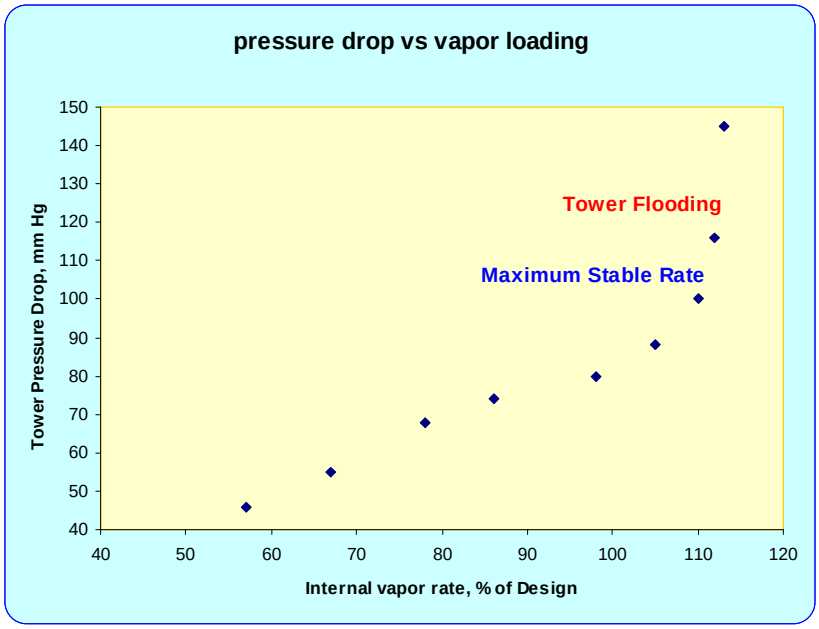
Hydraulic Issues

Tower hydraulic issues can frequency be diagnosed by careful analysis of the tower pressure drop data. First compare the actual tower pressure drop data with the predicted tower pressure differential. More important than the absolute magnitude of the pressure drop change, is the rate of change of the pressure drop verses internal vapor and liquid rate changes. A steep increase in pressure drop in response to a small increase in tower vapor and liquid loading is the classical indication of tower flooding.

If tower flooding is indicated by the overall pressure drop data, then determine in which tower zone the flooding starts. This may be straight forward if instrument taps are available to measure pressure drop across various tray or packing zones. In some cases it is necessary to have multiple differential pressure transmitters to facilitate simultaneous monitoring of pressure drop across several zones of trays or packing.

Once the limiting zone is found, it should be determined whether the flooding is premature compared to design conditions (or previously documented good operation) or whether the flooding conditions are reasonably close to those predicted from published tower flooding correlations. Premature column flooding can stem from many causes, such as tray fouling, sticking valves, improper feed entry or product draw, tray or packing damage, incorrect tray installation, foaming, fouling, etc.

Plotting pressure drop against vapor loading can many times indicate the presence of tower flooding. (3)



Tower Efficiency Issues

Some of the same factors that can cause tower flooding may result in efficiency problems as represented by off specification products. The cause of inadequate separation may be suggested by comparing abnormal operating conditions with the design set. For example, a careful comparison of the feed composition with regard to the ratio of light key to heavy key as well as the presence of light and heavy impurities may indicate that the feed composition is vastly different from design.

Common concerns in distillation test runs are those situations which look on the surface to be caused by one problem, and the underlying cause is really another kind of problem. For example symptoms caused by distillation tower peripheral equipment or instrumentation are often perceived to be problem with tower internals. In one case a tower was retrayed with high capacity trays and a welder's plug was accidentally left in the reboiler return line. The first impulse was to look to the tower internals as the cause of the problem. The tower was shutdown and the internals modified. However, during this outage the welder's plug was discovered.

Preliminary Data Analysis

To obtain a heat and material balance around a column sounds like a simple task. In most cases commercial columns are not instrumented sufficiently to check the heat and material balance by independent measurements on all streams. Sometimes even the major streams are not measured (i.e. recycle streams or vapor feeds). In some cases local instruments can be added. In other cases it will be necessary to use a

“reasonableness test.” If the overall flow rates and component balances match within 5%, this data can be considered excellent and be utilized. Typically flow meters have a 2% accuracy therefore exact balances may not be possible.

A heat balance should be executed around any heat exchanger that impacts both the product and feed streams as well as any water exchanger where the water flow rate and temperature change can be measured. To verify the low rates of any stream, a control valve flow rate can be generated from the valve percent opening. Many times a pressure drop across a flow element can be easily obtained and applied to a simple orifice equation to get a rough idea of the mass flow rate. This easy test is most often performed when the conversion factors in the control system are questionable or the system is operating far from original design.

Once the heat and material balances have been reconciled and the analysis of the samples has been completed, simulation of the distillation unit can be started. The beginning of the solution to any distillation problem begins with the operating data and not with the simulation tool. The simulation is only as good as the data that was supplied. If the quality of your data is compromised, the results from the simulation will be in error.

Test runs take advantage of the three measured quantities to define the state of a stream: temperature, pressure, and compositions. From these three measured quantities information about the enthalpy and mass of a stream.

Successful revamps generally have several key steps. The first step is a high load test to accurately determine the existing distillation equipment’s available capacity. The second step is to reconcile the data gathered in the high load test by a heat and material balance. This normally utilizes distillation software such as Pro II. The third step is with the reconciled data. The fourth step is to select the key items to be upgraded with the maximum return on investment.

Process engineers must establish the system boundaries within the plant and set the strategy as to how to test each section effectively. A multi-disciplined task force will be most beneficial with pooled experiences from many sources. Communication between all relevant personnel has to be clear and objective. As a high load test proceeds, some unexpected results are sure to occur and the task force faces their greatest challenge of making every stumbling block a stepping stone to a successful revamp.

5. Optimize Distillation Energy (Reduce Energy Cost)

For distillation the most significant non-capital component to the life cycle cost would be energy, followed by maintenance losses. To minimize energy, a designer should focus on column sequence and optimizing individual tower performance, as well as considering the impact of tray and packing efficiencies. The designer should also review the reliability of the equipment and scrutinize the complexity of the process to achieve minimal downtime for maintenance.

5.1 Column Sequences

5.2 Optimizing Individual Tower Performance

5.3. Tray and Packing Efficiencies

Stage Efficiency

There are certain "rules of thumb" in distillation that apply to stage efficiency behavior. Some of these are:

a. Increased pressure increases tray efficiency
b. Decreased pressure increase packing efficiency
c. Increased viscosity decreases tray and packing efficiency
d. Increased relative volatility decreases tray efficiency

Many things influence stage efficiency. The first and foremost is the type device employed for the service. Next is the system itself including the pressure, L/V ratio, relative volatility, and physical properties.

The choice of device is important from the viewpoint of capacity, but many times a higher capacity device will inherently have a lower level of efficiency performance. Generally, higher capacity devices exhibit lower efficiency. The reason for this is that the contact time between the liquid and the vapor is greatly reduced at higher throughput.

Design

Design of Trays to Improve Efficiencies and Capacities

Trayed Columns utilize a pressure and temperature differential to separate the products. For most trayed columns, the weir holds a certain amount of liquid level on each tray. The vapor must overcome this liquid head to move up the column. On the tray the vapor and liquid are contacted and then above the tray they are separated. Any deviation that restricts the vapor and liquid from contacting and then separating will deteriorate the column's ability to meet design specifications.

Items that lead to improvements in tray efficiency include;

1. Path flow length
2. Deck opening size
3. Elimination of stagnant zones
4 Down comer outlet devices / froth promoters
5. Weir Heights

1. Path Flow Length

The longer the path flow length, the higher the tray efficiency. At short path flow lengths, less than 300 mm a tray will achieve the point efficiency. Longer flow path lengths can actually allow a try to achieve efficiency in excess of 100%.

2. Opening Size

There is an optimum bubble size, therefore an optimum opening size. Too small or too large can effect the size of the bubble, leading to loss of efficiency. Here is the normal trade off between capacity and efficiency.

3. Elimination of stagnant zones

Parallel flow across a cordial surface can lead to stagnant areas. Liquid directional push valves can help eliminated the stagnant zones.

4. Down comer outlet devices / froth promoters

The clear liquid exiting the down comer becomes froth on the tray. Items that assist this froth generation improve efficiency.

5. Weir Heights

The weir height has an effect on the tray efficiency. Recommendations are not to exceed 100 mm or 1/6 of tray spacing, and 50 to 75 is suggested for all services except vacuum services.

Optimum Reflux Rates

Optimum reflux rates particularly for the cold refrigerated column can lead to very large energy savings. A cost of each reflux and reboiler energy needs to be calculated and incorporated in operations Key Performance Indicator.

6. Verify Distillation Efficiency (Recover High Value Products)

Tray and packing design can be improved to optimize distillation efficiency leading to recovering more of the high value products.

Tower Recovery

Many towers are designed to recover 98% of the higher value product. For very high valued product this number can approach 99%. It is important that you review the designed tower recovery percentage and set this as one of operations Key Performance Indicators.

7. Verify Distillation Revamps

There are many reasons to revise a distillation system. These include improved operability, improved reliability, reducing and or eliminating an environmental impact, improved system safety, better product purities, and the need for new products. The most common reason cited is to increase capacity. The incremental cost of producing a unit of product goes down with higher throughput. In addition profits are typically enhanced with higher throughput.

Increased profit is the fundamental driving force for most distillation unit revamps. Often small design or operating changes can result in capacity or energy improvements. The converse can also happen. To identify a tower to be retrayed, when it is not a limitation, wastes capital and results in the repair of false problems. It can also reduce unit reliability if the real problems are not found and corrected.

This identification can be the difference between a revamp that has a high ROI or an expensive and unjustifiable project..

8. Verify New Distillation Instillations

A distillation tower design is normally made in two steps; a process design, followed by a mechanical design. The purpose of the process design is to calculate the required stream flows and number of required theoretical stages. Required steam flows could include reflux rate, side draws, and the heat duties (number of pump arounds and the condenser and reboiler).

The purpose of the mechanical design is to select the tower internals, column diameter and height. The process and mechanical designs can be completed very quickly utilizing “cook book” procedures that many Engineering Procurement and Construction (EPC) firms have established. Often the “cook book” designs can be optimized for improved profitability, operations and maintenance. A typical EPC firm’s designed can easily be improved by more than 5% in energy and 7% in capacity.

9. Distillation Trouble Shooting

Even in the best run plants operations degrade over time or some processes do not work as well as expected. Plant operating and equipment changes introduce new problems and reveal, older, unappreciated problems.

Troubleshooting, the systematic investigation or problems and their solution, is key to maximizing plant profits. A unit with malfunctioning equipment or an incorrect process configuration cannot be optimized by the best control system available. Processes and equipment must work correctly for maximum profits.

Key aspects of successful troubleshooting include: a thorough understanding of both the process and the equipment: application of chemical engineering basics to problem solving: and good field technique and data interpretation skills. The process is not independent of the equipment.

The equipment works as part of a process. Both must be understood for effective troubleshooting. Chemical engineering basics are required for understanding both the equipment and the process.

Finally, field technique and data interpretation skills are needed to gather required information. Often, troubleshooting fails due to faulty, incomplete and misleading numbers.

10. Operations Training

The success of every company depends of each employee's understanding of the business's key components. Employee training and development will unlock the companies' profitability and reliability. When people, processes and technology work together as a team developing practical solutions, companies can maximize profitability and assets in a sustainable manner. With separation being typically over 40% of a plants cost and energy it is vital that your operation team understand distillation fundamentals.

The unit on stream time is an indication of operations training. A first quartile-operating unit's on steam factor is greater than 97%. If the on stream factor is below 97% a review of operation training and development is warranted. If on stream factor or average years of operating experience is declining a review of operations training and development should be considered.

A review of each trainer's experience and knowledge is critical when choosing an operations development program. Suppose the trainer understands 90% of the subject. At best, he might be able to teach the students 75% of his knowledge base on a short course basis. Therefore the student's knowledge base is 67%. If this person goes and trains someone else, the second student’s knowledge base is 51%.

Make sure that you have qualified instructors with a high level of the subject understanding or your results will not be satisfactory. Be careful in "Train the Trainer" philosophy to get a high level of the subject knowledge to your trainer.

Operations training and development is an investment in the future - maximize your return on investment. Give your employees the keys to success.

References

1. Kolmetz K, Dr. Wai Kiong Ng, Siang Hua Lee, Tau Yee Lim, Daniel R. Summers Cyron Anthony Soyza, Optimize Distillation Column Design for Improved Reliability in Operation and Maintenance, 2nd Best Practices in Process Plant Management, Nikko Hotel, Kuala Lumpur, Malaysia, March 14-15, 2005

2. HZ Kister “Recent Trends in Distillation Tower Malfunctions”.

3. Hasbrouck, JF, Kunesh, JG, Smith VC, “Successfully Troubleshoot Distillation Towers”, Chemical Engineering Progress, March 1993

4. Kolmetz K, Dr. Wai Kiong Ng, Siang Hua Lee, Craig G. Cook, Energy Optimization of Cryogenic Distillation, DISTILLATION 2005, 2005 Spring AIChE Meeting, Atlanta, Georgia, April 10-14, 2005

5. Kolmetz K, Sloley AW, Zygula TM, Ng WK, Faessler PW, Design Guidelines for Distillation Columns in Fouling Service, American Institute of Chemical Engineers, The 16th Ethylene Producers Conference, Section T8005 - Ethylene Plant Technology, Advances in Distillation Technology for Ethylene Plants, 29 April 2004, New Orleans, Louisiana, USA