How to Evaluate an Existing NGL Recovery Plant Before Finalizing a Process Retrofit Design

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ABSTRACT

A great number of simple expander NGL recovery plants were retrofit to GSP or RSV designs in the 1990's. With the installation of many "standard plant" GSP designs during the shale boom, opportunities for improving both ethane and propane recovery using new retrofit technology are once again of interest to plant owners as they compete for gas and as producers anticipate higher liquids product prices.

This paper covers the techniques and typical requirements for evaluating the existing NGL recovery plant and its equipment prior to finalizing a retrofit process design. The principles described can be applied to any existing NGL recovery plant design and to any retrofit process design, and will provide an accurate estimate of the retrofit process design performance. This conclusion is based on years of experience in providing retrofit process designs and the subsequent performance testing for nearly 50 retrofit projects.

The purpose of this paper is to provide a common starting point and understanding for both the plant owner/operator and for the retrofit process engineer to evaluate the existing plant and equipment and prepare an accurate estimate of the retrofit process design's performance. Developing and verifying the process simulation and gathering the field data needed to accurately model and evaluate the equipment are discussed. Methods for cross-checking reported analyzer and plant material balance flow measurements are described, and the typical constraints used for the process data-match simulations are provided.

INTRODUCTION

Existing natural gas liquids (NGL) recovery plants do not always accomplish the processing goals which would be most economically advantageous. Others simply do not achieve the process performance for which they were originally designed. Some reasons for these circumstances include changes in feed gas conditions (flow, temperature, pressure and/or composition), and/or aging/fouled equipment. Also, fluctuations in NGL product and pipeline gas demand or value can change such that it makes economic sense to increase recovery and/or throughput, or change the mode of operation of the NGL plant from ethane rejection to ethane recovery mode and vice-versa. All of these factors can make a plant retrofit attractive, considering older technologies can be easily converted to new current ones that allow increases in overall plant efficiency and/or throughput while providing operational flexibility.

Note, for the purposes of this paper, "NGL recovery plants" refers to a cryogenic turbo-expander plant for natural gas liquids recovery which recovers liquids comprised of either ethane and heavier components (often referred to as C2+ liquids or Natural Gas Liquids) or propane and heavier components (often referred to as C3+ liquids or Liquefied Petroleum Gas).

In the 1990’s, many simple expander plants for NGL recovery that were once state-of-the-art were retrofitted to the Gas Subcooled Process (GSP) or Recycle Split-Vapor (RSV) designs as these technologies emerged. With the shale boom in the late 2000's, many standard plant GSP designs which could not provide liquid recoveries as high as customized plants were also installed in the United States due to a number of commercial factors including shorter delivery schedules. Now, as producers anticipate higher liquids product prices in the near future, plant owners competing for gas are interested in improving performance of these standard plants.

Retrofits of existing NGL recovery plants, including both custom and standard plant designs, can be a cost effective approach to improving product recoveries and plant efficiency. Retrofit technology based on proven process design concepts is commercially available, both in traditional arrangements as well as new, compact arrangements while still using nearly all of the existing plant equipment. Both arrangements offer unique advantages that are dependent on their application and the retrofit design basis. The latest retrofit technologies are tailored to not only improve product recoveries for a single mode of operation, but also improve plant flexibility, when applicable, in order for the owner/operator to adjust plant operations based on ethane market conditions while minimizing the loss of propane recovery.

This paper covers the techniques and typical requirements for evaluating an existing NGL recovery plant and its equipment prior to finalizing the decision to implement a retrofit process design. An evaluation for a current retrofit is included as an example. The principles described herein can be applied in implementing any new retrofit design to any existing NGL recovery plant design, and are useful in providing an accurate baseline from which to develop the retrofit. The purpose of this paper is to provide a common starting point and understanding for both the plant owner/operator and the retrofit process engineer to evaluate the existing plant and equipment and to prepare an accurate estimate of the retrofit process design's performance.

STEPS FOR RETROFIT EVALUATION

When considering a retrofit, the retrofit design has to be based on the actual process conditions in the field. In many ways, retrofits are more complex than new plant designs, since the retrofit design must be built around as much of the existing equipment as possible to minimize overall cost of the retrofit design.

Here are the key steps in evaluating an existing NGL recovery plant for retrofit:

1) Identify goals and all areas of the plant impacted by the retrofit
2) Duplicate an original design case simulation using the design material balance
3) Gather plant data and equipment specifications
4) Build a data-match simulation using field data
5) Determine operating limitations of existing plant equipment
6) Establish baseline existing plant performance for the retrofit design basis
7) Identify appropriate retrofit technologies for evaluation
8) Compare the retrofit technologies to the existing plant performance

Each of these steps is explained in detail below.

1. IDENTIFY GOALS AND ALL AREAS OF THE PLANT IMPACTED BY THE RETROFIT

From the very beginning, it is important to identify the goals of the retrofit. The goal might be to increase recovery, increase throughput, to add flexibility, or perhaps some combination of the three. A retrofit design basis provided by the plant owner specifying a target feed composition, rate, and other requirements usually clarifies this. In addition, before a process simulation is created, one must determine all the areas of the plant and the equipment that will be impacted by the retrofit. Some questions to ask are: will the retrofit apply to multiple trains and are the trains identical? If not, what differences should be noted? What other systems outside of the cryogenic plant may be impacted by the retrofit project?

One specific example of a system outside of the cryogenic plant that can impact the retrofit is external mechanical refrigeration. If external refrigeration is used in the NGL recovery section as well as in other areas of the plant, it will be necessary to include the entire refrigeration system and all the users of refrigeration in the scope to be simulated. In this way, one can account for any limitations that this system may impose on the NGL plant retrofit design.

To further demonstrate the possible limiting effect of a system outside of the NGL plant, consider that an increase in overall throughput will likely increase chilling demand upstream of the NGL facility in the gas treating section, leaving less chilling available for the NGL facility. Or, if the ethane recovery is increased by the retrofit, the refrigeration demands of users in downstream units such as fractionation and/or product treating will most likely increase.

Also, an increase in ethane recovery can have undesired effects on the NGL product such as an increase in CO_2 content. This could lead to overloading downstream product treaters that remove CO_2 from the NGL/LPG. Further, because higher ethane recovery usually means lower operating temperatures in the demethanizer, it can result in CO_2, BTEX, or cyclohexane freezing, even if there was sufficient treating for the original design conditions.

Retrofits that result in an increase in throughput often have other impacts that spread throughout the entire facility as well. The effects include higher pressure drops through all pieces of equipment, an increase in load on the piping and equipment associated with liquid product handling, and the previously discussed impacts on the refrigeration system (if present).

Retrofitting a plant for flexible recovery modes often has complicating factors that must be identified and addressed. Many standard gas plants that were designed for ethane recovery may experience issues when operated in rejection mode due to a number of factors. The major ones are column sizing, reboiler heat source, and limitations on CO_2 in the residue gas. These will be addressed further in the section on retrofit technology selection. The key point to remember is that standard plants are typically designed to operate in recovery mode only. These process technologies can operate in rejection mode, but are typically inefficient unless modifications are made.

2. DUPLICATE ORIGINAL DESIGN CASE SIMULATION

To understand the extent to which a retrofit will improve plant performance, it is important to first have a good understanding of what the plant was designed to achieve. This is best done by obtaining or developing an accurate original design case simulation. This model will be used as a basis of comparison to the current actual plant performance as well as the plant retrofit model. The original design case simulation is also used to confirm and understand original equipment data sheet process information.

Process simulation software has been shown to be very accurate in modeling NGL recovery processes. If a simulation of the existing plant is not available or cannot be acquired, it will be necessary to generate a simulation from scratch. It is easiest to start with as-built PFDs, P&IDs, and material balances to develop the equipment arrangement and throughput conditions for the process simulation. An equipment data sheet for the column is essential for determining the number of stages in the original design. If compressor curves are available, these should be entered into the process simulation to get an understanding of the operating range available. Note that some plants may have multiple design points listed in the data sheets for different conditions and/or feed compositions (e.g., rich feed, lean feed). In this situation, there may be separate PFDs, heat/mass balances, and/or equipment data sheets for each case. Determine which case was used for equipment sizing and use that information to model the plant. If there are multiple trains, determine whether all trains are identical. If not, note what differences exist in each train's design, as you may need a different simulation for each train.

When developing a simulation arrangement, it is important to include liquids (if any) from separators upstream of the dehydration system, and to account for the liquid feed in the recovery. In some plants, it is typical to have refrigeration loads upstream of the cryogenic plant, such as amine cooling, heavy component separation upstream of molecular sieve dehydration, and/or gas chilling for plants in desert locations. The key takeaway here is that when an NGL plant is retrofit, it is usually not sufficient to model just the NGL plant.

Another complicating factor that often impacts standard plant designs is the potential mismatch in rating data between equipment bought for the original design basis and the re-rating of that equipment for the end user's design conditions. It is common for a client to have data sheets for the standard plant equipment that represent the rating of that equipment for the standard design basis, and also to have a simulation that represents that equipment's performance on the client specified design basis. Therefore, when possible, it is best to have the original design basis and plant equipment process datasheets to re-rate equipment according to a consistent and reliable method for all the process modeling work to follow.

Once the original design case simulation of the plant has been created, determine if there is agreement between the developed simulation and the original design basis simulation. If there is not agreement, spend the time to understand the differences. This includes checking if similar equipment efficiencies, property packages, and design margins were used. Also, confirm that there are no phase envelope, physical property, or CO_2 freeze problems at the original design simulation conditions. Once these checks have been made, the heat exchanger UAs, piping, equipment pressure drops, compressor operating conditions, column staging, internals, and loadings from the original design simulation can be used as a reasonable basis for the original equipment constraints. These can also later be used to identify design margins which may exist that can be used in the retrofit design.

3. GATHER PLANT DATA AND EQUIPMENT SPECIFICATIONSS

Once all of the impacted equipment and systems have been accurately modeled for the original plant design, field data must be acquired for the existing plant operation to create a data-match simulation. The goals of this step are to create a model of the existing plant that accurately reflects how the plant is currently operating, to identify any problem areas in the equipment, and to understand what the limitations actually are with regards to the operation of the plant. A good retrofit utilizes engineering margin in existing equipment where possible, while making as few changes to the existing plant as possible to accomplish the processing goals.

As-built P&IDs can be useful in identifying which instrument readings are needed and how they are identified so that these names/tags can be used to request the field data from the plant operations personnel. Additional PFDs and P&IDs may need to be requested in order to identify instrument tag numbers around equipment outside of the NGL facility (e.g., the refrigeration system and any other systems with refrigeration loads that will impact the overall plant refrigeration demand, thereby reducing available refrigeration capacity for the NGL facility.)

The key data needed to produce an accurate data-match simulation are:

a) Feed and product compositions

b) Process stream data in and out of the plant including temperatures, pressures, compositions

c) Process conditions in and out of each piece of equipment including temperatures, pressures, and flows

Verify with operations that the instrumentation is well calibrated before any data is collected.

When assembling a list of instrument tags for which DCS data are needed, or sample points where lab sample data are needed, be aware of plants with multiple trains that have instrument readings or sample points at a combined header. It is best to get the sample or DCS reading at a point specific to only one train so there is no uncertainty regarding how each individual train is performing when trying to match plant data. Requesting collection and analysis of lab samples for the feed gas, NGL product, and residue gas stream compositions during the same time frame in which the instrument and analyzer readings are taken is also critical to developing an accurate model. These will be used to verify the accuracy of the material balance between the inlets and outlets of the plant as discussed in the next section.

Check if there have been any plant upgrades since the original as-built P&IDs were developed and include those changes in the data-match simulation to generate the most accurate plant model (e.g., compressor re-works, changes in column packing, column re-tray, etc.). It is also helpful to try to get a sample of the DCS data before the official field data are gathered to verify the readings make sense. A common mistake to avoid is receiving data for which no feed composition is provided, or data taken during a time when there was a known plant upset. Review the data for completeness, including correct units, time increments, and instrument tag labeling. Look for obvious transmitter errors or instrumentation problems, such as readings outside transmitter ranges, pressure increases across dP instrumentation, etc. It is critical that the average feed gas, NGL product, and residue gas compositions be known before attempting to match the simulation to other instrument readings within the NGL unit.

Start with an entire 24 hour period of data taken at 5 minute increments or less, and analyze the entire data set by graphing key operating parameters (e.g., flows, temperatures, and pressures for feed gas, NGL, residue gas, cold separator, compressors, expanders, etc.) to find the most stable one hour window of operation. Ideally, the data should be obtained as close to the design capacity as possible, and preferably close to the time at which the feed and product stream lab samples are taken. A discussion with plant operations can be beneficial in avoiding a time window in which any known upsets may have occurred. In summary, the data set should include:

a. Refrigeration and compression system temperatures, pressures, and flows (and compositions if refrigeration is used)
b. Stream conditions for all column feeds
c. Ambient conditions for use in aerial cooler modeling
d. Pressure drops between equipment
e. Temperatures and pressures at the inlet and outlet of each piece of equipment
f. Column overhead and bottoms temperature and pressure

g. Laboratory GC data obtained for the same time period as the DCS analyzer data for the inlet and outlet stream compositions

4. BUILD A DATA-MATCH SIMULATION

The purpose of the data-match simulation is to understand the performance and limitations of the equipment in operation and how it compares to the original equipment design as indicated by equipment data sheet process information and the original design simulation. This is because some plants do not perform the way they were originally designed. Once reliable plant data have been acquired and analyzed for stable operation, a data-match simulation can be generated.

It is helpful to annotate the simulation environment PFD by inserting text boxes with the field instrumentation readings near relevant streams that are being calculated by the simulator. This puts the target value right next to the simulation calculated value, thereby eliminating the need to refer back to field readings over and over again each time adjustments are made to independent variables in the simulation. It is also helpful to annotate heat exchanger UAs on the simulation environment PFD below heat exchanger calculated results, so that if any calculated UAs exceed design UAs it will be immediately evident.

Some key areas to consider for ensuring that a good match is achieved are:

1. Feed composition:

   Determining the actual feed composition to the plant is often an iterative process. It is not unusual to have disagreement in column operating conditions when using the feed composition provided by the feed analyzer and flow meter instruments. In this situation, the feed composition may need to be calculated from the sum of the NGL and residue gas products instead of using the analyzer feed composition to get a more accurate data–match simulation. There are two methods to test the accuracy of field data:

   a. Direct entry: Enter the feed composition given from the field analyzer or lab analysis and all other data and check if the NGL and residue gas product compositions calculated in the simulation at the column operating conditions match the NGL and residue gas product compositions reported in the field data.

   b. Sum of Products: The sum of the products method simply calculates the feed composition by taking the NGL and residue gas products and summing the component molar flow rates from these two streams to recreate the inlet flow (making sure to account for fuel gas or regeneration gas taken from the residue gas stream). This method is usually used if calculated process conditions for the column do not match the field data, but it also serves as a good double-check of the reported feed composition.

   Also, it is typical for the NGL product analyzer to under-report heavier components. This should be taken into consideration when trying to establish the actual NGL plant feed composition. If the column bottom temperature calculated by the simulation is lower than the field measurement, it is likely that there is a greater amount of heavier components in the actual feed compared to the simulated feed. The way to get closer to the actual feed composition in this case is to make small increases to the heavier components in the feed while maintaining the relative proportion of each of the heavier components in the field sampled composition. With each change, monitor the effect to column bottom temperature until a close match is achieved. Also watch on the overhead temperature and composition while making these adjustments. The gas stream readings are the most accurate, and therefore should match the closest to what is in the simulation.

If there is a problem with the sum of the products reconstruction of the feed, then component balances can be used to get a better match with the temperatures and pressures. In NGL recovery plants, virtually all of the methane in the feed goes overhead at the demethanizer. Therefore, the methane flow rate from the feed can be used to confirm the reading of the residue gas flow meter. Similarly, the ethane or propane in the column bottoms can also be used as a verification of the bottoms analyzer and flow rate. An easy way to compare the calculated component balances is to use the component splitter unit operation in the simulator with the assumed recovery rates to get an idea of how the compositions might be modified to match the data.

2. Temperatures:

   In general, we expect simulation temperatures to match the field data within 2 °F (1 °C) if the composition data is accurate.

3. Pressures:

   The pressure values in the simulation which should match to field data are the NGL plant inlet, expander inlet flange, column overhead, booster compressor suction flange, booster compressor discharge flange, residue gas compressor suction flange, and residue gas compressor discharge flange.

4. Expander/Booster Compressor:

   a. If the expander outlet temperature is significantly warmer than the calculated simulation value (> 2 °F (1 °C) difference), something is wrong – either the actual equipment adiabatic efficiency is lower, or the J-T valve is leaking in the field. Most expanders will have suction and discharge conditions in their control panel to analyze the efficiency; therefore the issue of having a J-T valve leak can be quickly verified.

   b. The booster compressor outlet temperature and pressure should match as well. If there is more than a 2 °F (1 °C) difference between the field measurement and calculated value, the actual equipment polytropic efficiency may be different than what is in the simulation.

5. Column:
   a. Adjust the staging efficiencies at the top of the column until the overhead temperature matches within 2 °F (1 °C).

   b. Adjust reboiler duty to match the heat exchanger outlet temperature.

   c. Calculate the dewpoint temperature of the column overhead composition as reported by lab analysis. If the dewpoint temperature is not very close to the column overhead temperature seen in the field, something is wrong. Verify with operations that the temperature instrument has been calibrated recently. It also may be that the calculated residue gas composition is not correct, and adjustments may need to be made to the feed composition to make the calculated temperature closer to the field measured value.

   d. Ensure the column bottom temperature matches the reported data within 2 °F (1 °C). It is not unusual to have sampling inconsistencies on NGL liquid composition measurements. As previously mentioned, the NGL liquid analyzers tend to under-report heavier components. If the calculated column bottom temperature is > 2 °F (1 °C) lower than the field measurement then the proportion of heavy components in the feed composition will need to be increased.

   e. If a C_1/C_2 specification is used in the column, make sure there is good agreement between the calculated column bottom temperature and the field measured value. Keep in mind that temperature readings tend to be more reliable than liquid composition analyzers.

6. Heat exchangers:

   a. The UAs calculated in the simulation typically should not exceed the original design UAs by more than 15%; however, if the actual plant throughput is significantly higher or lower than the original design flow, it will have an impact on the UA. Details on how to adjust heat exchanger UA for a different flow rate are given in Section 6.

   b. Low calculated UAs can be expected for approach-limited exchangers.

   c. Pressure drops across the heat exchangers are specified (entered) values, and should match what is currently observed in the plant. Note that while increases in flow through the plant will result in increases in pressure drop, higher than expected pressure drops may indicate obstruction from debris or ice.

7. Other equipment:

   If there are front-end chillers, deethanizer reflux condensers, or fractionation rundown chillers, those will have to be rigorously simulated as well to account for their associated refrigeration loads.

Once the data-match simulation is complete, any equipment limitations can be identified by creating a table comparing process data between the data-match simulation and the original design simulation. Process data to consider include rotating equipment efficiencies, heat exchanger UAs, equipment pressure drops, column staging, feed conditions, and required compression power.

5. DETERMINE OPERATING LIMITATIONS OF EXISTING PLANT EQUIPMENT

The data-match simulation will provide useful information with regards to the amount of margin available in the existing equipment. The information can be used to determine limitations of existing plant equipment and help owners decide whether it makes sense to replace or repair any existing equipment before or during the retrofit. It can also aid in the decision-making process of whether or not a retrofit is necessary, and if so, which retrofit technology is the best choice.

For example, if there is significant residue gas compression margin available, more options are available than if the design is compression-limited. It may be more economical to operate the plant in such a way as to utilize this margin, or select a retrofit that can take advantage of the installed compression.

Understanding what the existing plant equipment can and cannot achieve is necessary for achieving an optimized retrofit design. This includes reviewing**:**

1. Piping

   Check what limitations exist with the current piping regarding:

   a) Pressure drops / hydraulic issues that may require size increases

   b) Design pressures

   c) Minimum design temperatures

2. Equipment

   Check what limitations exist with the current equipment regarding:

   a) Compressor and driver speed and power limitations, curve limitations for surge and stonewall

   b) Expander nozzle throughput and efficiency limitations

   c) Column diameter, internals, staging, and throughput/loading limitations

   d) Side reboiler hydraulics

   e) Heat exchanger pressure drop limitations

   f) Pump head and flow limitations

   g) Separator sizes and internals, mesh pad velocities, liquid holdup times

   h) Heat exchanger UAs

By comparing the data-match simulation to the original design simulation, problem areas or performance limitations in the plant can be identified. For example, if the chiller outlet temperature is warmer than design, what is the reason? Are the other process loads on the refrigeration system higher than design? Is the chiller undersized? Is the refrigerant composition different from what the compressor was designed for? Are there unusually high pressure drops in the column or through any heat exchanger passes? If possible, talk with plant operators about day-to-day operations, as they may be able to provide valuable information about the plant that explains anomalies such as these. For additional plant troubleshooting advice in detail see the reference papers below[1].

If any performance limitations or problems are identified, these issues should be brought to the attention of the plant owner so that action can be taken to rectify them, if possible, in advance of the retrofit. If the issues cannot be rectified, or the plant owner chooses not to take action, it is important to identify the limitations these issues will place on the plant performance after the retrofit.

This step not only identifies the limitations in the existing equipment, but also opportunities for substantial improvement at minimal cost. This is most often true in the compression area of a cryogenic facility. For example, deferred maintenance on a gas turbine driver for compression could be scheduled during the retrofit and the benefits of having a machine back at its nameplate capacity instead of being limited by age/operational issues could be realized as a part of the overall retrofit effort. Another example of improving capacity and/or recovery involving the compressors is the opportunity to utilize unused or inefficiently used compressor power capacity with a more modern process design.

6. ESTABLISH EXISTING PLANT BASELINE PERFORMANCE FOR THE RETROFIT DESIGN BASIS

The data-match simulation can now be used to determine the current process performance, or recoveries, with the retrofit design basis. This will represent the plant baseline performance with the existing plant as-is, to be compared with the plant recovery and performance that can be achieved when the plant is retrofitted to a newer technology.

In evaluating the turbo-expander nozzle throughput, it is crucial to know the actual volumetric flow (ACFM) that will pass through the inlet nozzle. A good rule-of-thumb is to limit the flow to 110% of the original design maximum actual volumetric flow without modifications. If details about the inlet guide vanes position is available, determine if they are currently operating fully open or near fully open. Are the J-T valves close to opening? If available, the expander curves can provide an idea of how much margin is available. It is often necessary to convert Lb/H to ACFM when using these curves. The turbo-expander can be checked by using the supplier's rating program or the owner can contact the supplier directly and include their recommendations in the list of recommended retrofit changes.

In evaluating column internals, it is essential to look at mass flow rates of liquid and vapor for each stage. Low liquid flow rates may result in tray weeping or channeling within packed beds, whereas high liquid or vapor traffic may result in flooding. Both conditions would mean that a more conservative approach should be taken with regards to the tray efficiencies used in the simulation.

Other examples of column limitations to consider are maximum inlet rate and minimum column pressure. If the inlet rate is too high, it may not be possible to pull the column pressure down to the desired operating point due to compression limitations. There may also be a risk of CO_2 freezing occurring if the column pressure operates below a certain pressure due to the lower temperatures associated with lower pressure. Side reboilers and reboiler hydraulics also have to be checked both for original design and especially for retrofit design. Requesting that the plant operators provide details on other limitations they have observed in the performance will help provide important information for the assessment.

For evaluating heat exchanger performance, target heat exchanger pass UAs for the retrofit condition can be adjusted by the ratio of the retrofit flow rate and the original design flow rate through each pass raised to the 0.6 – 0.7 power:

$$\boldsymbol{Retrofit\ UA = Original\ Design\ UA \times \left(\frac{Retrofit\ Flowrate\ (ACFM)}{Original\ Design\ Flowrate\ (ACFM)}\right)^{0.6\ or\ 0.7}}$$

If available, simulator add-on programs for heat exchanger design can be used to obtain more accurate estimates of heat exchanger performance at the retrofit design conditions.

Pressure drops through piping and equipment can be adjusted using the square of the ratio of the flow rate of the retrofit design to the original design:

$$\boldsymbol{Retrofit\ dP = Original\ Design\ dP\ \times \left(\frac{Retrofit\ Flowrate\ (ACFM)}{Original\ Design\ Flowrate\ (ACFM)}\right)^{2}}$$

For simplification, the plant hydraulic profile can typically be broken down into two main segments: from the inlet of the NGL plant up to the suction nozzle of the turbo-expander, and from the column overhead to the inlet of the booster compressor.

7. IDENTIFY APPROPRIATE RETROFIT TECHNOLOGIES FOR EVALUATION

Once the baseline plant performance level for the retrofit design basis has been established, the retrofit design can proceed. This is similar to creating an "off-design" case for a new plant design, except you will use the actual heat exchanger UAs and pressure drops to adjust UAs and pressure drops at the retrofit design conditions, instead of using the values from the field data.

In general, a design for higher recovery at an inlet flow rate close to original design is much easier to develop than a design for a higher throughput because one can usually start with the assumption that the piping, column internals, and expander/compressor will not need to be replaced or extensively modified. It can also be assumed that the pressure drops will not change dramatically. However, when higher throughput is sought, the residue gas compression power and the throughput or pressure ratio of the compressors may become a limitation.

When choosing an appropriate retrofit, the process engineer is trying to achieve the end user's desired retrofit performance goals with the least overall impact to the existing plant. Some considerations are:

- What is the goal of the retrofit (additional capacity, recovery, flexibility, or a combination)?
- What are the performance capabilities of the existing plant without retrofitting, by taking advantage of any existing equipment margins?
- What are the limitations to higher recovery? (e.g., expander capacity, compressor staging, column diameter and internals, etc.)
- Is the retrofit design basis gas composition richer or leaner than the original design?
- Compression (inlet, residue gas, or refrigeration)
    - Is a retrofit with or without additional compression power desired?
    - Compression arrangement – single or parallel units?
    - Compression changes usually have the greatest economic impact due to the potential for extended shutdown of a machine for re-wheeling or gas turbine upgrades.
- What is the turbo-expander capacity? Are J-T valves often partially open?
- What is the increase in load for downstream fractionation if there is increase in NGL recovery?

Sometimes multiple sets of boundary conditions are given in the design basis. Start with simulating the most onerous set of conditions (rich feed composition, high inlet temperature, low inlet pressure, max residue delivery pressure, summer or winter conditions) for each retrofit option to get a feel for which retrofit may work best.

The most comprehensive approach would be to compare and evaluate the performance results of a selection of technologies commercially available for retrofits. This may include both proprietary and open-art technologies.

In optimizing the performance of the plant with the retrofit technology, it is important to verify that existing plant equipment such as pumps, heat exchangers, turbo-expanders, compressors, columns, and separators can be used in the retrofit. Using the equipment data sheets, evaluate capacities, minimum design temperature, design pressure, and metallurgy for all equipment. Make sure to properly optimize UA design margin on existing heat exchangers.

Select the best retrofit option(s) and create additional equipment sizing cases that cover the operating range and power limitations. For example, it may be necessary to create a case for expander re-wheel in order to achieve a targeted increase in recovery and/or capacity.

Roughly size the retrofit equipment to get an idea of the equipment costs involved. Evaluate column internals using rigorous methods for current loadings and retrofit loadings in order to ensure there is no flooding/weeping. Compare the retrofit technologies to the baseline plant performance under the same retrofit design basis conditions. Provide recovery and power requirement results to the plant owner to confirm the choice of process design. In some situations, capacity may not be expected to increase for a few more years, and a flexible retrofit design is needed for both the normal and increased capacities. Be sure to include both scenarios in the comparison presented to the plant owner, highlighting any benefits of staggering the implementation of the retrofit portion for increased capacity at a future date.

Dual Mode/C_2 Rejection Mode Considerations

The profitability of gas processing plants is dependent on the ability to respond effectively and efficiently to market conditions. The plant should be able to achieve maximum ethane recovery when its relative value as a liquid is high. When recovering ethane is less profitable, the plant should be able to reject ethane efficiently so the plant owner is able to take advantage of its value as part of residue gas sales. New ethane rejection/recovery technologies can be retrofitted into existing gas plants to improve their flexibility.

For rejection mode, limitations are often the turbo-expander volume flow capacity and/or the column size and bottom capacity. After completing the data-match simulation, check the performance of the column internals at the rejection mode vapor liquid traffic conditions to determine if an existing plant can be retrofitted to accommodate rejection mode. Key parameters to evaluate are pressure drop and percent flooding. The cutoff point for when a new train is needed versus retrofitting an existing train is typically when the column is the limiting factor, since replacing the column is expensive and time-consuming in an operating facility which results in excessive plant downtime.

The turbo-expander volume flow capacity must also be checked. If the expander cannot handle the new flow rate without exceeding its maximum speed, the owner will have to decide whether or not to re-wheel the machine.

With rejection mode, actual volumetric flow is typically higher than recovery mode, thus check the cold separator's ability to hydraulically handle the new volumetric flow rates in ethane rejection mode. Check any other equipment not in the NGL unit scope that may impose limitations on performance.

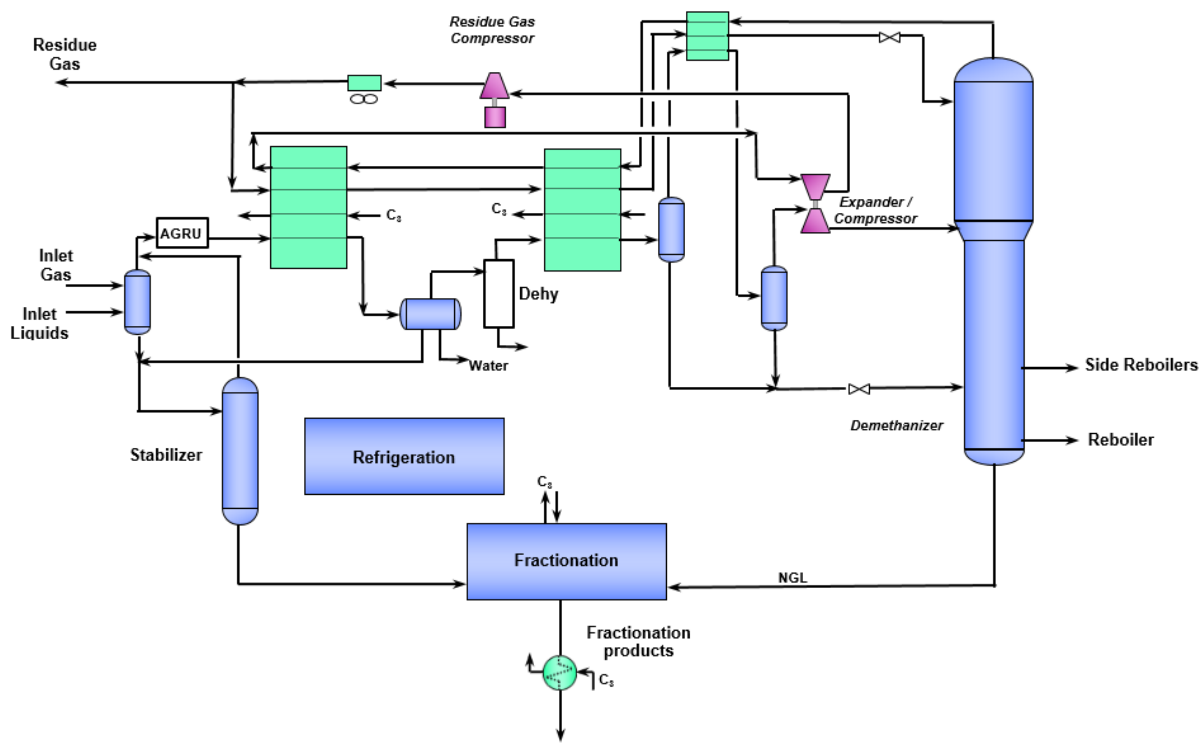
8. COMPARE THE RETROFIT TECHNOLOGIES TO THE EXISTING PLANT PERFORMANCE

A Design Feasibility Study should be prepared to compare and document the performance of the retrofit technology options. A report containing a table of the comparisons discussed in step 7 above should be given to the owner for the purpose of evaluating the options available and making a decision on a retrofit design and recovery level. Once a retrofit technology is selected, off-design cases can be run to confirm the controlling simulations for the range of operating conditions that the owner has provided. Of course, obtain the owner's approval for the retrofit performance over the range of conditions before proceeding.

EXAMPLE CASE

The following case illustrates how the previously discussed steps were used to evaluate an older plant for a NGL recovery retrofit, and covers many of the issues one might encounter with other plants. The numbers used here are not the exact numbers of a particular plant, but the example addresses a variety of issues that are typically seen in an international plant. Standard plant retrofits typically experience only a subset of the following issues discussed.

The plant to be studied uses the Residue Recycle Process (RRP) to process 320 MMSCFD (340 T/H) of natural gas (see Figure 1). The plant owners wanted to address existing limitations on product recoveries and identify feasible options to improve the ethane recovery from 70% to a minimum 90%.



Note: Side reboilers and main reboiler not shown

Figure 1 - Plant schematic for example case

The plant has a refrigeration system that provides cooling at the front-end of the plant, cooling for the fractionation system rundown chillers, and cooling in the NGL recovery plant. The plant was designed for 92% ethane recovery, however, it never achieved its design recovery level due to unstable operation. The plant was only able to achieve ethane recovery in the 70-75% range and the owner wanted to retrofit the existing plant to increase the ethane recovery from 70% to 90% or higher.

The client provided the following information initially to aid in the evaluation:

1. Original design PFDs with Heat and Material Balance for 2 compositions – Rich and Lean
2. P&IDs
3. Datasheets
    a. Demethanizer column
    b. Column internals (before and after one field modification)
    c. Heat exchangers (NGL recovery unit only)
    d. Compressors (including performance curves)
4. Operating data over three days in 5 minute increments
5. Internal study reports that had been completed over the years examining some equipment limitations that could be contributing to the low ethane recovery, such as past performance tests, a refrigeration study, and column performance reports
6. Design basis to be used for retrofit design

The following steps were taken for the technical evaluation and feasibility study of a retrofit design:

1. All required plant design information that was provided, including auxiliary equipment and equipment from other units that would affect the accuracy of the evaluation of the NGL Recovery Plant, was used to perform the technical evaluation.
2. An original design simulation was developed to evaluate any original plant design limitations.
3. Plant operating data was then used to build a data-match simulation in order to determine plant performance and identify any current plant or equipment limitations. This helped develop an understanding for why the plant was under performing on ethane recovery.
4. Existing equipment constraints were established using the results from the data-match simulation and used to evaluate possible retrofit design options that best utilized the owner's existing equipment margins.

Table 1 below compares the results between the original design, the data-match simulation, and the retrofit design and is referenced in the subsequent sections.

Table 1 - Comparison between Original Design, Data-match Simulation and Retrofit Design Basis

	Original Design	Data-match Simulation	Retrofit Design Basis
Inlet feed gas C_2+ content, GPM	3.26	3.07	4.06
Inlet gas flow, MMSCFD (T/H)	321 (336)	296 (311)	322 (338)
Inlet pressure, psia (bara)	1,015 (70)	972 (67)	1,015 (70)
Inlet temperature, °F (°C)	84 (29)	79 (26)	86 (30)
Sales gas flow, MMSCFD (T/H)	253 (207)	246 (202)	252 (207)
C_2 Recovery, %	92	74	96
C_3 Recovery, %	100	100	100
Sales gas power, HP (kW)	21,000 (15,700)	18,000 (13,400)	20,000 (14,900)
Refrigeration power, HP (kW)	7,000 (5,200)	4,600 (3,400)	6,300 (4,700)
Demethanizer overhead pressure, psig (barg)	464 (32)	406 (28)	435 (30.01)
New absorber overhead pressure, psig (barg)	N/A	N/A	430 (29.67)
Residue recycle, % of Dehy outlet	36	26	23
Cold sep temp, °F (°C)	-53 (-63)	-44 (-47)	-34 (-29)
Cold sep phase envelope approach, °F (°C)	14 (8)	34 (19)	49 (27)
Overall HX UA, Btu/°F-H (kJ/°C-H)	8,252,000 (15,672,000)	9,060,000 (17,205,600)	7,637,000 (14,503,300)
New subcooler UA, Btu/°F-H (kJ/°C-H)	N/A	N/A	4,779,000 (9,075,000)

Original Plant Design

The original plant design was simulated and the heat and mass balance on the PFDs provided by the owner for this case. The sales gas compression equipment was modeled using the compressor curves provided for each machine. A site rating for the gas turbines in both residue and refrigeration services of 26,800 HP (20 MW) total for two machines was used as the maximum power limitation.

Review of the simulation revealed that the column pressure 464 psig (32 barg), was higher than usual for a demethanizer, and the cold separator was operating too close 14 °F (8 °C) to the phase envelope for stable operation. The minimum approach to the phase envelope should be 15 °F (8.5 °C).

Data-match Simulation

Using the field data provided, a data-match simulation was created to get a close match to the field data. The calculated C_2 recovery was 74% using 18,000 HP (13,400 kW) of sales gas compression and 20,000 HP (14,900 kW) of refrigeration compression, which was significantly lower than the 26,800 HP (20 MW) power for which the sales gas and refrigeration compression were each rated. The phase envelope approach at the cold separator was wider at 34 °F (19 °C) instead of 14 °F (8 °C) in the original design.

The factors identified limiting the trains to the 70-75% ethane recovery range included:

1. The data-match residue delivery pressure was 116 psi (8 bar) lower than the original design. Normally, that would help reduce the residue compression power. However, in the RRP design used in this plant, the recycle stream is harder to subcool due to the lower pressure at the subcooler exchanger, so there is more flash vapor and less liquid reflux at the column top feed than in the original design. The data-match vapor fraction at the top feed to the column was 34%, compared to the original design value of 9%. Further, the recycle rate was about 60% of the original design recycle flow rate; thus, the total amount of reflux liquid was about half of design. This resulted in lower ethane recovery. This issue is common for RRP and RSV process designs if the residue gas delivery pressure is reduced.
2. The owner had reduced the recycle rate to try to get the column pressure down. While this did make the column operation more stable, it did not address the inefficiency of recycle stream conditions. The recycle stream was fully condensed at the subcooler outlet, but it was not subcooled enough due to the lower than design residue compressor discharge pressure. Thus, a large portion of the reflux stream flashed off at the top of the column.
3. The column physical properties showed that the density differences between phases for the original design operating conditions were what would normally be considered too small at the top of the column for normal vapor-liquid separation without increased tray spacing. The cold separator operating temperature had a much wider approach to the phase envelope for the data-match conditions than for the original design. It was suspected that initial operation of the trains close to the original design operating temperature may have been too unstable for continuous operation.
4. Indications were that the sales gas compressor was running at full speed, but the compressor driver gas turbines themselves were not operating at rated power.
5. The data-match results and client-provided documents for the residue gas compressors revealed that:

a. The original design was not an optimum fit to the driver, and the driver was oversized
b. The lower than design discharge pressure further unloaded the oversized driver
c. There was excessive time between overhauls on the gas turbine and it would need to be overhauled soon

As the owner tried to pull the column pressure down to get the recovery up at a stable operating point, the volumetric flow rate through the column was above design at the lower column pressure, so the internals were being operated more closely to a flooding condition. The owner had tried to run the cold separator at a warmer temperature a little further away from the phase envelope than in the original design and then run the column pressure at a lower pressure to keep the recovery up at the warmer cold separator temperature. The owner had tried to find an operating point that struck a balance where the recycle rate was reduced, and compressor capacity was used to pull the column pressure down as low as possible without flooding; but the horsepower and column diameter were limiting. The owner wanted to operate at conditions that enabled stable cold separator operation without sacrificing performance. The owner's past performance test report also noted that they had experienced flooding in the past which led to replacement of trays in the top section to improve recovery and stability.

Retrofit Design

The plant owner provided a design basis to consider for the retrofit design, and stipulated that retrofit design options were to be limited to bolt-on modifications of the existing demethanizer column. Starting with the boundary conditions used for the data-match simulation, the necessary equipment for a proprietary retrofit design was added. The expected ethane recovery achievable was 96% using the retrofit design basis conditions. The new equipment consisted of a large heat exchanger (subcooler), an absorber column, and a pair of absorber bottoms cold pumps to send the absorber column liquids to the top feed of the existing column. The sales gas compressor and expander/compressor were operating close to their design limits and these operating conditions would need the manufacturer’s confirmation as suitable for the retrofit design conditions. A reflux system was designed to use a portion of the existing recycle stream in combination with an additional reflux stream source incorporating a Gas Subcooled Process (GSP) design feature. All of the existing equipment would be kept in service and five process line tie-ins would be required.

For the preliminary pass, the refrigeration duties were held to no more than what was calculated from the original material balance. The CO_2 freeze, phase envelope approach, and limitations on the existing demethanizer column were checked and no issues were found. The main compression options were:

a) Re-wheel the existing compression for an operating point that would load up the re-wheeled driver,

b) Operate at higher speed at current throughput, or

c) Re-wheel for a lower column pressure and higher ethane recovery.

Ortloff’s proprietary RSV technology was selected for this retrofit design because it reduced the recycle stream requirement by providing some of the column reflux using the cold separator vapor similar to a GSP design. The compressors could keep the column pressure down with the reduced recycle flow, enabling high ethane recovery. This process design allowed the owner to make the best use of the existing gas turbine power without adding a new compressor.

The retrofit recovery level was dependent on the maximum residue gas compressor power available within the existing compressor frame size after re-wheeling. The proprietary process design would function over a wide recovery range, so the owner could choose the compressor modifications that would provide the best economic return from 90% ethane recovery to 96%, and possibly higher. The required size and function of the new heat exchanger and absorber column would not change significantly over this ethane recovery range. Rather, the upper limit on ethane recovery would be constrained by CO_2 freeze.

The plant owner's existing demethanizer column would remain in service, since preliminary checks did not show a flooding issue. The piping tie-ins would be external to the old column to facilitate commissioning of the new equipment and minimize downtime.

Summary

Due to the instability of this facility's plant operation at design conditions, it was necessary to run the plant at a lower ethane recovery. For this reason, the owner sought ways to improve recovery, including considering a plant retrofit. A significant amount of time had passed since the plant's initial start-up, and over that time period there were personnel changes, as well as changes in operating needs. The combination of all of these factors made gathering of field data and a data-match simulation imperative for this retrofit case so that all would have a clear understanding of whether or not the retrofit was necessary for achieving the owner's goals.

The following observations were made clear by developing an original design simulation and creating a data-match simulation for comparison.

1) Field data indicated a very wide difference between the original design performance and actual performance.

2) There was compression power available for the retrofit if the owner's retrofit budget would support restoration of the gas turbine drivers to their original design performance capability.

3) The plant operational instability at the original design conditions was caused by the cold separator operating too near the phase envelope and the demethanizer operating at too high a pressure.

4) The gas turbine drivers for the residue gas compression and refrigeration compression were operating at low load due to the plant operating at a lower ethane recovery level. As a result, the time between overhauls (TBO) had been greatly extended. The retrofit would require more power, and as a result the turbine driver TBO would be reduced. This would need to be considered during the economic evaluation of the retrofit project.

In this case, an RSV retrofit was a good option, as it would eliminate a number of operational issues the plant was experiencing. However, the best retrofit option in this circumstance would not have been clear to the process designer without thorough analysis of the original design, followed by analysis of current plant operation.

Conclusion

Plant retrofits can be an excellent means of increasing profitability and/or improving the operational flexibility of older NGL recovery plants. The methods outlined in this paper facilitate and optimize the retrofit decision-making process by providing a thorough understanding of existing plant operation, as well as an understanding of existing equipment limitations, margins, and/or operational issues. In applying these methods, the process designer can provide the owner/operator with a much clearer understanding of whether or not a plant retrofit is appropriate and, if so, which retrofit design is the best choice for each unique situation.

REFERENCES

1. *Practical Troubleshooting Techniques for Cryogenic Gas Plants.* 79th Gas Processors Association (GPA) Convention, 2000