HOW TO COMPARE CRYOGENIC PROCESS DESIGN ALTERNATIVES FOR A NEW PROJECT

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ABSTRACT

There are many design alternatives that must be evaluated when selecting the most efficient NGL/LPG recovery process for a new gas processing facility. For those unaccustomed or unfamiliar with evaluating competing process designs, the evaluation process can be long and arduous. This paper explains some of the more important concepts used to streamline the evaluation process and ease the selection of the optimum technology for a given project.

In many instances, the design case requirements for the new plant do not set the key constraints for the technology selection process. It is often crucial to perform a consistent analysis of the off-design cases for each technology to be evaluated, which typically includes different gas compositions, different plant throughputs, different product recovery levels, and other variations. A proper evaluation of these off-design cases requires maintaining consistent values for a number of important parameters affecting heat transfer, column operation, and machinery performance in all of the plant simulations.

For some new plant projects, the minimum liquid recovery levels have already been established based on current or planned infrastructure, project economics, or other factors. In these cases, evaluation of the technology options should generally be performed on a constant recovery basis. Other new plant projects begin with the selection of the plant compression equipment, so a constant power basis is more appropriate for the technology evaluation. An example for each evaluation basis is presented.

HOW TO COMPARE CRYOGENIC PROCESS DESIGN ALTERNATIVES FOR A NEW PROJECT

INTRODUCTION

Early in a new cryogenic plant project, process designs are evaluated so that a preliminary process selection can be made. Costs for compression as well as the plant itself can then be estimated. Several process engineers or design firms may be asked to submit a process design for evaluation. The evaluation is sometimes done before a firm project design basis is established and before the project is fully defined. The process design chosen at this stage is usually adopted for the project, therefore a good choice is critical. This paper presents some of the items that must be considered in determining whether a given process design is reasonable and consistent with the project requirements. Recommendations for streamlining the evaluation process and to facilitate receiving realistic designs are provided.

For illustration purposes, the examples in this paper present two fictional process engineers using non-proprietary process designs to meet a plant owner's requirements. The examples illustrate how it is possible to achieve very different results depending upon the assumptions each engineer uses in his simulations. Too many degrees of freedom for the engineer may make it difficult to tell whether the differences in performance for designs from different engineers are due to skillful process design or to different assumptions regarding equipment capabilities.

EXAMPLE PROJECT

A hypothetical, but typical, cryogenic plant project for ethane recovery with a preliminary design basis is used to illustrate the procedure for evaluating process designs. The plant feed gas is lean enough so that no refrigeration is required. The CO_2 content is low enough that freezing will not occur for even the highest ethane recovery level regardless of the process design selected. An NGL product containing ethane and heavier components is delivered to a high pressure pipeline, and residue gas is delivered to a sales gas pipeline at 15 psi lower than the inlet pressure. The design case plant inlet rate is specified as 100 MMSCFD. Table 1 on the following page shows the design basis conditions and Table 2 shows the lean, normal, and rich inlet gas compositions.

Base Design Cases

In this example the plant owner has an existing gas turbine driven compressor package available for consideration for this project. This compressor package will be used if it can provide enough compression to support ethane recovery of at least 85% for the normal feed composition and design basis conditions. The first design case is to determine the maximum ethane recovery that can be achieved using this existing compressor package, which is to be used in the new plant without a compressor re-wheel.

The minimum acceptable ethane recovery for the new plant is 85%. If the existing compressor is too small, or it gets diverted to another location before it can be used in this project, the plant owner needs to know how much compression is required to achieve the 85% minimum ethane recovery level.

Table 1 – Design Basis Conditions

Stream	Conditions
Plant Inlet	100 MMSCFD 800 psig 120°F
Residue Gas	785 psig 120°F max
NGL Product	$C_1/C_2 < 2.0\%$ molar 980 psig 120°F max

Table 2 – Inlet Gas Compositions

Component Mole%	Lean	Normal	Rich
N_2	2.00	2.00	2.00
CO_2	0.40	0.40	0.40
C_1	87.66	85.90	83.90
C_2	6.00	7.00	8.00
C_3	2.50	3.00	3.50
i-C_4	0.38	0.40	0.50
n-C_4	0.55	0.60	0.70
i-C_5	0.16	0.20	0.25
n-C_5	0.27	0.30	0.35
C_6^+	0.08	0.20	0.40
GPM	2.78	3.28	3.86

New compression would then have to be purchased and the process design which requires the least horsepower at 85% ethane recovery would be selected, all other considerations equal. The second design case is to determine the minimum power requirement needed to achieve 85% ethane recovery.

Off-design Cases

In addition to the two base design cases, there are two off-design cases of interest to the plant owner. The first is a rich gas composition case in which the owner needs to know what the ethane recovery will be if the inlet gas composition is richer than the normal (design) composition, and no provisions are otherwise made to accommodate the rich gas. The existing compressor is assumed to be used in this off-design case. The result may impact the compressor selection and final design basis if the probability of processing the richer gas increases. The process design which provides better recovery when processing the rich gas with no change to the base design equipment is an advantage to the owner.

The second off-design case of interest to the owner is the ethane recovery which will result if the inlet gas rate is increased to 110% of design when using the existing compressor and processing the normal composition gas. This recovery number will be helpful to the owner in evaluating the need for a new compressor. The process design with better process performance at the higher rate is of interest to the owner.

COMPARISON 1 – BASE DESIGN WITH FIXED HORSEPOWER

Two engineers each submit a process design simulation for the base case using the existing compressor package, site-rated at 6,800 HP. Engineer A submits a Gas Subcooled Process (GSP) design (Figure 1) and Engineer B submits a Residue Recycle Process (RRP) design (Figure 2). Both processes are non-proprietary, and both include a single reflux stream feeding the demethanizer above the expander feed point. The main difference is the source of the reflux stream – GSP uses inlet gas, while RRP uses residue gas. The calculated ethane recovery presented for Design A is 93% while the ethane recovery for Design B is 99%. Obviously, there is great interest in Design B using the existing compressor.

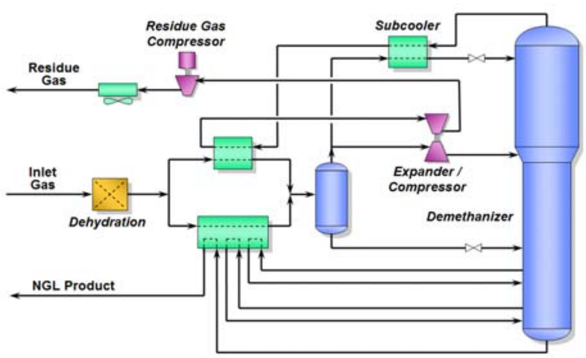

Figure 1 – Gas Subcooled Process (GSP)

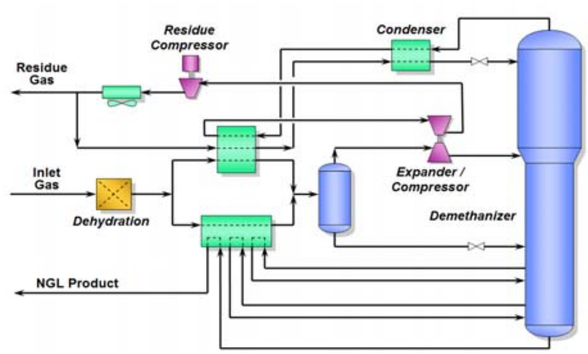

Figure 2 – Residue Recycle Process (RRP)

Tabulation of Design Parameters

The first step in evaluating the process alternatives is to summarize the details extracted from the simulations for each design. With differences in the equipment used in proposed process designs it may not always be possible to have an exact comparison between processes. The concept is what is important. By tabulating as much data as possible, it will be easy to identify differences in the assumptions made by the design engineers. This tabulation is very helpful in determining whether higher product recovery is a result of a better process design, or just the result of one engineer using larger equipment or assuming higher efficiencies for the rotating equipment.

Differences in recovery can, of course, be a result of different skill levels in applying a particular process design. It is not unusual to have two process engineers come up with different ethane recovery values for an identical GSP process flow arrangement simply due to differences in reflux flow rates, use of side heaters, etc. The plant owner wants to identify the engineer with the higher skill level, not the one with the most optimistic assumptions on equipment performance. The same equipment and piping are generally available to all engineers, especially for the non-proprietary designs used as examples here.

Data from the competing designs should be tabulated in a manner similar to the examples shown here. The values for the submitted designs for Comparison 1 have been extracted from the simulations and are presented in Table 3. Note that the list of variables used in the examples in this paper is not comprehensive. Expander bearing losses, column bottoms specification, air cooler process side outlet temperature, number of theoretical stages in the column, for example, should also be tabulated in real world comparisons. In the example comparisons, the only differences between the two designs are in the variables that are tabulated.

Table 3 – Existing Compressor Base Case Design Parameters

	Design A	**Design B**
Inlet rate	100 MMSCFD	100 MMSCFD
Inlet composition	Normal	Normal
Compression power, HP	6,800 HP	6,800 HP
Calculated ethane recovery, %	93%	99%
Rotating Equipment Efficiencies		
Residue Gas Compressor (polytropic)	75%	78%
Expander (adiabatic)	82%	84%
Booster Compressor (polytropic)	75%	78%
Pressure Drops		
Dehy Inlet to Expander Nozzle	35 psi	25 psi
Column Overhead to Booster Suction	23 psi	10 psi
Booster Disch. to Residue Comp. Suct.	10 psi	10 psi
Residue Comp. Intercooler	10 psi	10 psi
Residue Comp. Disch. To Sales	10 psi	10 psi
Exchanger UAs and Temp. Approach		
Gas / Gas Exchanger, UA / ΔT	1.70 / 5°F	3.55 / 3°F
Gas / Liquids Exchanger, UA / ΔT	0.44 / 10°F	0.47 / 7°F
Subcooler / Condenser, UA / ΔT	0.98 / 5°F	0.79 / 3°F
Total Exchanger UA (MMBTU/°F-hr)	3.12	4.81

Rotating Equipment Efficiencies

Engineer A had been informed of the efficiency to use for the existing compressor package and was familiar with the efficiencies typically achieved by expanders for this size plant. Engineer B assumed a re-wheel of the existing compressor, if needed, to achieve 78% polytropic efficiency and had not been informed of the re-wheel constraint. Engineer B had also recently worked on a larger plant where the expander was rated for 84% adiabatic efficiency and the booster compressor was rated for 78% polytropic efficiency. He mistakenly assumed that those numbers could be achieved in the smaller machine required for this plant. By assuming efficiencies that were not possible for the available equipment, Engineer B has overstated the power and expansion cooling available for the gas stream in his simulation.

Pressure Drops

Engineer A included a 35 pounds per square inch (psi) allowance for the pressure drop through the dehydration and filters, cryogenic heat exchangers, cold separator, and associated piping. Engineer B allowed 10 psi less pressure drop for the same inlet gas path. Engineer A also included 23 psi of pressure drop from the demethanizer overhead to the booster compressor suction, including both the subcooler and gas/gas exchangers, whereas Engineer B only allowed 10 psi. Engineer B's equipment will have to be much larger and more expensive than Engineer A's to achieve the relatively low pressure drops upon which his calculated recovery is based.

Exchanger Sizing

Engineer A used 5°F temperature approaches for the gas/gas and subcooler exchangers and 10°F for the gas/liquid exchanger. These are typical minimum approaches for the process designs in these examples. These approaches are generally a good compromise between exchanger size and compression power. Larger exchangers can help reduce the power requirement at a given recovery level, but only up to a temperature approach limitation. One reaches a point of diminishing returns where increasing exchanger size only adds cost to the project without increasing recovery.

Engineer B used much tighter approaches, 3°F in the gas/gas and subcooler exchangers and 7°F in the gas/liquid exchanger. His exchangers are about 54% larger than Engineer A specified in his design.

Summary of Comparison 1 Process Designs

The difference in calculated ethane recovery for the 6,800 HP case is at least partially attributable to the differences in the design assumptions made by each engineer. Engineer B was very optimistic in his assumptions, and needs to make adjustments to his compressor and expander efficiencies no matter what else he changes. However, if Engineer B chooses not to change the pressure drops and exchanger approaches, the owner knows that the plant will be significantly more expensive than the competing design, and the recovery level will have to be significantly better than Engineer A's design to justify the additional expense.

The design evaluator now has to decide whether to adjust Design A or Design B to minimize differences in the assumptions used by the two engineers. Since it is believed that Design A is based on the more realistic assumptions, the decision is made to ask Engineer B to adjust his simulation and resubmit the results.

Adjustments to Design B

Engineer B then revises his base case design using the existing residue compressor efficiency limitation, expected expander efficiencies, higher pressure drops, and wider temperature approaches. Engineer B makes one change at a time to see the impact on ethane recovery from each adjustment. The results are shown in Table 4 below.

Table 4 – Revisions to Design B with 6,800 HP

Revisions to RRP Design	Change	Recovery
Original Base Case Assumptions	---	99%
Residue Compressor Efficiency	78% to 75%	96%
Expander / Booster Efficiencies	84 / 78% to 82 / 75%	94%
Pressure Drops (psi)	25/10/30 to 35/23/30	80%
Exchanger Approaches (°F)	3 / 7 / 3 to 5 / 10 / 5	74%

Reducing the residue gas compressor efficiency from 78% to 75% drops the ethane recovery three percentage points. Changing the expander efficiency from 84% to 82% and the booster compressor efficiency from 78% to 75% results in an additional two percentage point drop in recovery. The recovery plummets 14 percentage points, however, when the pressure drops are increased to 35 psi through the inlet equipment and 23 psi upstream of the booster. Finally, decreasing the size of the exchangers by widening the temperature approaches dropped the recovery an additional six percentage points. Obviously, the RRP design was no longer a good process design choice for this project given the fixed horsepower available and the changes in the assumptions.

Differences in the Two Process Designs

The effects of the new constraints were quite surprising to Engineer B. The RRP process chosen by Engineer B can provide very high ethane recovery above a threshold horsepower level. Engineer A had considered RRP but his initial screening simulations using his design assumptions for both designs indicated that GSP was the better choice when limited to the horsepower available from the existing compressor. Engineer A had generated performance curves for both process designs at the base case design conditions showing how ethane recovery changed with residue compressor power when using the same set of assumptions for efficiencies, pressure drops, and approaches in both designs. The results are shown in Figure 3 below. (Note that these curves are specific to the design basis used in the examples for this hypothetical project. The shape of the curves, intersection, and slope changes are a function of inlet gas composition and boundary conditions. The curves are shown to illustrate how the choice of process design is affected by the assumptions used in the analysis.)

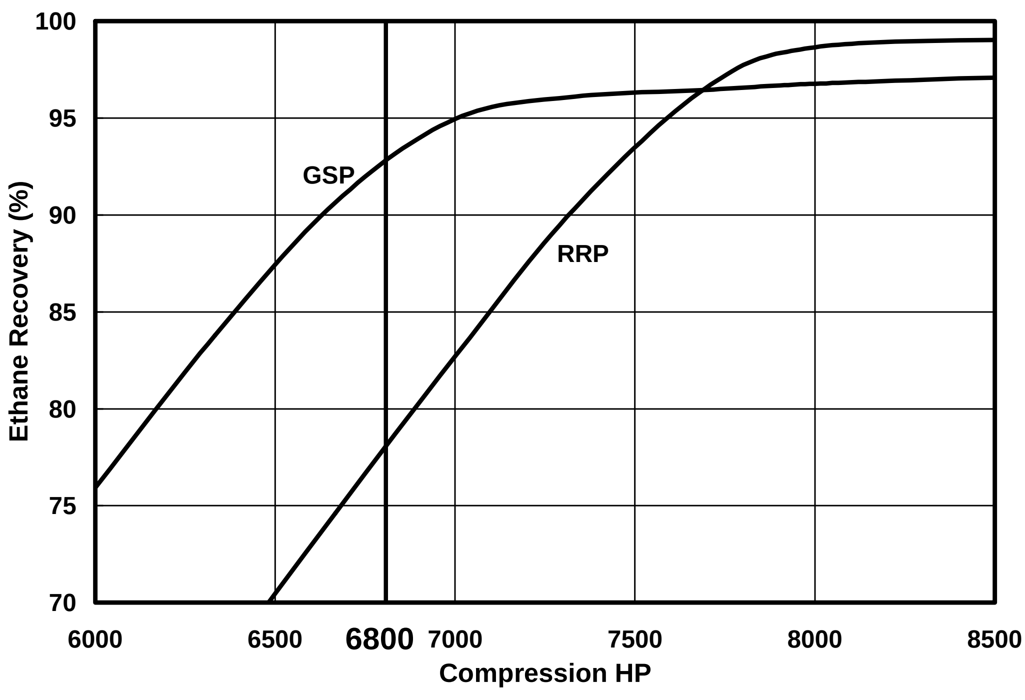

Figure 3: Engineer A’s Recovery vs. Horsepower Curves for GSP and RRP

The ethane recovery for the RRP design is lower than GSP for horsepower levels below approximately 7,700 HP. Above 7,700 HP, the RRP recovery continues to rise to the 99% level. The GSP recovery, however flattens out above 7,100 HP. This is due to the equilibrium limitation noted in previous papers [1].

For this case, Engineer B believed he had enough power available to be operating in the high recovery section of the RRP curve. He was correct, but only if the efficiencies, pressure drops, and exchanger approaches specified in his initial simulation were included in the design at additional project cost. If Engineer B had generated a similar set of curves for both processes using his original assumptions, both curves would have been about 1,200 HP to the left of the curve generated by Engineer A. The shape of the curves would have been the same, but the 6,800 HP level intercept for the RRP design would have been at the 99% ethane recovery level. (Only the portion of the GSP curve above 95% would remain on the graph in Figure 3.) One can visualize the changes in the recovery as the assumptions are changed one at a time by moving the RRP curve to the right enough at each step so that the 6800 HP intercept moves down to the values given in Table 4. The performance curves move to the right, until, after incorporating all of Engineer A's assumptions, Engineer B's RRP curve would have nearly overlaid Engineer A's curve, except for differences due to optimization.

Engineer B realizes that he needs to switch to a GSP design for the base design case when using the existing compressor with the efficiency, pressure drop, and exchanger constraints the owner wants to use on this project. He abandons the residue recycle design and submits a GSP design. For this 6,800 HP case he submits a 91% recovery design, not quite as good as Engineer A's design at 93%, but good enough to stay in contention. His GSP design now differs from Engineer A's only in the level of optimization. Engineer A's submission appears to be the better choice.

Conclusion for Comparison 1 – 6,800 HP Case

The existing compressor is a very good fit for the GSP process design given the design conditions and design feed composition. The recovery is above the minimum 85% level required for the project, but not so high that the equilibrium limitation typical of the GSP design is reached.

This example illustrates how the choice of design assumptions used in working out the base case design can dramatically affect the choice of a process design. This occurs because the optimum process design changes with the ethane recovery level. A GSP design would not usually be chosen for a 97% ethane recovery level and an RRP design would not usually be considered for an 85% ethane recovery level.

COMPARISON 2 – BASE DESIGN WITH FIXED RECOVERY

Each engineer has also submitted base case process designs for the 85% minimum recovery case requested by the owner. Engineer A has calculated a 6,350 HP compression requirement using the same design assumptions for efficiencies, pressure drops, and temperature approaches he used in the 6800 HP base case design. All Engineer A did was take his 6,800 HP, 93% ethane recovery base design, raise column pressure, and reduce compression power until the 85% recovery level was reached. Some optimization of the reflux split and side heater duty and reboiler splits resulted in the final 6,350 HP requirement.

Engineer B knew that RRP was not a good choice for this 85% ethane recovery design, so he submitted a GSP design for this case. His GSP design horsepower requirement is 5,310 HP, nearly 1,000 HP less than Engineer A's design. Because Engineer B submitted his fixed recovery design at the same time as the original fixed horsepower design (RRP), he used almost all of the same assumptions for approaches, pressure drops, and efficiencies as he had used initially to generate the RRP design analyzed in the first example.

Tabulation of Design Parameters

The key values for the two plant designs are shown in Table 5. As before, Engineer B's efficiencies are too high, the pressure drops are too low, and the exchangers are 19% larger than Design A. Since similar assumptions were used here as in the fixed horsepower case, the same comparison comments apply. It is not clear, however, whether all the improvement in Engineer B's submission is due to his optimistic assumptions, or whether he just has a better GSP design.

Table 5 – Fixed Recovery Base Case Design Parameters

	Design A	Design B
Inlet rate	100 MMSCFD	100 MMSCFD
Inlet composition	Normal	Normal
Compression power	6,350 HP	5,310 HP
Calculated ethane recovery	85%	85%
Rotating Equipment Efficiencies		
Residue Gas Compressor (polytropic)	75%	78%
Expander (adiabatic)	82%	84%
Booster Compressor (polytropic)	75%	78%
Pressure Drops		
Dehy Inlet to Expander Nozzle	35 psi	20 psi
Column Overhead to Booster Suction	23 psi	10 psi
Booster Disch. to Residue Comp. Suct.	10 psi	10 psi
Residue Comp. Intercooler	10 psi	10 psi
Residue Comp. Discharge To Sales	10 psi	10 psi
Exchanger UAs and Temp. Approach		
Gas / Gas Exchanger, UA / ΔT	1.67 / 5°F	2.49 / 3°F
Gas / Liquids Exchanger, UA / ΔT	0.42 / 10°F	0.47 / 8°F
Subcooler, UA / ΔT	1.00 / 5°F	0.72 / 3°F
Total Exchanger UA (MMBTU/°F-hr)	3.09	3.68

Engineer B is already hard at work revising his submission to make corrections to the efficiencies, pressure drops, and temperature approaches requested by the plant owner. As in the fixed horsepower case, he makes the changes one step at a time, and notes the cumulative increase in minimum horsepower requirement for each step to maintain 85% ethane recovery. The results for each step are shown in Table 6 below. Changing the residue compressor efficiency from 78% to 75% increases the horsepower requirement by 230 HP. Reducing the expander and booster compressor efficiencies increases the residue compression by another 200 HP. Increasing the pressure drops raises the requirement by an additional 480 HP. Finally, reducing the exchanger sizes raises the power by 190 HP to 6,410 HP, just slightly higher than Engineer A's design at 6,350 HP. The difference is now in optimization, and the result is consistent with the fixed horsepower case example, with Engineer B's revised design slightly less efficient than Engineer A's.

Table 6 – Revisions to Design B at 85% Ethane Recovery

Revisions to GSP Design	Change	Power
Original Base Case Assumptions	---	5,310 HP
Residue Compressor Efficiency	78% to 75%	5,540 HP
Expander / Booster Efficiencies	84 / 78% to 82 / 75%	5,740 HP
Pressure Drops (psi)	20/10/30 to 35/23/30	6,220 HP
Exchanger Approaches (°F)	3 / 8 / 3 to 5 / 10 / 5	6,410 HP

One can visualize Engineer B's GSP performance curve shifting to the right as the changes are made to the assumptions, this time with the 85% recovery line intercept horsepower changing to the values shown in Table 6 for each step until the curve almost overlays the GSP curve shown in Figure 2.

Conclusions for Comparison 2 – Fixed Recovery Case

This example also shows how sensitive the overall results are to choice of design assumptions used by individual engineers. Here, Design A still has better efficiency. The base case designs are now set for the off-design comparisons.

OFF-DESIGN VS. DESIGN CASES

Off-design cases should be run as if the plant equipment is already specified, bought, and installed per the requirements of the design case. Nothing can be changed about the equipment. Performance for the rotating equipment must be estimated for the off-design conditions, starting with the assumptions for the base design cases. Pressure drops and exchanger UAs may also have to be adjusted for the off-design conditions based on performance assumptions at the design conditions.

Since we are at an early stage in the design for the project, off-design performance of the equipment, and therefore of the plant, is based on estimates extrapolated from the expected design case performance. This means that all the assumptions used in the design case affect the calculations for the off-design cases. This is another reason why it is so important to use good assumptions in the base case design.

The interest in off-design cases increases with the uncertainty in the design basis for any new project. The more variables that remain as estimates, the more likely there will be additional off-design cases to run. The existing compressor, rich gas case is an example. The plant owners are not sure about the inlet gas composition because the source wells are not completed yet.

Note, however, that if changes in the plant design basis come about as a result of the off-design cases, the off-design conditions become a new design basis. For example, if the recovery is too low with the rich gas composition and the owner decides to buy new, higher horsepower compression equipment, then the rich gas case becomes the design case and the normal composition gas case becomes an off-design case to be calculated using the new compression horsepower.

COMPARISON 3 – OFF-DESIGN FOR RICH GAS COMPOSITION

The owner wants to know what the recovery will be with the existing 6,800 HP compressor if the gas composition is richer than the normal plant inlet composition used in the two design cases. The results of this case will be used to determine if the existing compressor has sufficient design margin for the rich gas case. The 85% minimum ethane recovery requirement may also have to be relaxed for the rich gas case. Both engineers are now using a GSP design and the more conservative design assumptions from the 6800 HP base design case as the starting point for the off-design cases.

Rich Gas Case Simulation Results

Engineer A submits a calculated ethane recovery of 78% for the rich gas composition shown in Table 2. His recovery is, as expected, significantly lower than his fixed horsepower base design recovery of 93%. Engineer B reports a slightly better number of 79%, which is surprising since his revised 6,800 HP base case GSP design recovery was lower than Engineer A's by two percentage points at 91%. The parameters are shown in Table 7 (along with the design case values for the exchanger UAs and temperature approaches) for each engineer's submission.

Table 7 – Off-Design Rich Gas Case Design Parameters

	Design A	Design B
Inlet rate	100 MMSCFD	100 MMSCFD
Inlet composition	Rich	Rich
Compression power, HP	6,800 HP	6,800 HP
Calculated ethane recovery, %	78%	79%
Rotating Equipment Efficiencies		
Residue Gas Compressor (polytropic)	75%	75%
Expander (adiabatic)	82%	82%
Booster Compressor (polytropic)	75%	75%
Pressure Drops		
Dehy Inlet to Expander Nozzle	35 psi	35 psi
Column Overhead to Booster Suction	23 psi	23 psi
Booster Disch. to Residue Comp. Suct.	10 psi	10 psi
Residue Comp. Intercooler	10 psi	10 psi
Residue Comp. Discharge to Sales	10 psi	10 psi
Exchanger UA(1) and Temp. Approach		
Gas / Gas Exch. UA, Design / Rich	1.70 / 1.70	1.76 / 1.61
Gas / Gas Exch. ΔT, Design / Rich	4.9°F / 4.4°F	4.9°F / 5.0°F
Gas / Liquids Exch. UA, Design / Rich	0.44 / 0.43	0.38 / 0.48
Gas / Liquids Exch. ΔT, Design / Rich	9.9°F / 9.9°F	9.9°F / 9.9°F
Subcooler UA, Design / Rich	0.98 / 0.98	0.55 / 1.01
Subcooler ΔT, Design / Rich	4.9°F / 5.6°F	5.0°F / 5.0°F

(1) UA values in MMBTU/°F-hr

As before, Engineer A did everything correctly. Specifically, he maintained the same exchanger UAs as the design case by adjusting the temperature approaches as necessary. Engineer B did not base the rich case simulation on his design case UAs, however. Instead, he held the approaches constant. The problem with using the base design case temperature approaches for this off-design case is that the condensing curves are different for a richer gas composition, and the required UAs typically increase for a fixed temperature approach as the gas gets richer. Engineer B did not notice that his subcooler and gas/liquids rich gas case UAs are larger than used in his design case. In other words, two exchangers in his rich gas case simulation are larger than the ones in his base design case, which is not valid for an off-design case. This is acceptable only if he really intends to buy the larger exchangers, but then his base case recovery needs to be recalculated as well, and the rich case becomes the design case. This is not what the plant owner requested.

For this rich gas case example, neither engineer changed pressure drops or equipment efficiencies from their design case. This is because the flow rate was not changed. There will, of course, be a relatively small change in these parameters as well, but the effect is usually not as significant as properly applying the constraint on the exchanger UAs.

Engineer B is asked to recalculate his recovery holding the UAs constant with his base design. The result is a calculated ethane recovery of 73%, which is significantly lower than Engineer A's 78%. Engineer B's subcooler was a little too small in his base case design because he did not optimize the reflux rate properly. The effect of this error is magnified in the off-design case when the calculation is done properly using the base case design exchanger sizes. Design A performs better in the rich gas off-design conditions.

Although a lean case example is not provided, one can imagine the results. Engineer A would have held UAs constant, the temperature approaches would have narrowed, and recovery would have been above the design case results. Engineer B would have held the approaches constant, the calculated UAs would have been lower than design, and he would have underestimated the lean composition case ethane recovery.

Conclusions for Comparison 3 – Off-design Rich Gas Case

Designs which are not optimized for the base design may have their deficiencies amplified in the inevitable off-design cases needed in the initial stages of a new project. It is very important to have the best possible design case before running any off-design cases. Care must also be taken to ensure that off-design cases do not become design cases, unless the design basis is modified accordingly. All off-design case results should be tabulated and analyzed to see if they have been calculated properly based on the design cases.

COMPARISON 4 – OFF-DESIGN CASE FOR 110% FLOW

For this off-design case, the plant owner would like to see what happens if the gas rate is 110% of the design rate of 100 MMSCFD, using the normal feed composition and holding the boundary conditions for temperature and pressure the same as in the base case. The existing 6,800 HP compressor is used as in the fixed horsepower base case design comparison. The starting point for each engineer is the same 6,800 HP base case GSP design used in Comparison 3, where the recoveries were 93% for Engineer A and 91% for Engineer B.

For the 110% off-design case, Engineer A reports a calculated ethane recovery of 68%, while Engineer B reports 83%. This large difference was unexpected considering the difference in the base design recovery was only two percentage points. The design parameters for this 110% flow case are tabulated with the corresponding 100% design values in Table 8.

Table 8 – Off-Design 110% Flow Case Design Parameters

	Design A	Design B
Inlet rate	110 MMSCFD	110 MMSCFD
Inlet composition	Normal	Normal
Compression power, HP	6,800 HP	6,800 HP
Calculated ethane recovery, %	68%	83%
Rotating Equipment Efficiencies		
Residue Gas Comp., Design / 110%	75% / 73%	75% / 75%
Expander (adiabatic), Design / 110%	82% / 80%	82% / 82%
Booster Compressor, Design / 110%	75% / 73%	75% / 75%
Pressure Drops		
Inlet to Expander, Design / 110%	35 / 42 psi	35 / 35 psi
Column to Booster, Design / 110%	23 / 28 psi	23 / 23 psi
Booster to Res. Comp., Design / 110%	10 / 12 psi	10 / 10 psi
Res. Comp. Intercooler, Design / 110%	10 / 12 psi	10 / 10 psi
Res. Comp. to Sales, Design / 110%	10 / 12 psi	10 / 10 psi
Exchanger UA[(1)] and Temp. Approach		
Gas / Gas Exch. UA, Design / 110%	1.70 / 1.82	1.76 / 1.89
Gas / Gas Exch. ΔT, Design / 110%	4.9°F / 5.2°F	4.9°F / 4.9°F
Gas / Liq Exch. UA, Design / 110%	0.44 / 0.47	0.38 / 0.48
Gas / Liq Exch. ΔT, Design / 110%	9.9°F / 8.4°F	9.9°F / 9.5°F
Subcooler UA, Design / 110%	0.98 / 1.05	0.55 / 1.12
Subcooler ΔT, Design / 110%	4.9°F / 2.8°F	5.0°F / 5.0°F

(1) UA values in MMBTU/°F-hr

Analysis of Off-design Case Process Values

Engineer A has changed the equipment efficiencies, pressure drops, and exchanger UAs from the design case values. Engineer B has not made similar changes. Instead, Engineer B has carried over his base case assumptions to the off-design case. The only change Engineer B has made for the off-design case is to increase the plant inlet flow and converge his design simulation to the design case constraints while holding the compression power to the prescribed 6,800 HP level.

Rotating Equipment Efficiencies at 110% of Design Flow Rate

If the best efficiency point is specified for the 100% flow rate conditions, then the efficiencies can be expected to drop both above and below the design point flow rate. This is true for the residue gas compressor as well as for the expander/compressor. The question is how much will the efficiency drop? Off-design efficiency estimates can be generated using manufacturer-supplied rating programs, and this is generally what should be done in the early stages of a project. For this example, Engineer A estimated two percentage point drops in efficiency for the residue compressor, the expander, and the booster compressor. He also assumed that there would be enough expander inlet nozzle area provided in the expander design to allow operation at the 110% flow conditions without the J-T valve opening. (This assumption may not be valid without special design consideration by the expander supplier.)

Pressure Drops at 110% of Design Flow Rate

Pressure drops through equipment and piping generally increase by the square of the ratio of flow rates, all other variables being constant. A 10% increase in flow will result in pressure drops increasing by 21%. This change in pressure drops always has a significant effect on the plant performance and cannot be ignored for any process design. Pressure drops on the residue gas side of the plant will also increase by the same factor. With fixed compression power, the column pressure will increase over the design case value to compensate for the increased pressure drops. This results in a decreased pressure ratio across the expander, resulting in warmer temperatures throughout the plant and lower ethane recovery.

Exchanger Performance at 110% of Design Flow Rate

At higher flow rates the velocities through the exchangers increase. This has two effects. The first is an increase in pressure drop through the exchanger as noted above. The second is an increase in the heat transfer coefficient. Since the U value increases and the area stays constant, the UA increases at higher than design flow rates and decreases at lower than design flow rates. The change is not linear, however, but is instead approximately proportional to the ratio of the flow rates to the 0.7 power. For a 10% increase in flow rate, the UA can be expected to increase by about 7%, not 10%. This is a small but real change, and it helps offset the negative effect of the increase in pressure drops.

Analysis of Results for the 110% Case

Engineer B has some work to do. He must go back and make corrections similar to those made by Engineer A. When he does this, the calculated recovery for his 110% off-design case drops to 64%, slightly lower than Engineer A's 68% result. This result is expected since the weakness in Engineer B's base design is reflected in the off-design case results. The effect of each revision is shown in Table 9 below.

Table 9 – Revisions to Design B 110% Flow Off-Design Case

Revisions to GSP Design	Change	Recovery
Original Base Case Assumptions	---	83%
Residue Compressor Efficiency	75% to 73%	76%
Expander / Booster Efficiencies	82 / 75% to 80 / 73%	72%
Pressure Drops (psi)	Design $\Delta P \times (1.1)^2$	66%
Exchanger UAs	Design UA $\times (1.1)^{0.7}$	64%

In this case, the error by Engineer B in assuming fixed exchanger minimum approaches would not have been so significant if he had made the same error in setting the reflux rate that he made in the base case design. For his 110% case the reflux rate is closer to optimum, but in doing so, he has overstated the subcooler exchanger size. This was corrected in the last step when the temperatures were adjusted to match the corrected 110% flow UAs from his base design. Recovery drops another two percentage points as a result of this correction for the smaller subcooler, as expected. Engineer

B's revised simulation now reflects how his base design would perform at the 110% flow off-design conditions. Design A provides better performance for this off-design case.

RECOMMENDATIONS

Differences in process engineers' assumptions have been demonstrated to have a significant impact on the process design results. These impacts are then propagated to all the off-design cases. If the goal of a plant owner is to choose among process designs early in the design phase of the project, much time and effort can be saved if all engineers use similar assumptions as a starting point in their designs. This will make evaluating the process designs much easier.

The first step in evaluating process designs really starts with the design basis. If the assumptions that must be made by the process engineer can be minimized, the variations in the performance of the submitted designs which are due to differences in the assumptions can be minimized. The assumptions used in the Design A examples presented in this paper offer a starting point for some of the more common variables that could be specified in a design basis, at least for a small plant. Some values, for example, pressure drops, may need to be adjusted up or down for higher or lower operating pressures. Rotating equipment efficiencies generally increase with plant size and values higher than those used in the examples should be used for larger plants. A number of other variables have not been considered in the examples presented but should be tabulated in the evaluation of the designs, including items such as expander compressor bearing losses, air cooler outlet temperatures, etc. The important point is to make sure that the significant differences between designs are identified and challenged during the process design comparison. The evaluator can minimize the differences by specifying as many of the assumptions as possible in the design basis before the designs are submitted.

Note that some engineers may want to submit designs deviating from the guidelines specified in a design basis, and may have very good reason for doing so. In that case they should be asked to provide justification for the deviations during the evaluation period.

For off-design case comparisons, our recommendation is to carefully tabulate and analyze the results submitted to make sure that the requirements of an off-design case have been met. It is important to ensure that the engineer has not simply created another design case, with results that cannot be attained if the plant is built per the base design case constraints.

REFERENCES CITED

1. Pitman, R.N., Hudson, H.M. and Wilkinson, J.D., "Next Generation Processes for NGL/LPG Recovery", 77th Annual Convention of the Gas Processors Association, March 16, 1998.