A Comparative Study of Propane Recovery Processes

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ABSTRACT

There are many processes available for propane recovery plants. Some of these processes are licensed and others are available in the public domain. In either case, it is important to understand and examine the choices available before starting any project, new or revamp.

This paper presents an overview of the basic principles that affect propane recovery. Methods of how to compare different processes are discussed, and optimization of a process to achieve the highest return on investment is presented. An example is presented from a recent study.

The preliminary results from a comparative study of propane recovery processes are presented to demonstrate various points. These results illustrate how different processes perform over a range of operating conditions and compositions. The comparisons are made using a consistent basis and assumptions for all the processes evaluated.

The goal is to provide insight on how different processes perform under a variety of conditions. This type of analysis can be used in conceptual engineering and in contractor/ licensor evaluations.

BACKGROUND

Designing a new gas plant or upgrading an existing plant is a very challenging endeavor. Past studies have shown that up to 80% of the cost of a plant may be committed during conceptual engineering[1]. Therefore, when designing a new plant or upgrading an existing plant it is very important to understand and select the right process to minimize capital and operating expenses.

We have seen many new plants constructed and plant upgrades performed that have left us bewildered. In most cases, a process was hastily selected or a contractor was selected who imposed their preferred technology, leaving the operator with a plant that was far from optimal.

With the plethora of propane recovery processes available, it is easy to understand why there may be confusion over which process is best. Even defining what constitutes "best" can be very difficult. Making valid comparisons between processes can be difficult since many processes are licensed or proprietary. Many processes have certain niche conditions where they may excel over other processes, but under other conditions they may not compare favorably.

In this paper, we plan to present an overview of the basic principles affecting propane recovery and discuss the comparative technique of selecting the best process for certain specified conditions. We will present a methodology for optimization of process conditions in order to achieve a low cost, high efficiency propane recovery process.

We have initiated a comprehensive study comparing a number of available processes. The processes studied include licensed and public domain processes. The preliminary results from this study are used to illustrate the points discussed. General results from a recent study for a specific new plant are presented as an example of the need for adequate process evaluation during the conceptual engineering stage of a project.

PROPANE RECOVERY STUDY

We have identified over 25 propane recovery processes available either as a licensed process or in the general public domain. Some of these processes are already considered older technology, but many plants continue to operate with these processes.

After many frustrating attempts to compare different processes from papers, patents, and other sources, all of which utilized a different design basis, we decided to initiate our own study. The goal of this study was to utilize a consistent basis and examine each process over a wide range of process conditions.

The process conditions that were varied included gas composition, recovery level, and inlet pressure. Inlet gas compositions of 2, 4, and 7 gal/MCF were evaluated. For each composition, the CO_2 and N_2 were held constant and the other components were varied proportionally based upon past project experience. Propane recovery levels of 80, 90, and 95%, and inlet pressures of 500, 700, and 900 psig were evaluated. Other factors such as inlet rate, temperature, ethane content in the product, exchanger temperature approach, residue gas pressure, compressor efficiencies, etc. were all fixed to provide a consistent basis for comparison. Thirty-five parameters were specified in the design basis. Table 1 lists some of the key parameters specified for this study.

Table 1

Key Study Parameters

Inlet Rate	100 MMSCFD	Exchanger Min Temp Approach (PF's)	5 °F
Inlet Temperature	120 °F	Exchanger Min Temp Approach (ST's)	10 °F
Residue Pressure	500 psig	Exchanger Pressure Drop	5 psi
Product C2/C3 Specification	1.5 LV%	Residue Compressor Efficiency	75%adia
Expander Efficiency	80% adia	Refrigeration Compressor Efficiency	70%adia
Expander/Compressor Efficiency	70% adia	Refrigeration Minimum Process Temp	-30 °F

Each process was then simulated using HYSYS™ or HYSIM™ and the results were tabulated. The process configurations were developed from PFD/P&ID information available in-house from existing plants, from articles in the open literature, or from patent descriptions. Equipment sizing and cost estimation were performed using a combination of simulator available utilities and in-house programs. To date, we have performed and tabulated over 120 cases on seven processes.

BASIC PRINCIPLES AFFECTING RECOVERY

From the initial work on the propane recovery study we have developed a better understanding and confirmation of the principles that affect propane recovery. In very simple terms, the gas is cooled sufficiently to condense the propane and heavier hydrocarbons. However, energy must be supplied to cool the gas. This energy is usually supplied by either expansion or refrigeration or a combination of both. In either case, external power must typically be supplied in the form of compression. In order to recover more propane, the amount of external power supplied to the gas must increase. Figure 1 illustrates how the compression horsepower increases as the recovery level increases for three different inlet pressures.

Gas composition has an effect on the amount of compression horsepower required. Richer gas generally requires more horsepower to achieve the same recovery level than a leaner gas as shown in Figure 2. However, since the gas is richer more product is recovered.

External refrigeration, typically propane or a similar refrigerant, is usually required as the gas composition becomes richer. As a rule-of-thumb for richer compositions: one horsepower of refrigeration utilized will save two horsepower of residue compression. This is illustrated in Figure 3 for a four gal/MCF inlet gas at 900 psig inlet pressure.

In order to obtain higher recovery levels, colder temperatures must be achieved. As discussed above, more energy must be supplied to the gas in order to increase recoveries**.** This additional energy is used to cool the gas further and condense more of the propane from the gas. Figure 4 shows the minimum temperature in the process as a function of the recovery level for a 4 gal/MCF gas at different inlet pressures. As expected, the lower the inlet pressure, the colder the process must get to achieve the same recovery level.

Heat exchanger area increases as the recovery level increases. Again, the gas must be cooled to lower temperatures by using more energy. In order to transfer this energy to the gas to provide cooling, more heat transfer area is required. Also, as inlet pressure decreases, more heat transfer area is required to achieve the same recovery level. This is largely due to the higher temperature driving forces available at the higher pressures (greater overall expansion ratios). Figure 5 shows the relationship between heat transfer area (UA) and recovery for a 4 gal/MCF gas at different pressures.

As the recovery level and inlet pressure increases there are corresponding increases in vessel sizes as well. At higher recovery levels and at higher pressures more liquid condensation occurs. In addition to more propane being condensed, other components such as methane and ethane are also condensed. These must then be fractionated out of the product, resulting in a more separation-intensive process. This typically requires more tower volume to achieve both the higher product recovery level and still maintain product specifications. Figure 6 illustrates this trend.

SELECTING THE OPTIMUM PROCESS

We have divided propane recovery processes into three main categories: single tower, two tower, and other. In general, the single tower process utilizes a non-refluxed tower or a tower that is externally refluxed with a subcooled and flashed process stream. In the two tower processes the first tower is generally refluxed with a stream generated from the second tower. The first tower will make a rough component separation and the second tower will actually make the specification liquid product. The other category includes processes such as refrigerated oil absorption (ROA), straight refrigeration, and other similar processes, which are typically processes without an expander/compressor.

In order to compare processes, a set of comparative criteria must be determined. A simple measure for comparison has usually been total compression horsepower required. This indicates two things; 1) capital cost, since compression often makes up a large percentage of a gas plant's capital cost, and 2) operating expense, since compression requires the bulk of a plant's fuel and maintenance.

We have taken this one step further and developed a term called process efficiency (PE). This is defined as product volume per unit of energy expended, typically barrels per MMBtu. In our study we calculated this term from the compression horsepower required, plus the pump and other electrical energy required, plus the heat duty input, minus the potential heat duty that can be recovered from waste heat from the compression.

PE = Compression Fuel + Pump Energy + Heating Medium Heater Fuel – Available Waste Heat

It has been assumed in this study that all compression is driven by a gas fired engine or turbine. The PE can be modified to suit site specific conditions such as electric drivers if required.

Another term used for capital cost comparisons is called the perceived cost factor (PCF). This term is calculated from the compression horsepower, exchanger UA, vessel volume, and heater duty. Cost factors (A-D) were determined for the range of equipment sizes employed in this study and then applied and summed, resulting in the PCF. This term gives a relative capital cost that can be used to compare processes.

PCF = A(Compression Hp) + B(Exchanger UA) + C(Vessel Volume) + D(Heater Duty)

We present two sets of example comparisons to highlight the above comparative techniques. In these two examples we have included five different processes. Processes "B" and "C" are two tower processes, and processes "A", "D", and "E" are single tower processes.

Example 1

Two processes are compared in Figures 7, 8, and 9 in terms of horsepower, process efficiency, and perceived cost factor. The data presented are for two highly different process configurations, both with a 4 gal/MCF composition at 500 psig inlet pressure.

In Figure 7 these processes are compared in terms of total (residue and refrigeration) compression horsepower. At 80% recovery both processes require approximately the same amount of horsepower (5000 hp). However, as the recovery level increases, the horsepower requirements for process "A" begin to increase substantially. At 95% recovery, process "A" requires approximately 8500 hp, whereas, process "B" requires approximately 6000 hp.

The two processes are next compared in terms of process efficiency in Figure 8. Although at 80% recovery they both utilize approximately the same horsepower, process "B" is slightly more efficient, recovering 3.3 bbls/MMBtu versus 3.0 bbls/MMBtu for process "A". As with compression horsepower, the difference between the two processes widens as the recovery levels increase. At 95% recovery there is nearly a 1 bbl/MMBtu difference between the two processes.

An interesting comparison can be made from Figure 9 which shows the perceived cost factor for the two processes as a function of the recovery level At the 95% recovery level, not only is process "B" more efficient (i.e. less operating costs), it also has a lower capital cost (PCF) than process "A". It is not so clear cut at the lower recovery levels, where even though process "B" is slightly more efficient even at 80% recovery, it is also slightly more costly. Some simple economic modeling can be done to determine which process best suits a specific application.

The above example illustrates a key point in this paper: some processes perform well under certain conditions and comparatively poorly at other conditions. It is also not always clear what the best process is, as in the example above where process "B" has lower operating costs at 80% recovery, but a higher capital cost. Also, the optimum recovery level should be determined using simple economics of incremental capital and operating costs versus incremental product. In many projects this is arbitrarily specified with little regard for economic justification.

Example 2

Another illustration of variable performance is given in Figure 10. The process efficiency as a function of inlet pressure for five processes are compared at 95% recovery for a 2 gal/MMSCF inlet gas. The difference between best and worst at low inlet pressure (500 psig) is less than 2 bbls/MMBtu. However, at the higher pressures (900 psig) this difference is over 7 bbls/MMBtu. Obviously, process "B" is well suited to high inlet pressures and high recovery levels for a lean gas. For others, such as processes "A" and "E", the process efficiency is relatively insensitive to inlet pressure.

Figure 11 compares processes with different inlet compositions at 700 psig and 95% recovery. Processes "B" and "C" are significantly more efficient than the others at inlet compositions below 4 gal/MCF. However, with richer inlet gas, process "B" seems to suffer dramatically in terms of process efficiency, whereas, process "C" improves its process efficiency. This is a very good example of how important process selection is. One must understand that many processes have limitations and are not applicable to all conditions**.** More often than not, the one point at which a plant will never operate is the official design point. Flexibility in handling a defined range of conditions is a very important factor that should be evaluated when selecting a process.

The perceived cost factor for different processes is compared in Figure 12 as a function of the recovery level for a 4 gal/MCF inlet gas at 700 psig inlet pressure. For some processes, such as process "A", a large increase in the PCF is required to obtain a relatively small increase in recovery. This indicates that a 95% recovery level is probably not justified using a process such as "A". Other processes, such as "B" have a much flatter, almost linear, PCF versus recovery, making higher recovery levels more economically justifiable.

In Figure 11, for a 4 gal/MCF inlet gas at 700 psig inlet pressure and 95% recovery level, the most efficient process was "C", followed by "B", "D", and "A". The PCF rankings, from Figure 12, from lowest to highest are "B", "A", "D", and "C". Therefore, although process "C" is the most efficient, it is also the most costly. Process "B" was a close second in terms of process efficiency, and it appears to be the least costly.

OPTIMIZING PROCESS CONDITIONS

Each plant has its own economic circumstances that make it unique, and thus, any process applied to a given plant site must be refined in order to obtain the maximum return on investment. To obtain the maximum return on investment certain parameters should be optimized.

Recovery Level

An often overlooked parameter is recovery level. It does not make sense to achieve high recovery levels when it is not justified. Processing contracts, fuel prices, product prices, political stability, etc. are all factors that must be evaluated to decide what amount of additional capital is justified to recover more product.

Earlier examples (Figures 9 and 12) show that the PCF increases exponentially with recovery level for certain processes, while for others it is nearly linear. It has also been shown that the PE generally decreases as the recovery level increases as more energy is required to obtain the higher recoveries. Since operating and capital costs are increasing as recovery level increases, there is usually an optimum recovery level that can be justified based on a set of economic assumptions. In some cases the optimum may be 100%.

Inlet Pressure

Another parameter that should be evaluated is the specified inlet pressure. In some cases a gathering system or pipeline must be installed to bring the gas to the plant. In these situations, determining the plant inlet pressure that minimizes gathering or pipeline system costs is very important. In this study plant inlet pressures were assumed. However; in most cases this does not come without some costs, since field or gathering compression must often be installed to deliver the gas to the plant at the required pressure. Gathering system design and optimization is a very complex engineering task and will not be addressed in this study. However, understanding how inlet pressure affects process efficiency and the capital cost (PCF) is important and can be applied and incorporated into gathering system designs.

Generally, inlet pressures of 500 psig to 700 psig are favored for propane recovery due to the thermodynamics (i.e. K-values in the cold separators, towers, and operation within the two-phase region). Figure 13 shows the process efficiency as a function of inlet pressure. This is the same data as shown earlier in Figure 10, except that the additional inlet compression required for the 700 psig and 900 psig cases is added. Most of the processes decrease in process efficiency as the pressure is increased. However, there are some processes that require higher inlet pressures in order to perform competitively (e.g. process "D"). Therefore, each case must be examined carefully.

Processes with lower inlet pressures are generally higher in capital costs compared to high inlet pressure designs. Figure 14 illustrates how the PCF decreases as the inlet pressure is increased for a 7 gal/MCF inlet gas and 90% recovery. At the lower pressures, more heat exchange is required to achieve the same recovery levels due to smaller temperature driving forces. In addition, the lower pressure cases generally require more compression horsepower in comparison to the higher inlet pressure cases. All of this combines to offset the additional costs incurred for higher design pressure equipment.

Although lower inlet pressures may be favorable in terms of processing efficiency, there is a trade-off, since the capital costs increase. Another factor to be included in selecting the optimum inlet pressure is the gathering system costs. Here too, there are trade-offs since a low pressure gathering system may have less compression but larger pipelines when compared to a high pressure gathering system which would have more compression but smaller pipelines. Optimization of the integrated gathering system and plant should be performed in order to maximize investment returns.

Refrigeration

The use of refrigeration within processes is a parameter that can be used to "fine tune" a process. It is generally accepted that as the gas becomes richer, refrigeration is required since more product must be condensed from the gas stream. It is also generally true that as the inlet pressure is lowered, refrigeration is required more often to achieve a given level of product recovery. This is usually the most efficient way to input energy to cool the gas in the low pressure cases.

As described earlier, the use of refrigeration almost always saves on total compression horsepower, process efficiency, and capital costs (more so for the medium to rich composition gases than lean gases). Figures 15 and 16 show two processes both with and without refrigeration at 90% propane recovery for a 4 gal/MCF inlet composition and with a 900 psig inlet pressure. For both processes, the total compression horsepower (Figure 15) was reduced when refrigeration was used. This reduction in horsepower results in an increase in process efficiency of the refrigerated processes over the non-refrigerated processes (Figure 16).

When applied improperly, the use of refrigeration can actually decrease process efficiency and increase capital costs. It can lead to over-condensation of light ends such as methane and ethane, which must then be fractionated from the product. Although the net result may be the same or slightly lower total compression horsepower, the increased heat duty and tower sizes can actually decrease the process efficiency and increase the capital costs.

The use of refrigeration also becomes more advantageous as recovery levels increase. Figure 17 shows process "A" operating at 80% and 95% recovery with and without refrigeration. These cases were for a 4 gal/MCF inlet gas and 900 psig inlet pressure. At 80% recovery the difference between the process efficiencies with and without refrigeration was very small, approximately 0.2 bbl/MMBtu. At the 95% recovery level this difference increased to approximately 0.8 bbl/MMBtu.

Since utilizing refrigeration usually lowers the total compression horsepower, the capital costs are usually slightly lower than without refrigeration. As the recovery level increases, the differences in capital costs generally become greater, with refrigeration more heavily favored. Figure 18 shows the perceived cost factor as a function of recovery for the two processes presented in Figure 15 with and without refrigeration. As with recovery level, refrigeration is favored with increasing inlet gas richness based on capital cost savings. In some cases it may make sense to install a process without refrigeration since it eliminates an entire system that would have to be designed and constructed, plus it would lead to a somewhat simpler process to operate. Factors such as location and schedule can make these easy decisions.

Pre-Boost and Post-Boost Expanders

In this study all the processes simulated utilized a post-boost configuration for the compressor side of the expander. In this configuration the compressor side of the expander compresses residue gas. In certain situations it makes sense to evaluate a pre-boost configuration where the compressor side of the expander compresses inlet gas prior to entering the process. Common situations where pre-boost may be favored are when inlet compression is used at the plant and when the inlet pressures are low.

When inlet compression is used at a plant, some sort of after-cooling is employed to cool the gas before entering the process. This after-cooling is typically performed with air-coolers or cooling water. In this case using a pre-boost configuration works well since the heat of compression can easily be removed and the inlet temperature to the process remains the same. When there is no inlet compression, pre-boost is not always optimal due to the fact that the gas from the inlet pipeline is typically cooler than ambient temperature (buried or subsea pipeline) and compressing it with a pre-boost compressor adds heat to the inlet gas.

Low inlet pressures are generally favored for pre-boost configurations as well. As seen earlier (Figure 10), as the inlet pressure increases the process efficiency tends to increase. There is also a concern in some instances (i.e. 900 psig) that a pre-boost compressor might lead to pressures that are above the critical pressure of the gas.

APPLICATION STUDY EXAMPLE

A client with an existing plant decided to expand and add another process train. The original concept was to design the second train with the identical process utilized in the existing train. We performed a comparative study of nine processes and found a process that was more efficient and cheaper in capital than their existing process. In fact, the new process was so much more efficient, they were interested in possibly modifying their existing train so that they could save on compression.

The process efficiency of the nine processes studied ranged from 2.8 bbls/MMBtu to 15.4 bbls/MMBtu, with the existing process falling in the middle at 7.8 bbls/MMBtu. There were three other processes that outperformed the existing process in terms of process efficiency. The final process selected required neither refrigeration nor compression to meet the target recovery level, whereas the existing process required a significant amount of refrigeration. This was the biggest factor in cost savings.

The top two processes plus the existing process were selected for further sensitivity analysis. The sensitivity of the process in terms of compression horsepower, process efficiency, and exchanger area was evaluated for off-design compositions and recovery levels. In this analysis one of the processes was found to be very sensitive to recovery level, whereas, the other two were found to be relatively insensitive.

The selected process was estimated to cost 25% less than the existing process. The largest savings were in compression and elimination of the refrigeration system. The selected process also had half the number of heat exchangers (partly due to the elimination of the refrigeration system) compared to the existing process. The fewer equipment items along with the lack of compression led us to the conclusion that the new process would be easier to operate and maintain when compared to the existing process.

Further work was performed comparing the selected process to the existing process in order to explain to the client how the selected process could perform so efficiently. This analysis found three distinct points that accounted for the higher efficiency of the selected process: 1) expander horsepower, 2) tower pressure, and 3) heat exchanger duty/area.

The two processes used approximately the same amount of total horsepower, where total horsepower is defined as the sum of the expander, refrigeration, inlet, and residue. The two processes were within 4% of each other in terms of total horsepower. However, this total was broken down differently between the two processes. The selected process received all of its horsepower from the expander, but the existing process had an expander output approximately 30% less than that of the selected process.

The higher expander horsepower output resulted in a lower tower pressure (post-boost configuration). This lower tower pressure resulted in a better separation due to the thermodynamics of the separation process, required less reflux to achieve the same separation (recovery level), and less cold energy expended to create the reflux stream. Also, the tower operates at lower temperatures which can be cross-exchanged with feed gas to get colder temperatures in the main process as well.

The final major difference was in the heat exchange performance. The composite temperature curves for the two processes showed that the selected process was much more efficient at transferring the cold energy of the process. The weighted LMTD for the selected process was half that of the existing process. This is with the same minimum temperature approach specifications in each process. The more efficient heat exchange is not without some cost. The total UA for the selected process was approximately 40% greater than that of the existing process. However, past experience has shown that exchanger area is significantly cheaper in terms of both capital and operating costs than compression horsepower.

CONCLUSIONS AND RECOMMENDATIONS

This paper was prepared to illustrate the value of conceptual engineering and process selection. There are a number of factors that influence propane recovery process design. Some processes are highly effective under certain conditions, but perform very poorly at other conditions. A study, such as this, can be very valuable in screening processes to consider for a new plant or an upgrade to an existing facility.

Any comparative study performed should be done independently with a consistent basis. Operators should not be influenced or swayed by a contractor's licensed process until it has been compared to other processes over the entire range of expected operating conditions.

In the conceptual engineering phase, processes should be evaluated with regard to sensitivity to possible condition changes. This includes compositional changes, pressure fluctuations, and others.

Processes should be optimized where conditions permit. Recovery levels should be economically justified against incremental costs. The inlet pressure should be optimized relative to gathering system costs where applicable.

We plan to evaluate more processes as a part of completing this comprehensive study. As new processes are developed we hope to evaluate and add them to our results. There are also plans to perform a similar study for ethane recovery processes, ethane recovery/ rejection processes, and high CO_2 systems.

ACKNOWLEDGEMENTS

We would like to thank Joe Provine, who has been a mentor, friend, and esteemed colleague. It was years ago when Joe first discussed the merits of performing such a study. He has provided valuable insight and guidance over the years as this project was developed.

We would also like to thank Chris Pritchard for his hard work and assistance in preparing the numerous tables and graphs for this study and paper.

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Figure 1: Effect of Propane Recovery on Total Compression (Average of All Processes)

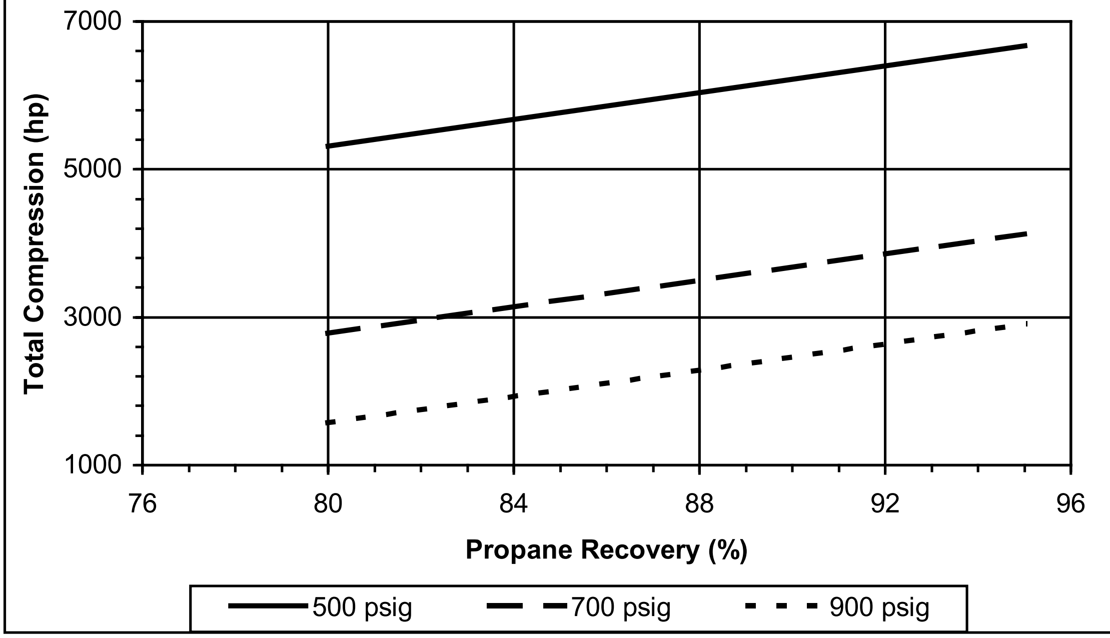


Figure 2: Effect of Feed Composition on Total Compression (80% Recovery and 700 psig)

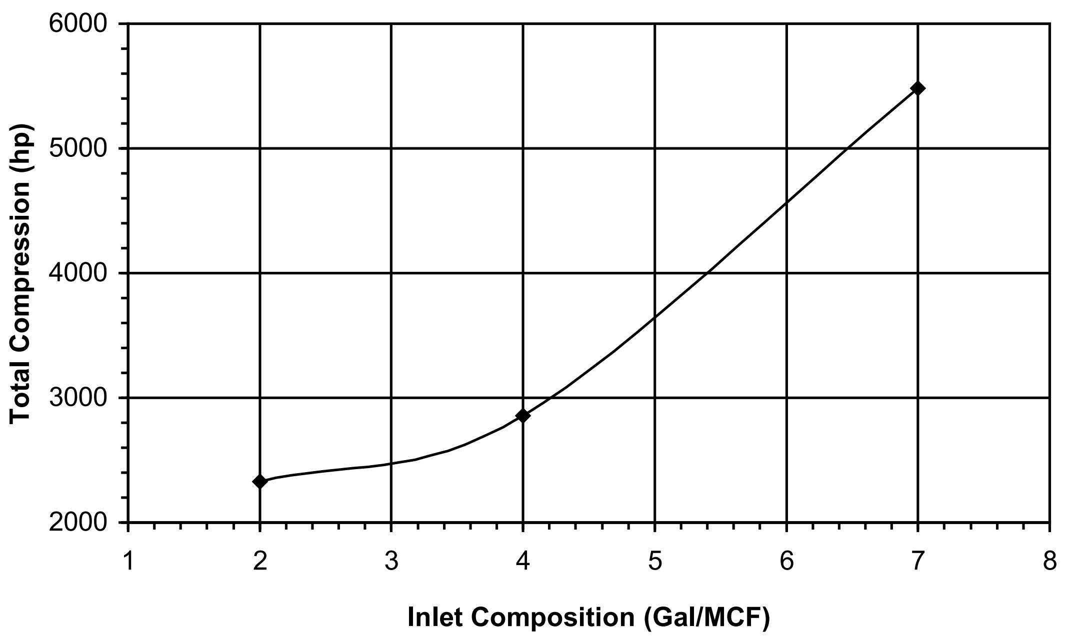


Figure 3: Effect of Propane Recovery and Refrigeration on Total Compression (900 psig and 4 gal/MCF - Process A)

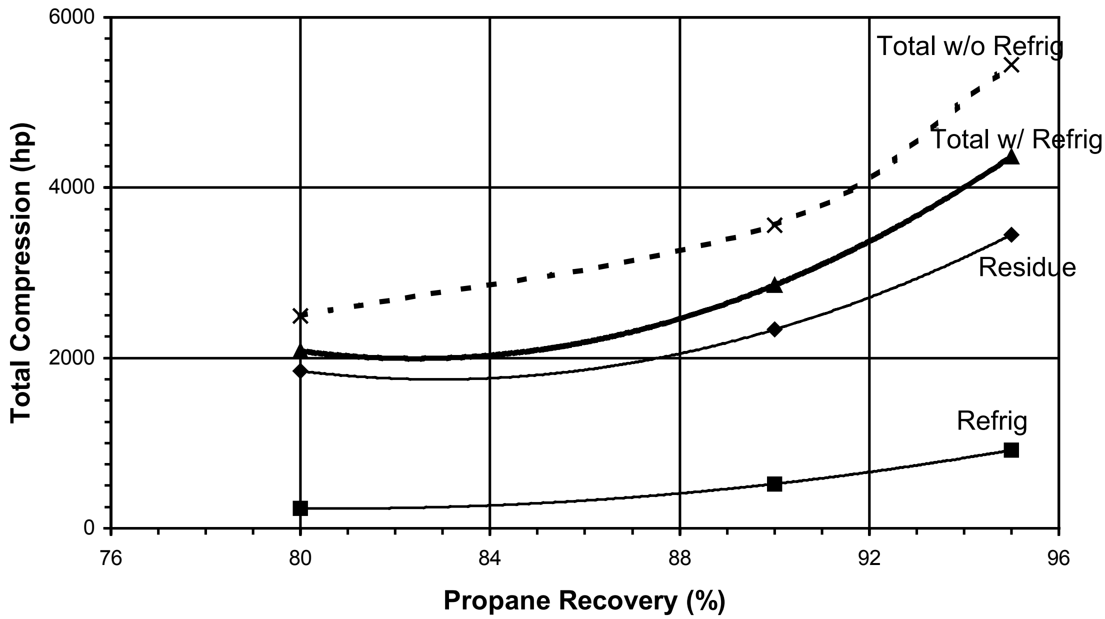
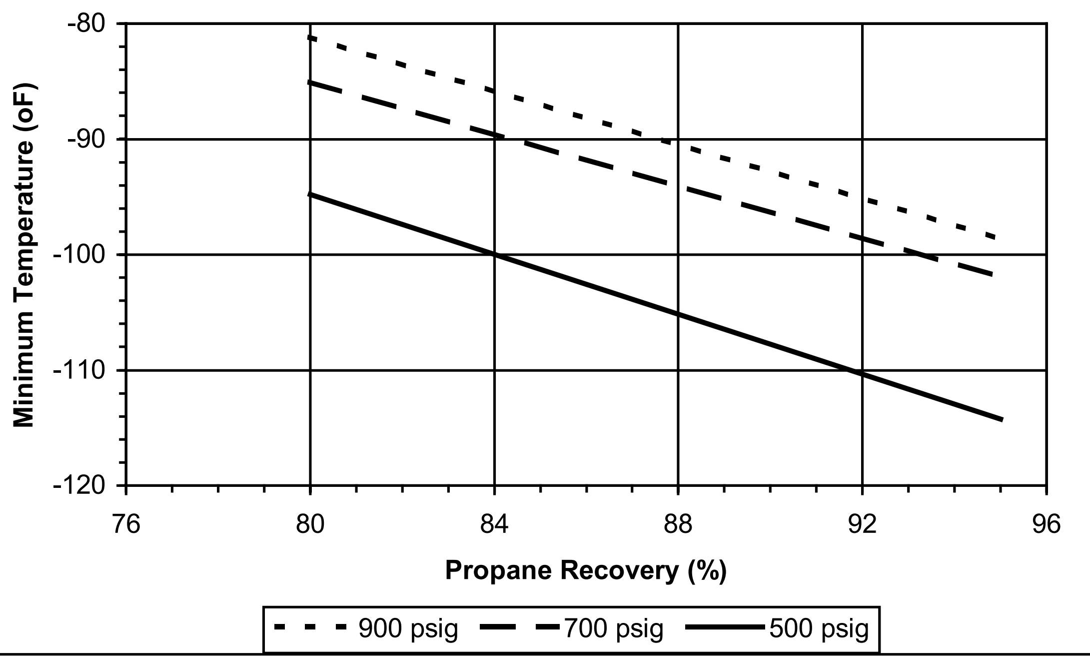


Figure 4: Effect of Propane Recovery on Minimum Temperature (Average of All Processes)



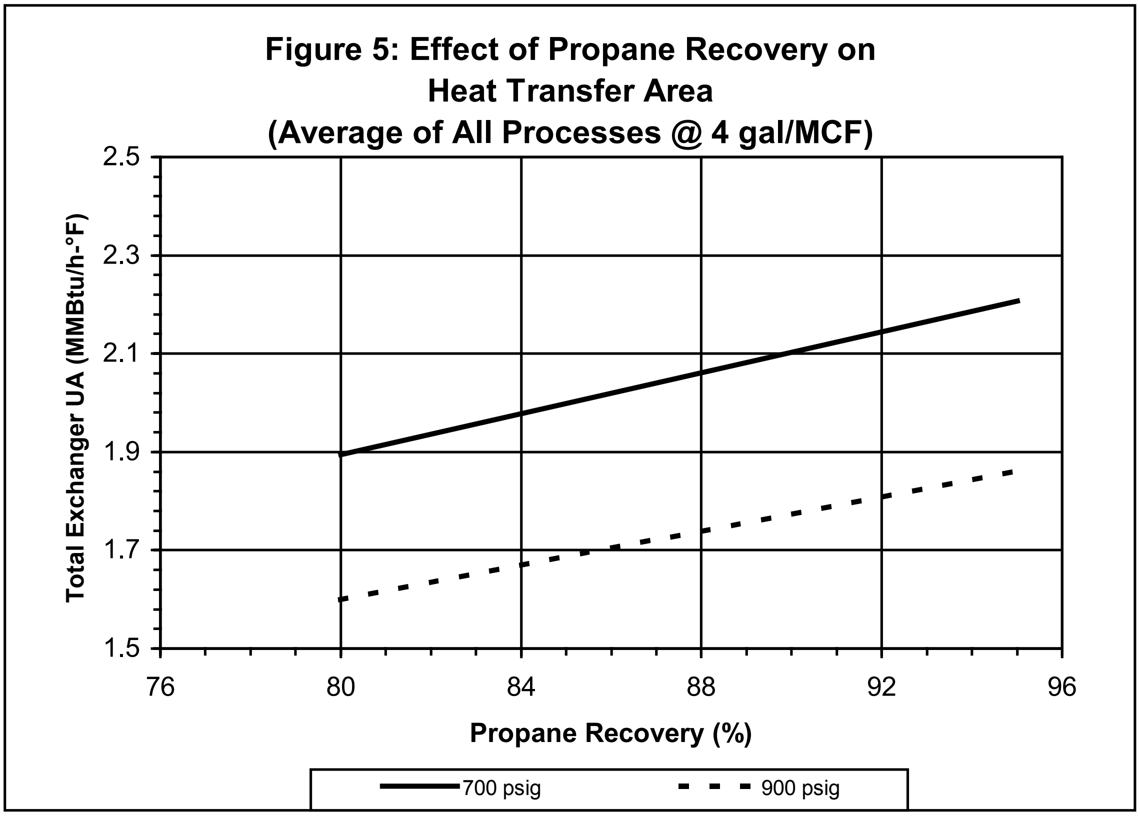


Figure 5: Effect of Propane Recovery on
Heat Transfer Area
(Average of All Processes @ 4 gal/MCF)
Total Exchanger UA (MMBtu/h-°F)
2.5
2.3
2.1
1.9
1.7
1.5
76
80
84
88
92
96
Propane Recovery (%)
700 psig
900 psig

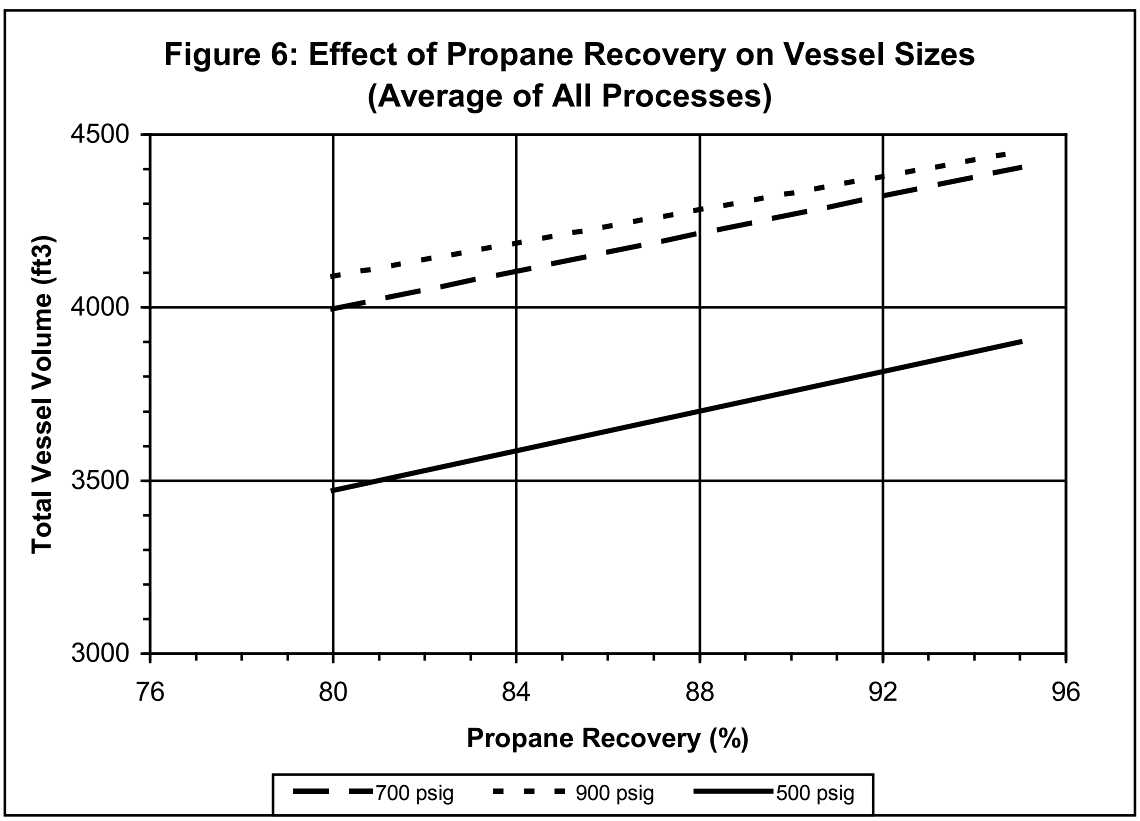


Figure 6: Effect of Propane Recovery on Vessel Sizes
(Average of All Processes)
Total Vessel Volume (ft3)
4500
4000
3500
3000
76
80
84
88
92
96
Propane Recovery (%)
700 psig
900 psig
500 psig

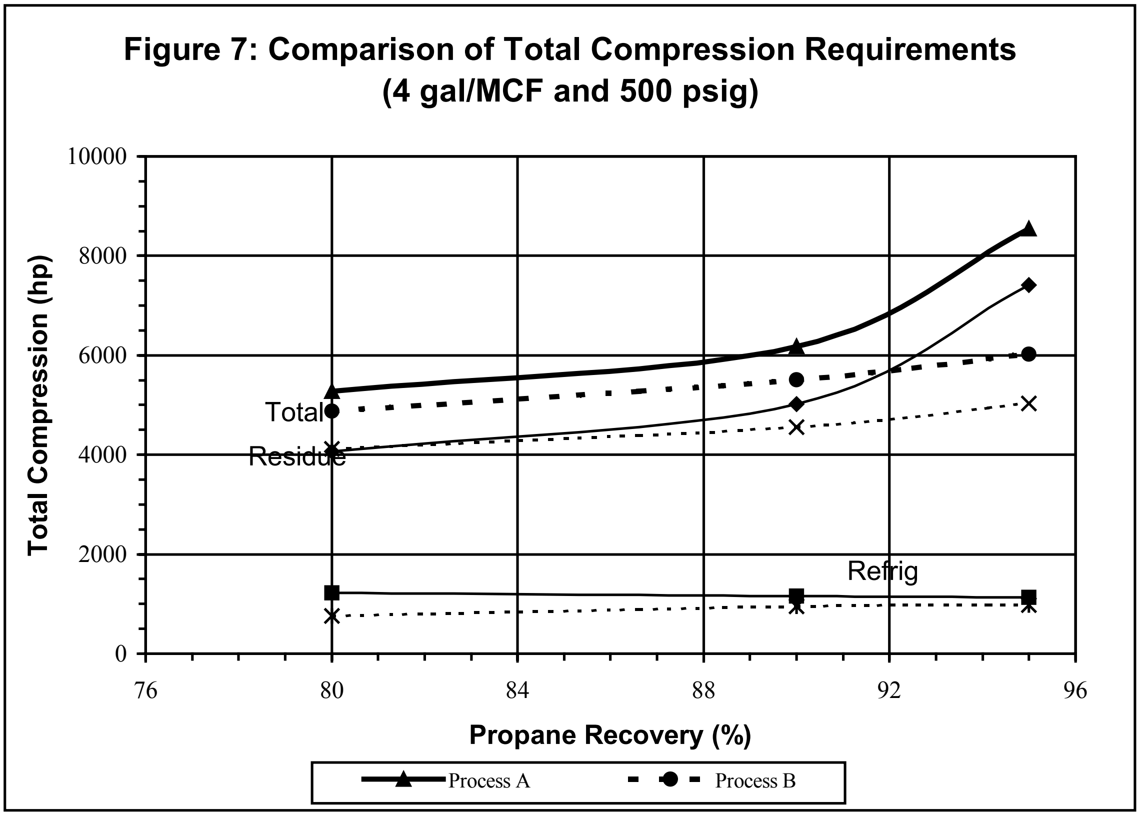


Figure 7: Comparison of Total Compression Requirements
(4 gal/MCF and 500 psig)
Total Compression (hp)
10000
8000
6000
4000
2000
0
Total
Residue
Refrig
76
80
84
88
92
96
Propane Recovery (%)
Process A
Process B

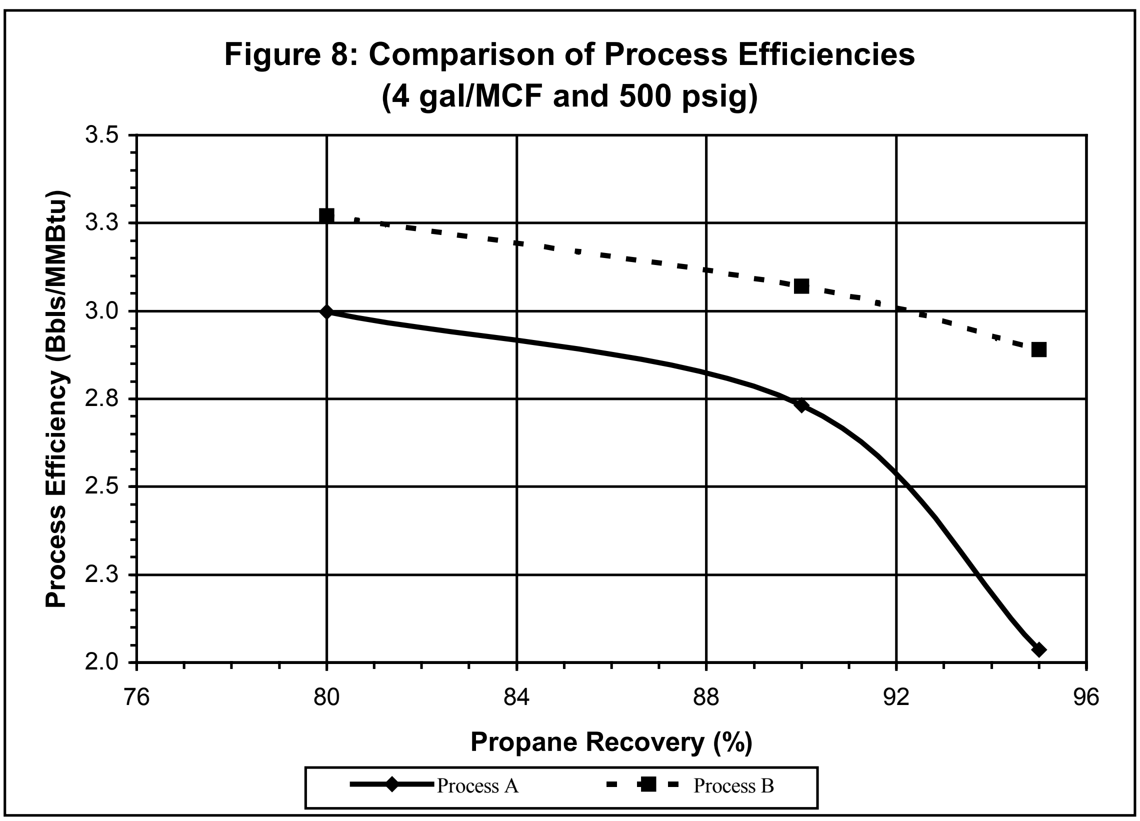


Figure 8: Comparison of Process Efficiencies
(4 gal/MCF and 500 psig)
Process Efficiency (Bbls/MMBtu)
3.5
3.3
3.0
2.8
2.5
2.3
2.0
76
80
84
88
92
96
Propane Recovery (%)
Process A
Process B

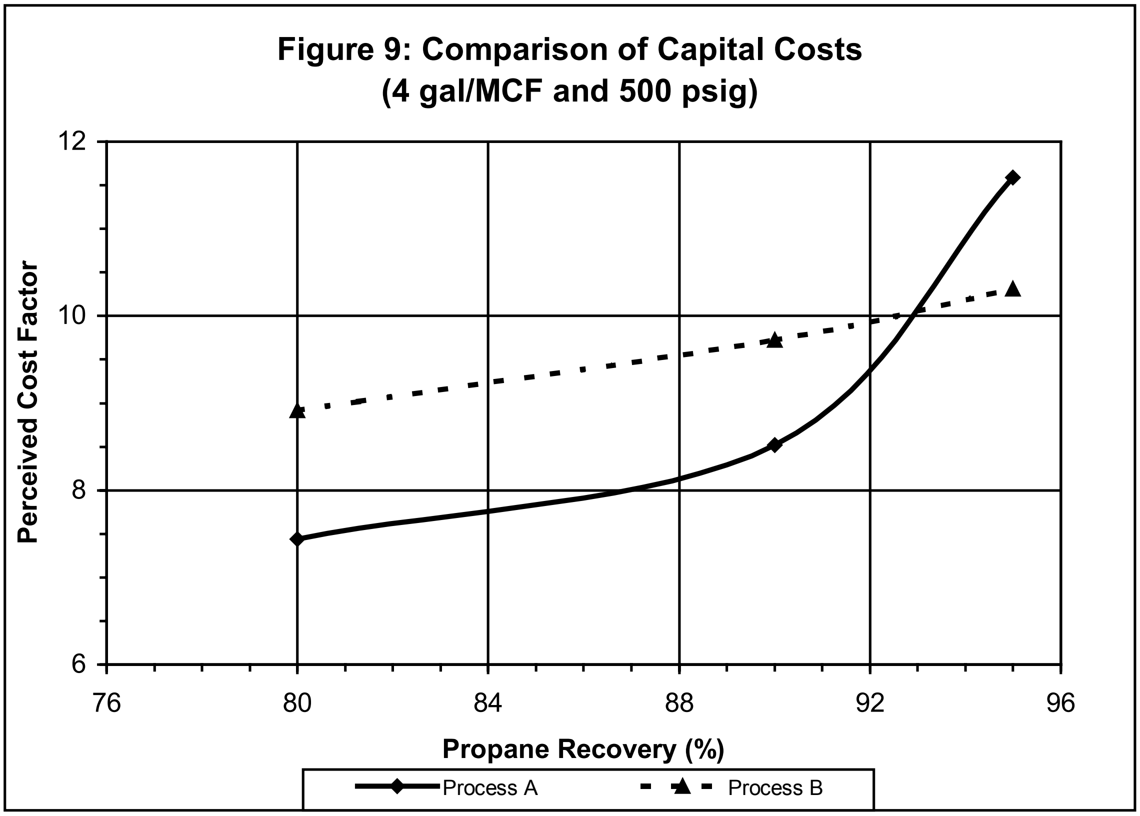


Figure 9: Comparison of Capital Costs
(4 gal/MCF and 500 psig)
Perceived Cost Factor
12
10
8
6
76
80
84
88
92
96
Propane Recovery (%)
Process A
Process B

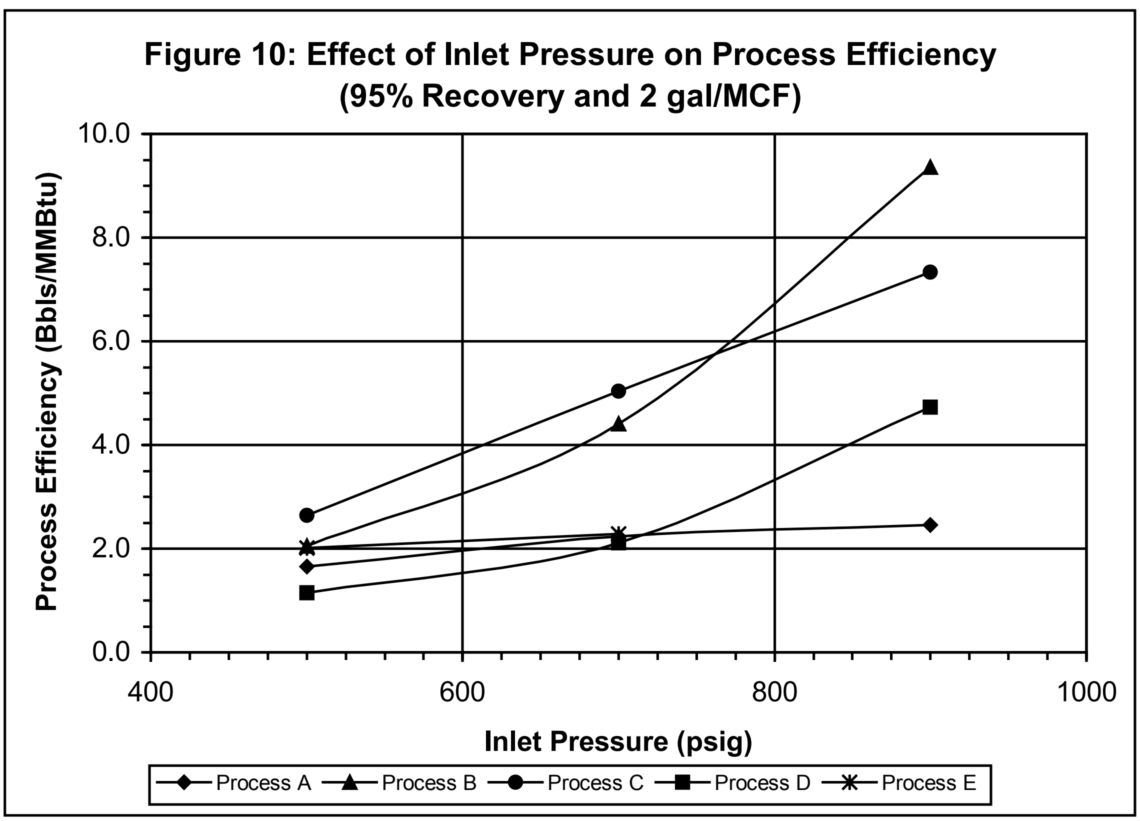


Figure 10: Effect of Inlet Pressure on Process Efficiency
(95% Recovery and 2 gal/MCF)
Process Efficiency (Bbls/MMBtu)
10.0
8.0
6.0
4.0
2.0
0.0
400
600
800
1000
Inlet Pressure (psig)
Process A
Process B
Process C
Process D
Process E

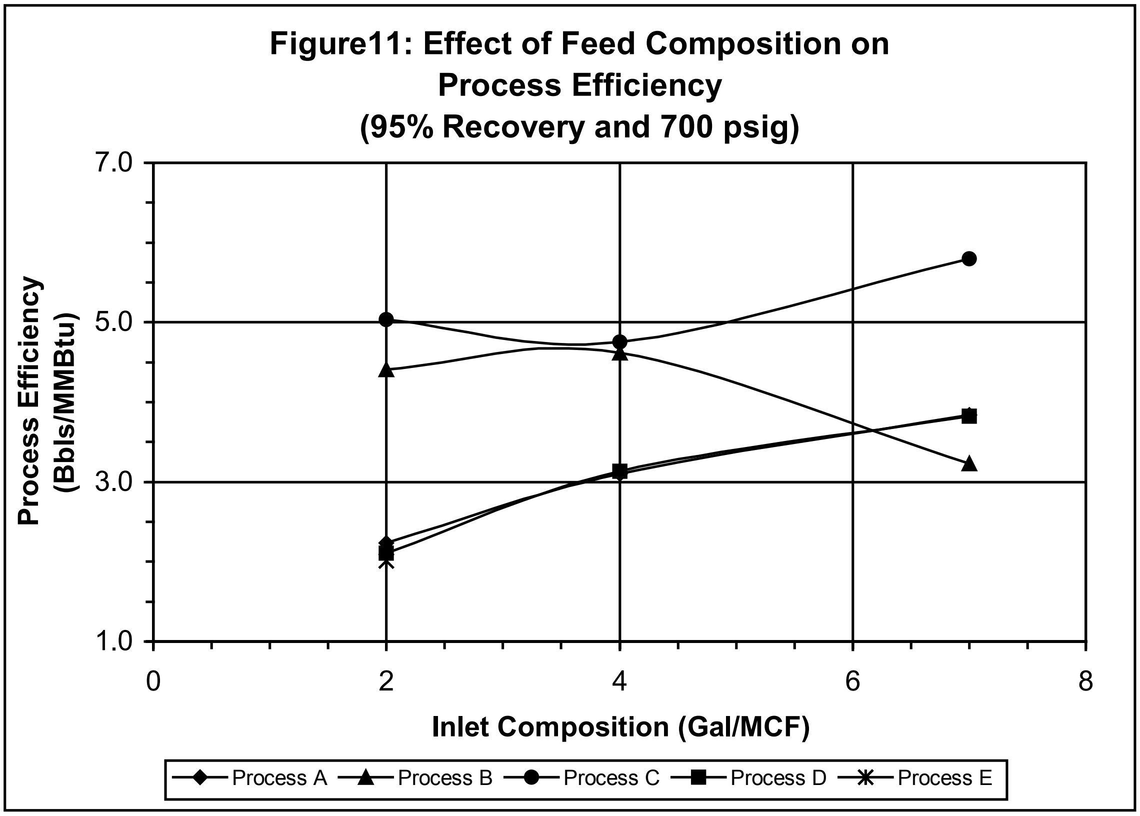


Figure11: Effect of Feed Composition on Process Efficiency (95% Recovery and 700 psig)
Process Efficiency (Bbls/MMBtu)
7.0
5.0
3.0
1.0
0
2
4
6
8
Inlet Composition (Gal/MCF)
Process A
Process B
Process C
Process D
Process E

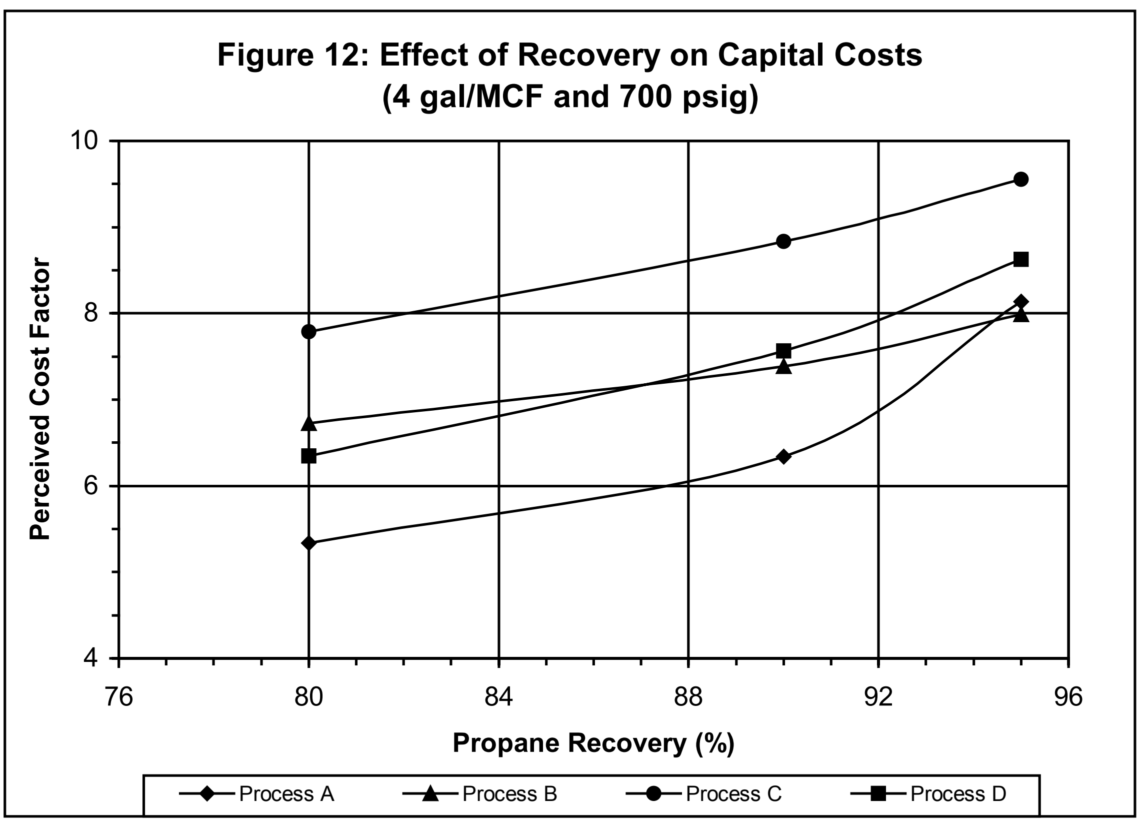


Figure 12: Effect of Recovery on Capital Costs (4 gal/MCF and 700 psig)
Perceived Cost Factor
10
8
6
4
76
80
84
88
92
96
Propane Recovery (%)
Process A
Process B
Process C
Process D

Figure 13: Effect of Inlet Pressure on Process Efficiency Compensated for Incremental Inlet Compression (95% Recovery and 2 gal/MCF)

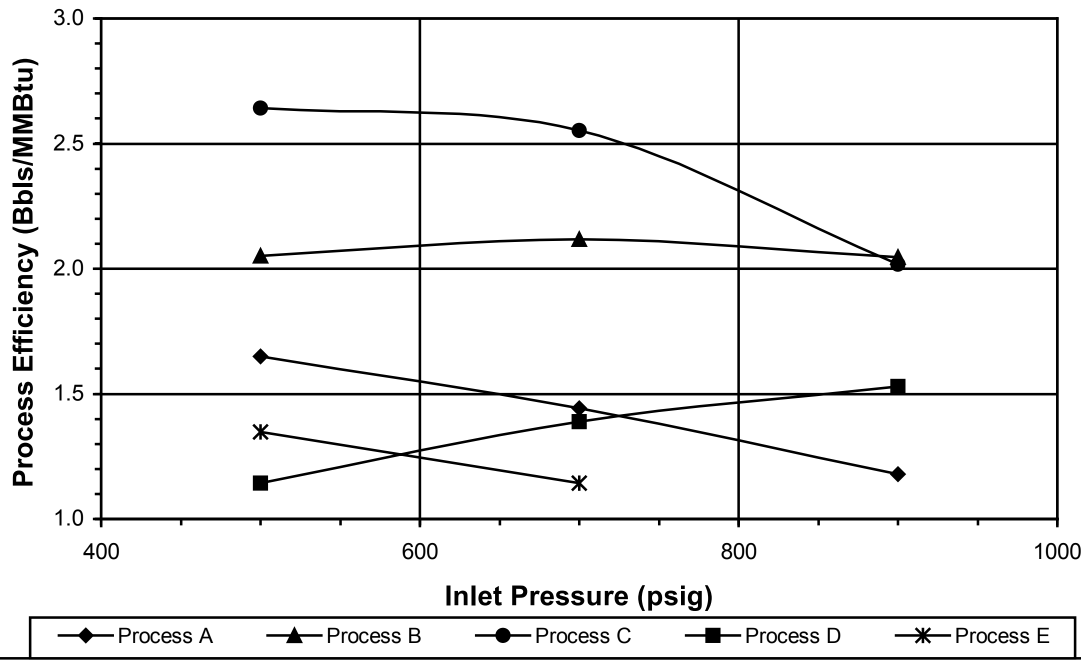


Figure 14: Effect of Pressure on Capital Costs (90% Propane Recovery and 7 gal/MCF)

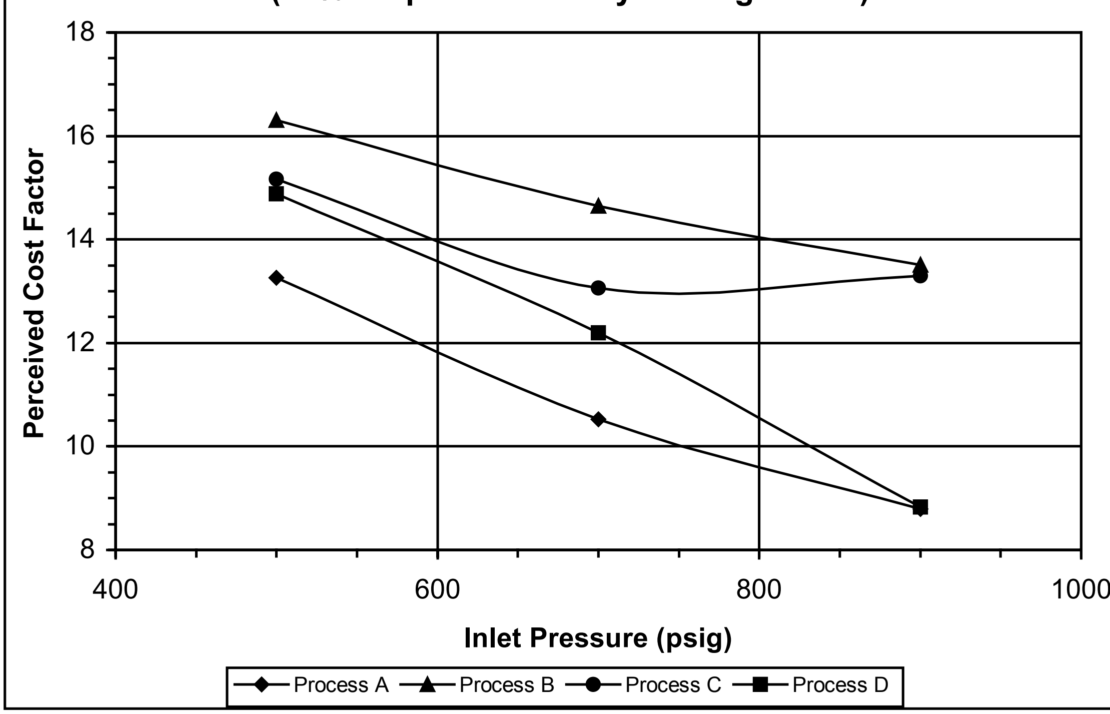


Figure 15: Refrigeration Impact on Total Compression (90% Recovery, 900 psig, and 4 gal/MCF)

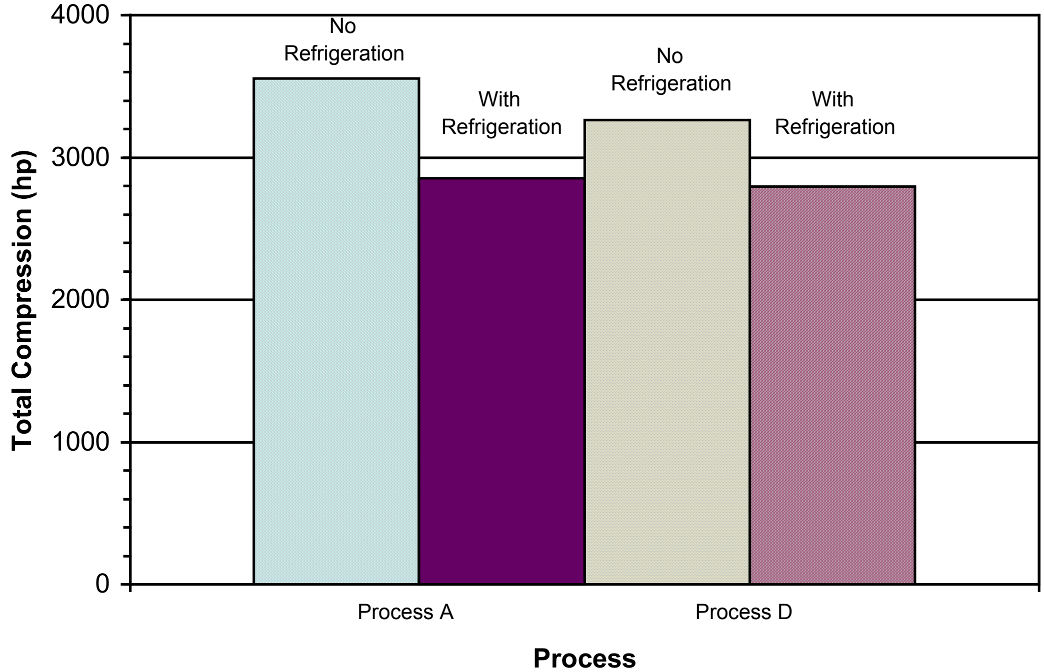
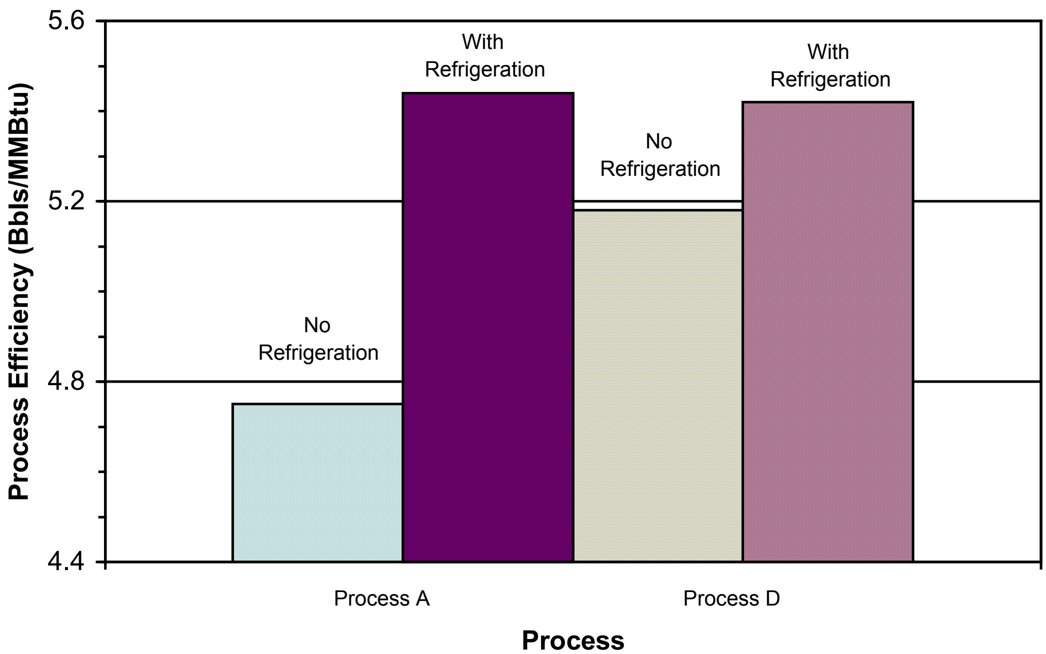


Figure 16: Refrigeration Impact on Process Efficiency (90% Recovery, 900 psig, and 4 gal/MCF)



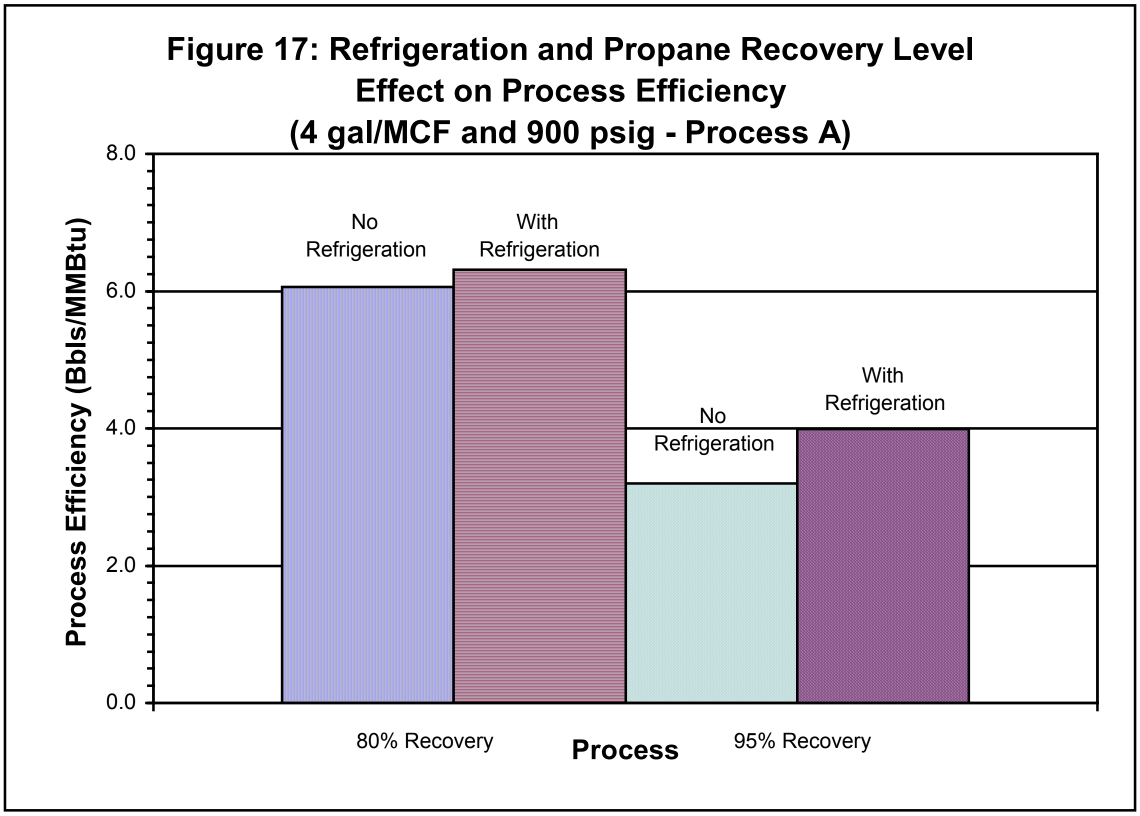


Figure 17: Refrigeration and Propane Recovery Level
Effect on Process Efficiency
(4 gal/MCF and 900 psig - Process A)
8.0
6.0
4.0
2.0
0.0
Process Efficiency (Bbls/MMBtu)
No Refrigeration
With Refrigeration
No Refrigeration
With Refrigeration
80% Recovery
Process
95% Recovery

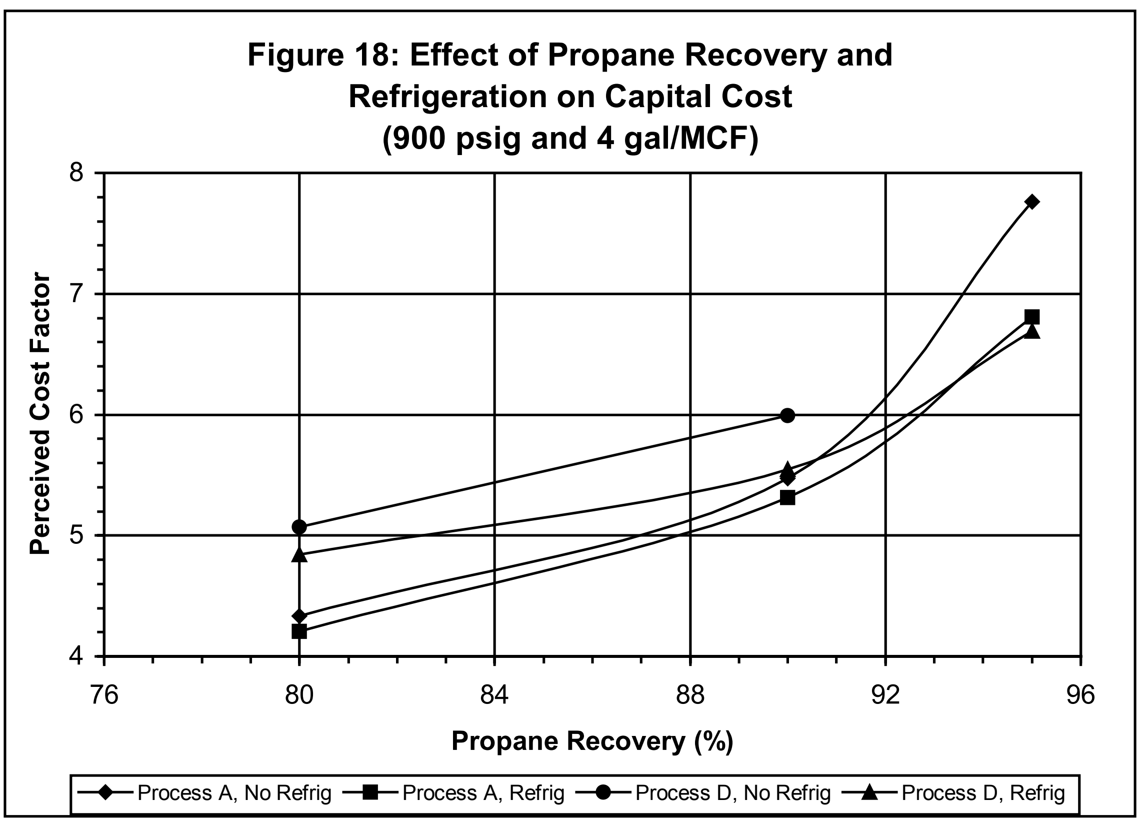


Figure 18: Effect of Propane Recovery and
Refrigeration on Capital Cost
(900 psig and 4 gal/MCF)
8
7
6
5
4
Perceived Cost Factor
76
80
84
88
92
96
Propane Recovery (%)
Process A, No Refrig
Process A, Refrig
Process D, No Refrig
Process D, Refrig