A COMPARATIVE STUDY OF ETHANE RECOVERY PROCESSES

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ABSTRACT

There are many processes available for ethane 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 will present an overview of the basic principles that affect ethane recovery. Methods of how to compare different processes are discussed, and optimization of a process to achieve the highest return on investment is presented.

The objective of this paper is to compare many of the available ethane recovery processes, including many licensed processes, on the basis of energy efficiency and capital costs. This comparison is made using a consistent basis and assumptions for all the processes evaluated. The processes were optimized and evaluated over different inlet pressures, compositions, and recovery levels.

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

Process selection is often overlooked as a key cost saver in any project. In many cases, in an effort to "speed" a project along, a process is hastily selected or a contractor is selected very early in the project who impose their preferred technology. This often leaves the operator with a plant that is far from optimal in both capital costs and operating costs.

With the numerous ethane 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.

In this paper, we present an overview of the basic principles affecting ethane recovery. Where relevant, comparisons are made between ethane recovery and propane recovery. A discussion of the comparative techniques of selecting the best process for the specified conditions is presented along with a discussion of optimizing process conditions in order to achieve a low cost, high efficiency ethane recovery process.

This study is a follow-up to our study on propane recovery processes presented last year[1]. The processes studied include licensed and public domain processes. The preliminary results from this study are used to illustrate the points discussed. A discussion of the results from a recent study are presented as an example of the need for adequate process evaluation during the conceptual engineering stage of a project.

ETHANE RECOVERY STUDY

We have identified over 20 ethane 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.

The number of processes continues to proliferate as evidenced by the number of patents issued in the past few years. Many of these patented processes are minor variations on other technologies and in some cases show no design distinction from other patented processes.

After completing an earlier study on propane recovery processes, we decided to initiate a study on ethane recovery processes. This was partially in response to queries from many readers of our previous paper about ethane recovery. 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. Ethane 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, methane content in the product, exchanger temperature approach, residue gas pressure, compressor efficiencies, etc. were all fixed to provide a consistent basis for comparison. Thirty 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 C1/C2 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™ and the results were tabulated. Each process was optimized with respect to flow splits, reboiler duty distribution, reflux rate and conditions, etc. Refrigeration was considered for each process and was utilized when optimal.

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 140 cases on ten processes.

COMPARISON CRITERIA

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.

In this study we have defined the term process efficiency (PE) as a measure of the process energy efficiency. PE is defined as product volume per unit of energy expended, typically barrels per MMBtu. In our study we calculated this term from the product rate, 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 = Product Rate / (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. For most ethane recovery processes the reboiler heat is provided by the inlet gas. Thus the PE becomes primarily a measure of compression and pump energy requirements.

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 quickly compare processes.

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

Another factor that may have an impact of process selection is the possibility of CO_2 freezing within a process. Pure CO_2 freezes at -109 °F at atmospheric pressure. Most ethane recovery processes operate at temperatures well below this. The amount of CO_2 in the inlet gas has a direct impact on the CO_2 freezing temperature within the process.

Some processes can achieve the same ethane recovery levels without CO_2 freezing, while others encounter freeze-up problems. The amount of CO_2 that a process can handle can have a large impact on the overall plant cost. More tolerant CO_2 freezing processes may eliminate or at least reduce the CO_2 treating system requirements. Consideration of treating costs can be of great importance in process selection.

We compare processes for CO_2 freezing by calculating the CO_2 freezing temperature approach (ΔT_{CO2}). This is the temperature margin between the simulated operating temperature and the predicted CO_2 freezing temperature. The CO_2 freezing temperature is calculated based on composition and pressure. The location for the lowest margin is identified by checking several locations (e.g. expander outlet, demethanizer overhead, etc.). Negative values of ΔT_{CO2} indicate a CO_2 freezing problem most likely will occur.

$$\Delta T_{CO2} = T_{oper} - T_{CO2\ Freeze}$$

COMPARING ETHANE AND PROPANE RECOVERY

Based upon relative volatility differences, ethane recovery is "easier" than propane recovery. However, the lower condensing temperature of ethane versus propane (-127.5 °F versus -43.7 °F, both at atmospheric pressure) is the primary reason more energy is required for ethane recovery.

To better understand the separations fundamentals we use the relative volatility of the key components in each system as an example. The relative volatility (α) is defined as "... an index of the relative separability of two chemical species[2]." The relative volatility is the ratio of the K-values of the key components:

$$\alpha_{ij} = K_i / K_j$$

For ethane recovery, the key components in the separation process are methane and ethane, and for propane recovery they are ethane and propane. Thus the primary need for demethanizers and deethanizers, respectively.

The relative volatility of the ethane recovery system is over twice that of the propane recovery system as shown in Table 2. This leads to the general conclusion that demethanizers should be smaller than deethanizers in terms of equilibrium stages. Optionally, less reflux is required of a demethanizer for the same component recovery as opposed to a deethanizer.

Table 2

Relative Volatilities

4 gal/MCF gas @ -150 °F & 250 psig

Component System	α_{ij}
Methane / Ethane	25
Ethane / Propane	11

In general practice, this can be best illustrated by the fact that in ethane recovery processes most of the processes are single tower processes. However, from our earlier study, we found there were a number of two-tower processes used in high efficiency propane recovery processes.

Some processes are capable of both ethane and propane recovery. A comparison of a process for both ethane and propane recovery is given in Table 3.

In ethane recovery mode, over twice as many barrels of product are recovered compared to propane recovery. Although the product volume increased over two-fold, the PE and PCF only increased by a factor of approximately 1.6. It appears that because the PE did not increase as much as the product rate, the lower condensing temperature required for ethane recovery has a greater effect on horsepower than the increased relative volatility.

Table 3

Comparing Ethane and Propane Recovery

4 gal/MCF gas @ 700 psig inlet and 90% recovery

Recovery	*Product (BPD)*	*PE (bbls/ MMBtu)*	*PCF*
Ethane	9080	5.72	12.78
Propane	4057	3.69	7.63

BASIC PRINCIPLES AFFECTING RECOVERY

From our previous study on propane recovery we developed a better understanding of the principles that affect propane recovery. These same principles can be applied in understanding ethane recovery.

In very simple terms, the gas is cooled sufficiently to condense the ethane 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 ethane, 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.

Significantly more energy is required to recover ethane than was required for propane recovery, as shown in Figure 1. This is primarily due to the lower condensing temperature of ethane, and thus the need for energy to cool the gas and condense the ethane product.

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. This is generally due to condensing more product (latent heat). This is true regardless of whether ethane or propane is being recovered. Since the gas is richer more barrels of product are recovered.

To achieve 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 ethane from the gas. Figure 3 shows the minimum temperature in the process as a function of the recovery level for a 4 gal/MCF gas at different inlet pressures.

Figure 3 also illustrates that colder temperatures are required for ethane recovery versus propane recovery. Again, this is due to the lower condensing temperature of ethane. The difference between ethane and propane condensing temperatures is approximately 115 °F at 250 psig. This difference increases from approximately 85 °F at atmospheric pressure. The difference in minimum temperatures between ethane and propane recovery as shown in Figure 3 ranges from 50 to 75 °F. This may be due to the lower relative volatility for propane recovery. Due to lower relative volatility, more reflux is required which is achieved with colder temperatures.

Heat exchanger area increases as the recovery level increases as shown in Figure 4 for a 4 gal/MCF gas at different pressures. 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.

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). This same trend applies equally to ethane or propane recovery. More exchanger area is required for ethane recovery than for propane recovery due to the higher amount of energy that must be transferred to cool the gas to the required temperatures.

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 ethane being condensed, other components such as methane 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 the higher product recovery level and maintain product specifications. Figure 5 illustrates this trend.

Figure 5 also illustrates that less vessel volume is required for ethane recovery than for propane recovery. This is because many of the propane recovery processes are two-tower processes, whereas, most of the ethane recovery processes are single tower processes. The two-tower processes are required due to the lower relative volatilities associated with propane recovery.

RESULTS

In analyzing the different processes in this study, we have found that there are four major categories of ethane recovery processes: conventional & classic, residue recycle, reflux enhancement, and others. The majority of ethane recovery processes utilize a single tower (demethanizer) and provide reflux to this single tower by either: direct flow from the expander (conventional), condensing a part of the inlet gas (classic), condensing recycled residue gas (residue recycle), and enhancing or purifying a portion of the inlet gas before condensing (reflux enhancement). The methods of forming the reflux are the distinguishing criteria between each of the categories. Other processes that do not fit into the above described categories include traditional and enhanced refrigerated oil absorption (ROA), cascade refrigeration, mixed refrigerant, etc.

We present some example comparisons to highlight the aforementioned comparative techniques as well as to illustrate the diversity of the different processes available. In the following examples processes "A" and "B" are of the conventional & classic category, processes "C", "D", and "E" are residue recycle type of processes, processes "F" and "G" are reflux enhancement type of processes, and "H" is from the "other" category. Not all processes were evaluated at all the conditions.

The process efficiency as a function of inlet pressure for five of the processes are compared at 90% recovery for a 2 gal/MSCF inlet gas in Figure 6. The process efficiency improves as the inlet pressure increases for all processes due to more energy in the inlet gas.

The differences in process efficiency among the processes tends to increase as the inlet pressure increases. The difference between the best and worst process at low inlet pressure (500 psig) is less than 1.5 bbls/MMBtu. However, at the higher pressures (900 psig) this difference is over 8 bbls/MMBtu.

Processes “B” , "C", and "D" are well suited to high inlet pressures and high recovery levels for a lean gas. For others, such as processes “A” and “G”, the process efficiency does not improve with inlet pressure and, therefore, are not desirable processes at higher pressures.

Figure 7 compares processes with different inlet compositions at 700 psig and 95% recovery. The process efficiency of all processes increases as the inlet composition increases in recoverable liquids (richness).

The differences in process efficiency among the processes tends to increase as the inlet gas becomes richer. The difference between the best and worst process for lean inlet gas is approximately 3.5 bbls/MMBtu. With the rich inlet gas the difference approaches 6 bbls/MMBtu. Processes “C” and “D” are more efficient than the other processes for all compositions investigated.

The effect of recovery level on process efficiency is shown in Figure 8 for processes with a 2 gal/MSCF inlet gas and a 700 psig inlet pressure. The process efficiency of all the processes decreases as recovery level increases. Process "D" is the most efficient process for these conditions, regardless of recovery level.

Some processes decrease rapidly across the recovery range while others are relatively flat. For example, the difference in process efficiency between 80% and 95% for process "A" decreases 4.5 bbls/MMBtu. Whereas, for process "C" the process efficiency decreases by only 1.2 bbls/MMBtu. A less sensitive process is typically desired due to uncertainties with design conditions.

The different processes are compared for CO_2 freezing potential in Table 4. There is a 40 °F difference between the best and worst process. From our study, the residue recycle processes appear to be somewhat more tolerant of the processes examined for CO_2 freezing, excluding absorption type of processes.

Table 4

Comparison of CO_2 Freezing Margins

4 gal/MCF gas, 700 psig inlet, 90% recovery

Process	ΔT_{CO2}
A	68
B	33
C	66
D	65
E	59
F	37
G	34
H	>100

Some processes' CO_2 freezing margins are relatively indifferent to recovery level, while others are very sensitive. Figure 9 shows the CO_2 freezing margin of two processes. The CO_2 freezing margin for process "D" decreases 17 °F from 80% to 95% recovery. While the margin for process "A" decreases 39 °F over the same range.

CO_2 freezing margin is generally related to the coldest operating temperature. Operating temperatures for the same recovery level tend to decrease as the tower pressure is lowered as discussed earlier (Figure 3). In order for a process to have a higher CO_2 freezing margin at the same recovery it must do so at a higher tower pressure. Figure 9 also shows the tower pressures for the respective processes at different recovery levels.

The perceived cost factor for different processes is compared in Figure 10 as a function of the recovery level for a 2 gal/MCF inlet gas at 700 psig inlet pressure. For some processes, such as processes “A” and "G", the PCF begins to increase rapidly at higher recovery levels. Other processes have a much flatter, almost linear, PCF versus recovery, making higher recovery levels more economically justifiable. The PCF generally follows the compression requirement trends.

From Figure 8 for the 95% recovery level, the most efficient process was “D”, followed by “C”. These processes also have the lowest PCF's from Figure 10. At lower recovery levels there appears to be very little difference in PCF amongst all processes with the exception of process "G", which is significantly higher than the others.

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. Processing contracts, fuel prices, product prices, political stability, etc. are all factors that must be considered when optimizing a process.

Recovery Level

An often overlooked parameter is recovery level. It does not make sense to achieve high recovery levels when it is not economically justified.

Earlier examples (Figure 8) showed that the PCF increases almost exponentially with recovery level for certain processes, while for others it is nearly linear. It has also been shown that the process efficiency generally decreases as the recovery level increases since more energy is required to obtain the higher recoveries. Since operating and capital costs are increasing as recovery level increases, there is usually a recovery level that can be justified based on a set of economic assumptions.

Although each case has its own set of economic criteria, we have provided an example case to illustrate justification of incremental recovery in Table 5 for process "B" at 700 psig inlet pressure. The basis used was typical Gulf Coast criteria and only summary data are presented. The comparisons shown are between 90 and 80% recovery, and between 95 and 90% recovery. The lean composition is a 2 gal/MCF gas and the rich is a 7 gal/MCF gas.

Table 5

Incremental Recovery Economics

700 psig inlet, 5 ¢/gal C_2 *margin*

	Recovery Level	***Incre EPBC (BPD)***	***Incre Comp (hp)***	***Payout (yrs)***
LEAN	80	--	--	--
	90	303	765	10.1
	95	166	1267	-11.7
RICH	80	--	--	--
	90	830	1894	6.0
	95	440	1314	15.1

For the lean inlet gas composition, justifying 90% ethane recovery over 80% recovery requires a 10 year payout. This is a marginal payout at best for most economic models. The 95% recovery case versus the 90% recovery case is not justified since the incremental fuel costs (opex) exceed the incremental revenue yielding a negative payout.

At 95% recovery the incremental barrels of product recovered for the rich inlet gas composition is approximately 2.7 times that of the lean inlet gas, while the incremental compression horsepower required is approximately equal. Therefore with the rich gas, the product revenue is approximately 2.7 times higher, while the capital cost is approximately constant. The additional revenue resulting from the increased product recovered leads to a more reasonable payout for the 90% recovery case, and at least a positive payout time for the 95%, although it is probably not justifiable.

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.

Figure 11 shows the compensated process efficiency as a function of the inlet pressure. This is the same data as shown earlier in Figure 6, except that the additional inlet compression required for the 700 psig and 900 psig cases is added into the process efficiency calculations.

From our study we found that most of the processes have an optimal compensated process efficiency at an inlet pressure of approximately 700 psig. This was found to be the case regardless of inlet composition or recovery level.

The reasons for this optimal pressure are a balance of two key parameters. First, at this pressure, the separators are generally operating far enough away from the critical point that over-condensing (methane) is minimized. Second, there is sufficient driving force for the condensing temperatures required to generate liquid reflux for the demethanizer.

Figure 12 illustrates how the PCF decreases as the inlet pressure is increased for a 2 gal/MCF inlet gas and 90% recovery. This would indicate that higher pressures would be preferable from a cost and efficiency point of view.

Another factor to be included in selecting the optimum inlet pressure is the gathering system costs. Here 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.

Another reason to optimize inlet pressure is in situations where the residue pressure requirements may be low enough that eliminating residue compression makes good sense. Also, in some instances trying to utilize one stage of residue compression instead of two stages can reduce capital costs and simplify the operations. Here again understanding the capital and operating cost impacts of inlet pressure, both for the plant and the gathering system, is very important and should be optimized 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.

When applied improperly, the use of refrigeration can actually decrease process efficiency and increase capital costs. It can lead to over-condensation of methane 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.

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, when the inlet pressures are low, and when trying to improve the CO_2 freezing margin.

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 6), 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.

Earlier it was shown that the CO_2 freezing margin was a function of tower pressure. The pre-boost configuration generally leads to a higher tower pressure for the same recovery level. This results in a more favorable CO_2 freezing margin.

RECENT EXAMPLE

A client with an existing plant wanted to examine the feasibility of converting from propane recovery to ethane recovery. Therefore, we performed a comparative study of ethane recovery processes that could be utilized to retro-fit their existing plant.

We evaluated eight processes and found process efficiencies ranging from 5.9 bbls/MMBtu to just over 9 bbls/MMBtu all at the same recovery level. Each process utilized as much existing equipment as reasonably possible. In some cases the final process configuration varied somewhat from the normal process configurations in order to fit within the existing plant's framework.

Several of the top processes were selected for further sensitivity analysis. The sensitivity of the process in terms of compression horsepower, process efficiency, and exchanger area were evaluated for off-design compositions and recovery levels.

Ultimately one process was recommended. At the design conditions it outperformed the other processes and it appeared to fit well with the existing plant, requiring the least amount of modifications. This also made it the least costly option.

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 ethane 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.

There is a greater range of process performance and costs between different processes as the inlet pressure and inlet composition increase. Under these conditions, process selection can be very critical in the success of any project.

Any comparative study performed should be done independently and 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. Flexibility in handling a defined range of conditions is a very important factor and should be evaluated when selecting a process.

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.

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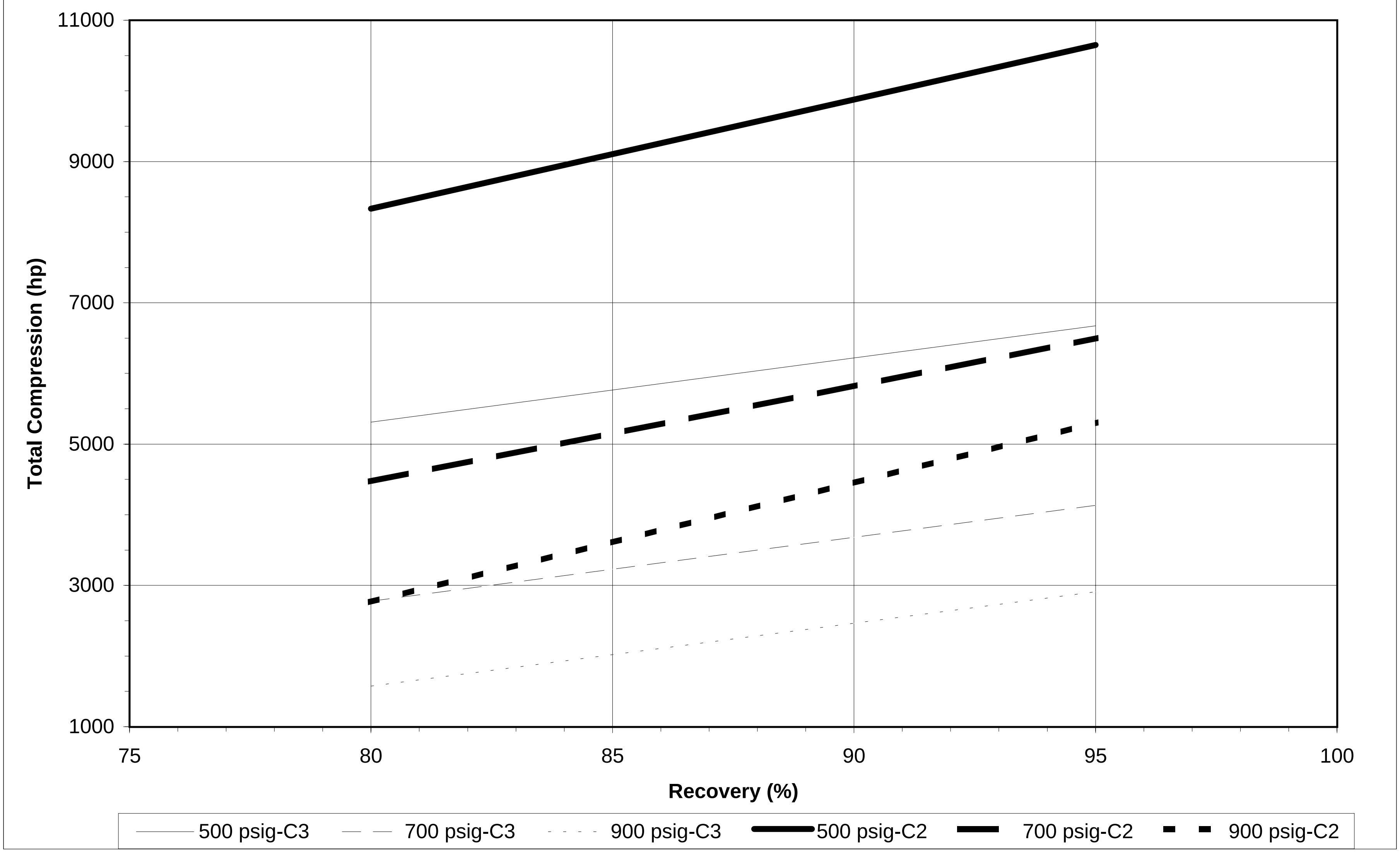
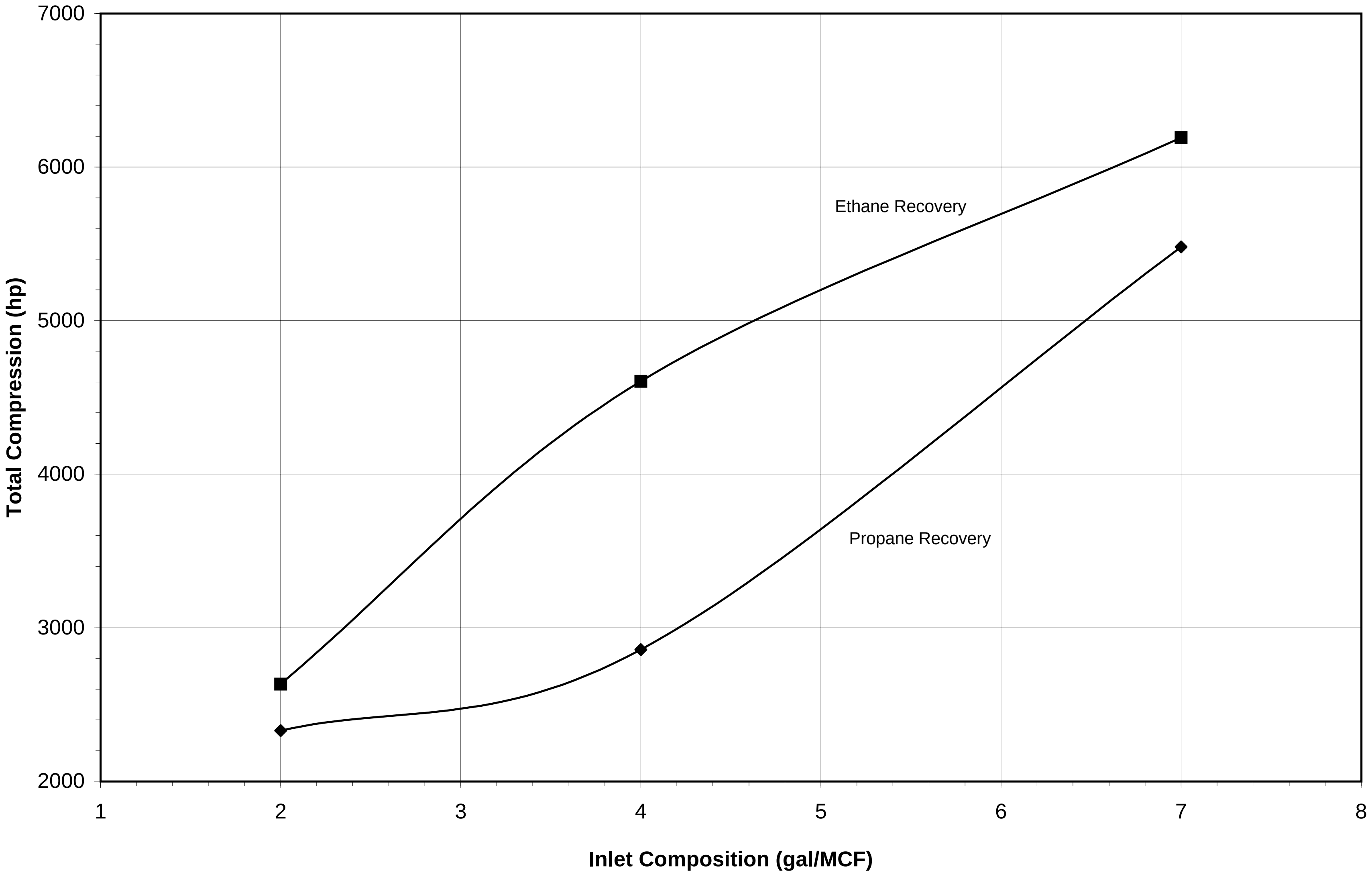


Figure 1: Effect of Recovery Level on Total Compression
(Average of All Processes @ 4 gal/MCF)

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



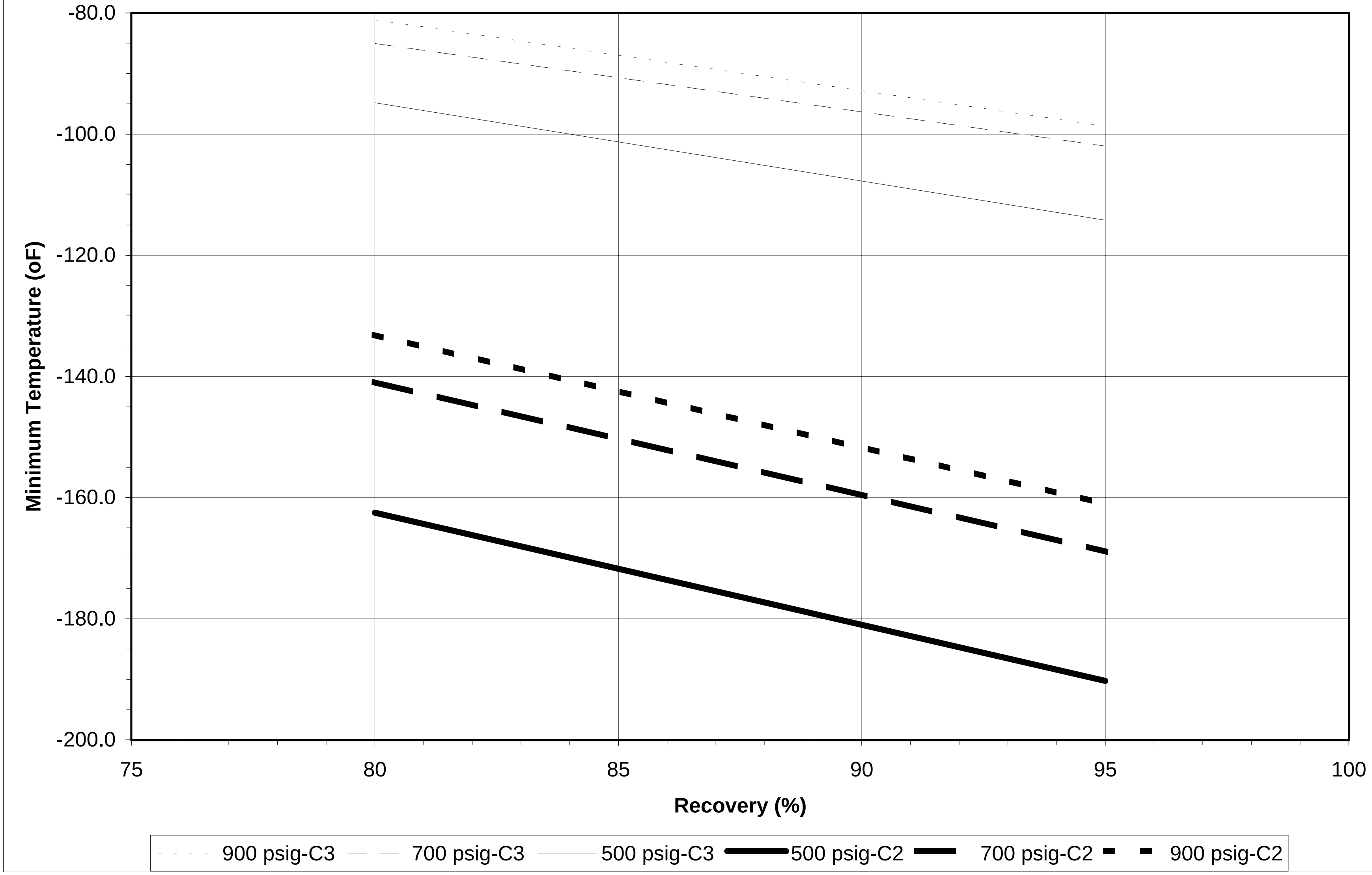


Figure 3: Effect of Recovery Level on Minimum Temperature
(Average of All Processes @ 4 gal/MCF)

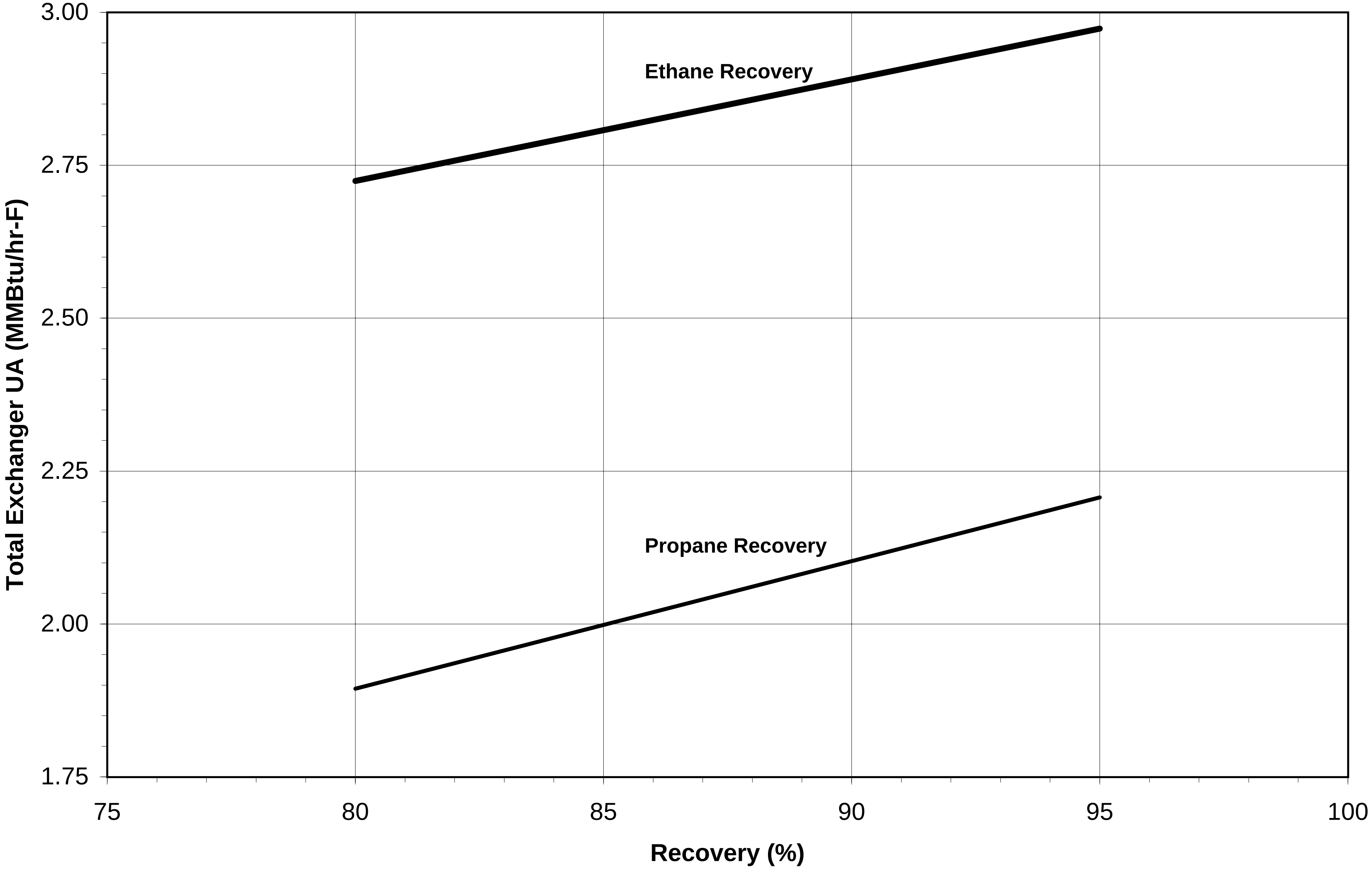
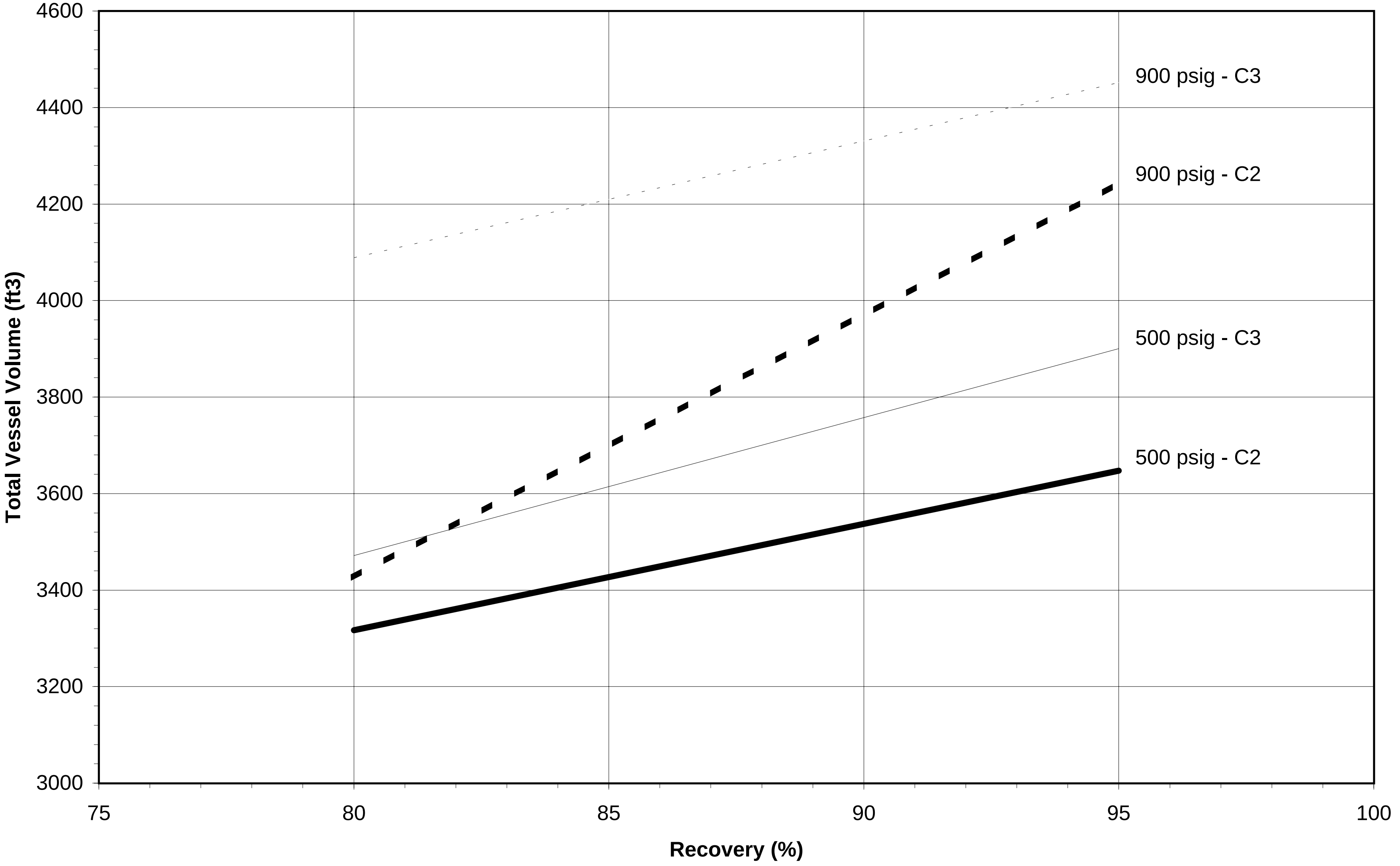


Figure 4: Effect of Process Recovery on Heat Transfer Area
(Average of all processes @ 4 gal/MCF and 700 psig)

Figure 5: Effect of Recovery on Vessel Sizes
(Average of All Processes @ 4 gal/MCF)



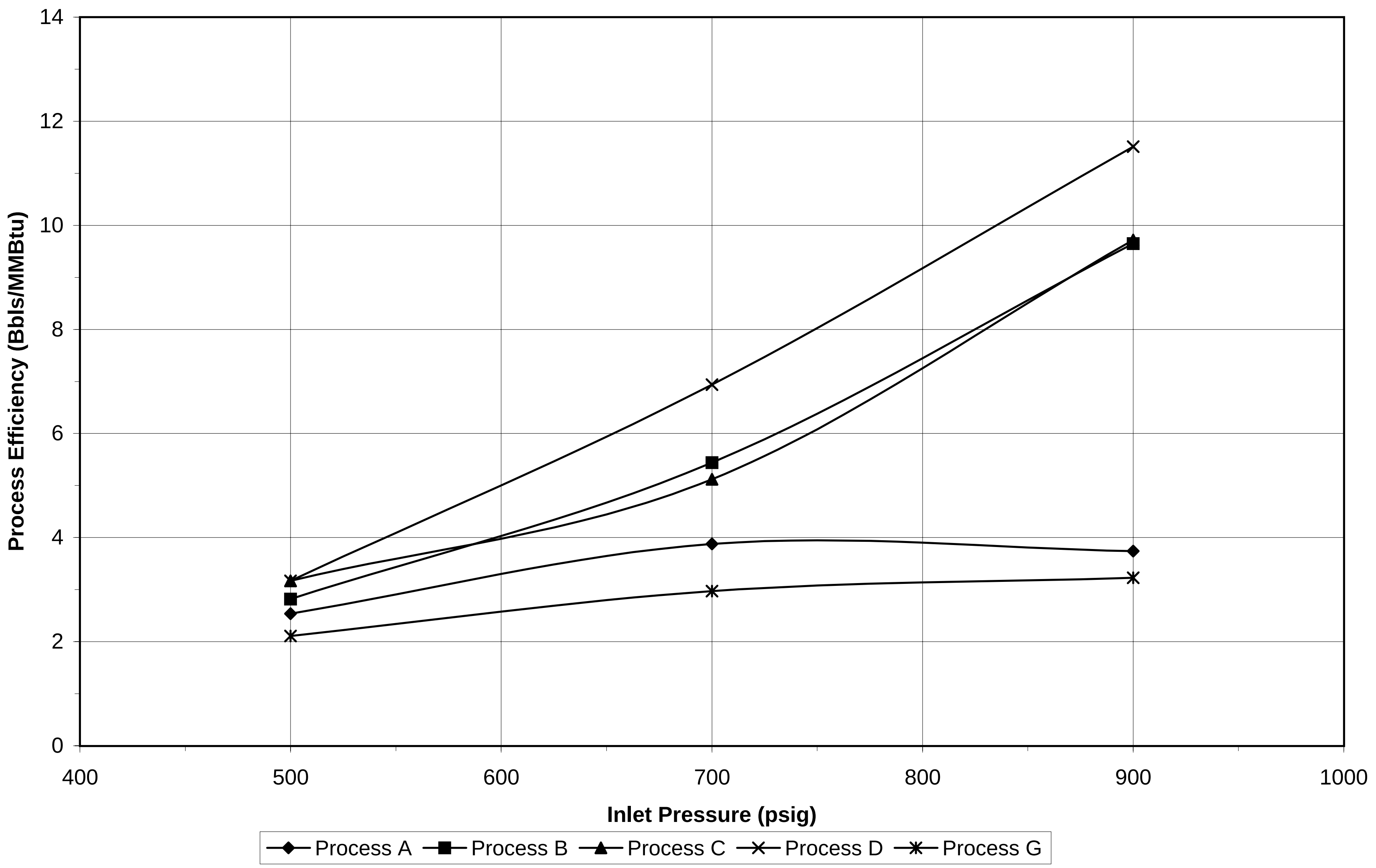
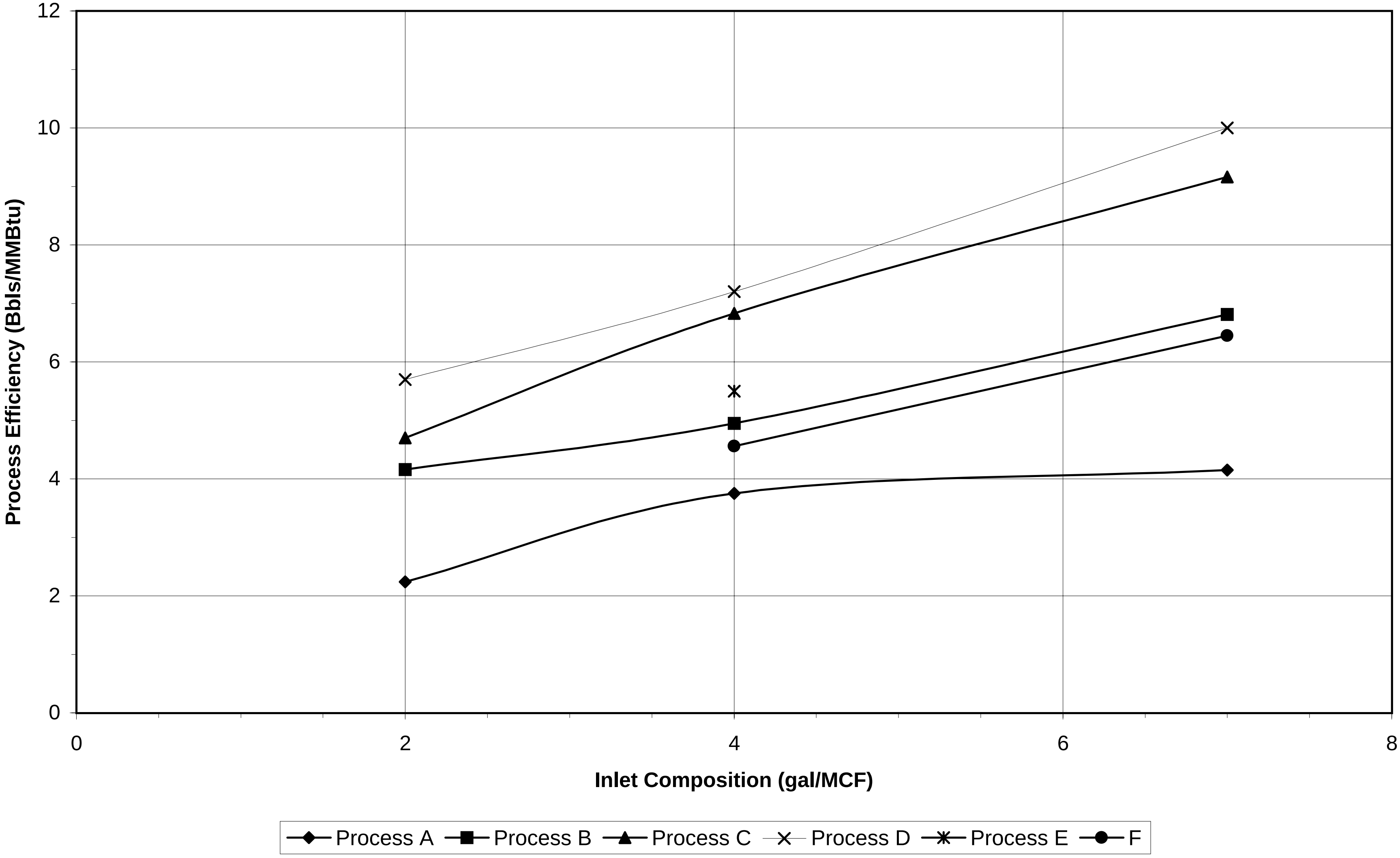


Figure 6: Effect of Inlet Pressure on Process Efficiency
(90% Recovery and 2 gal/MCF)

Figure 7: Effect of Inlet Composition on Process Efficiency
(95% Recovery and 700 psig)



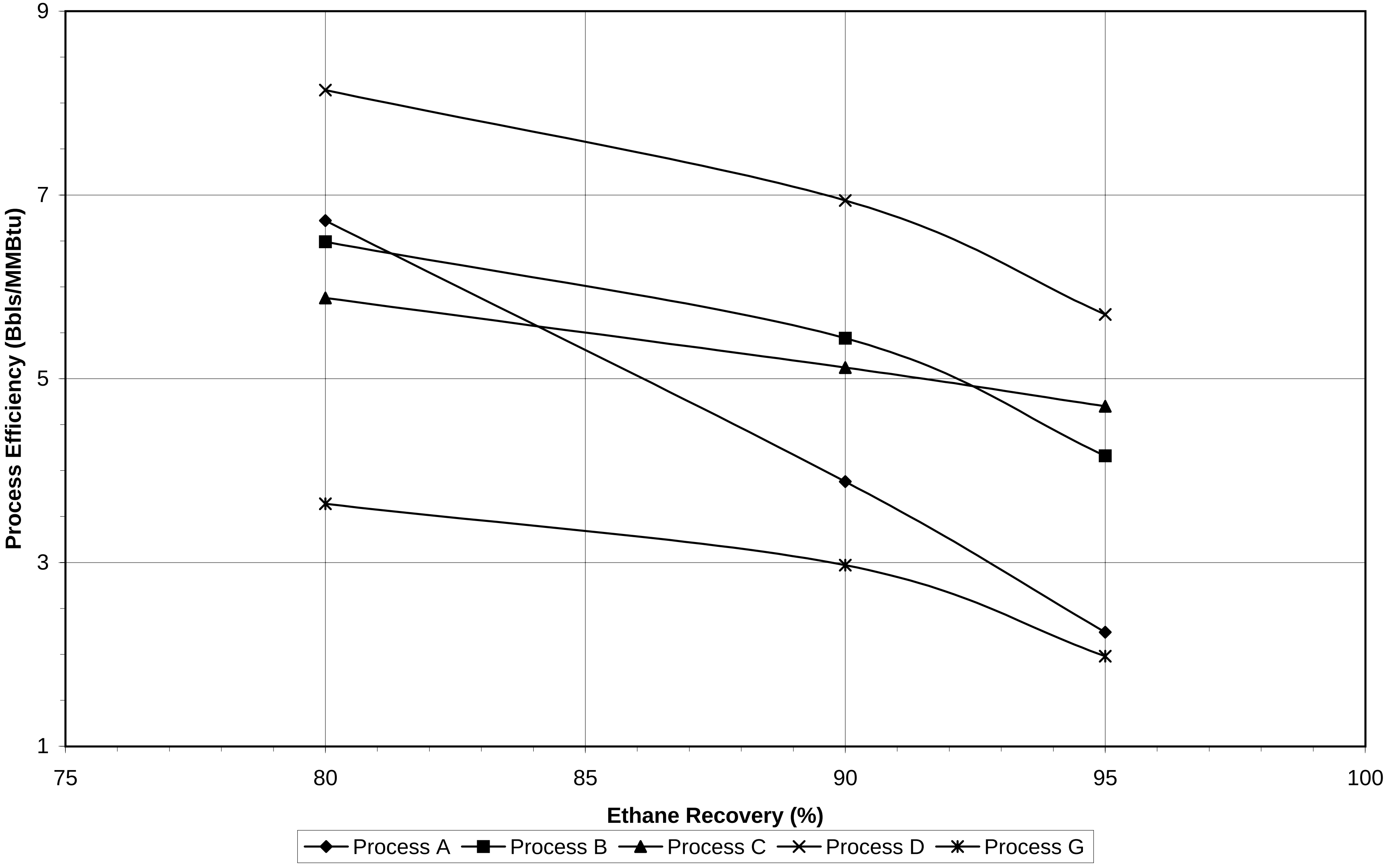


Figure 8: Effect of Recovery Level on Process Efficiency
(2 gal/MCF and 700 psig)

Figure 9: Effect of Recovery on CO2 Freezing Margin and Tower Pressure (4 gal/MCF and 700 psig)

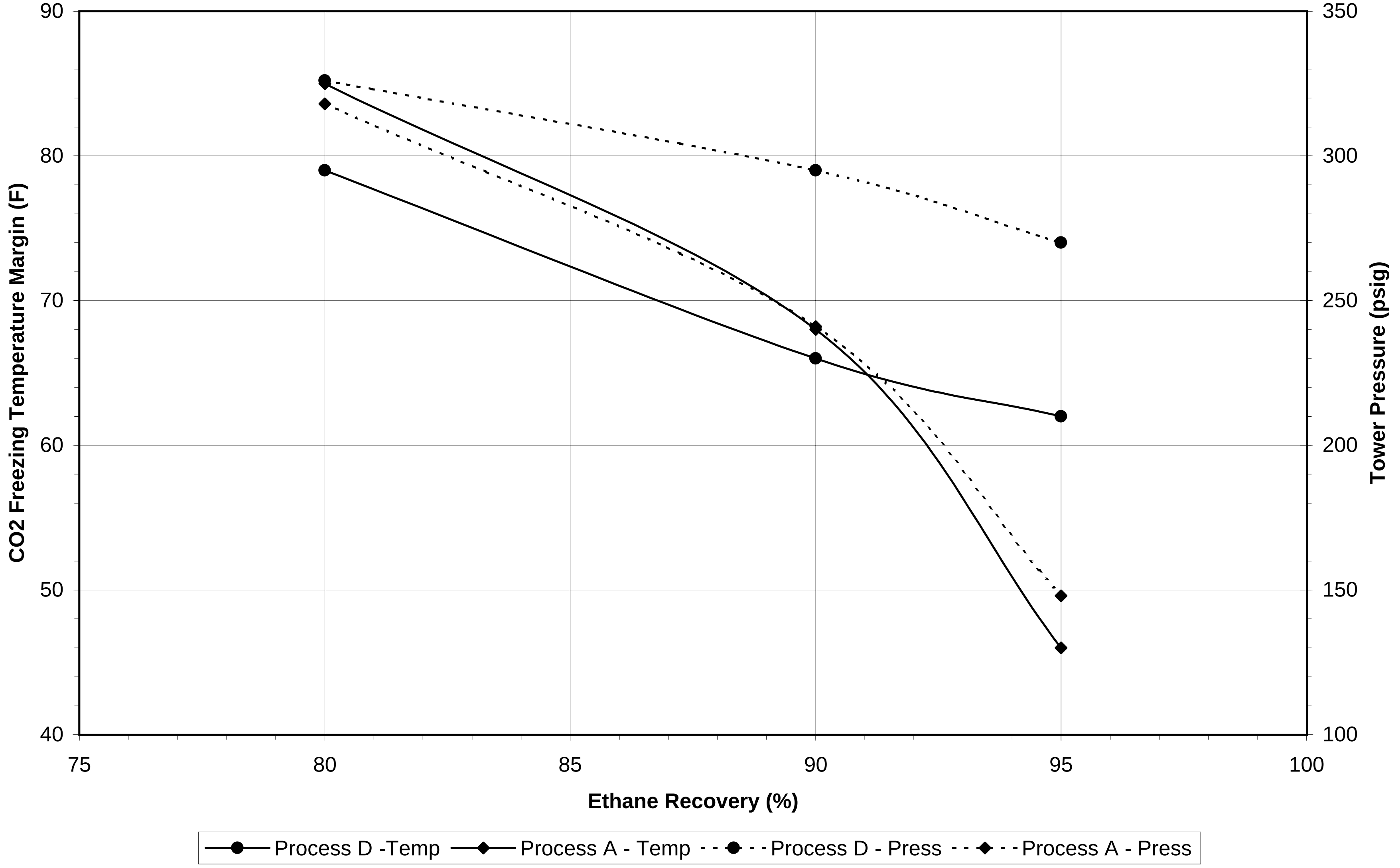


Figure 10: Effect of Recovery on Capital Costs
(2 gal/MCF and 700 psig)

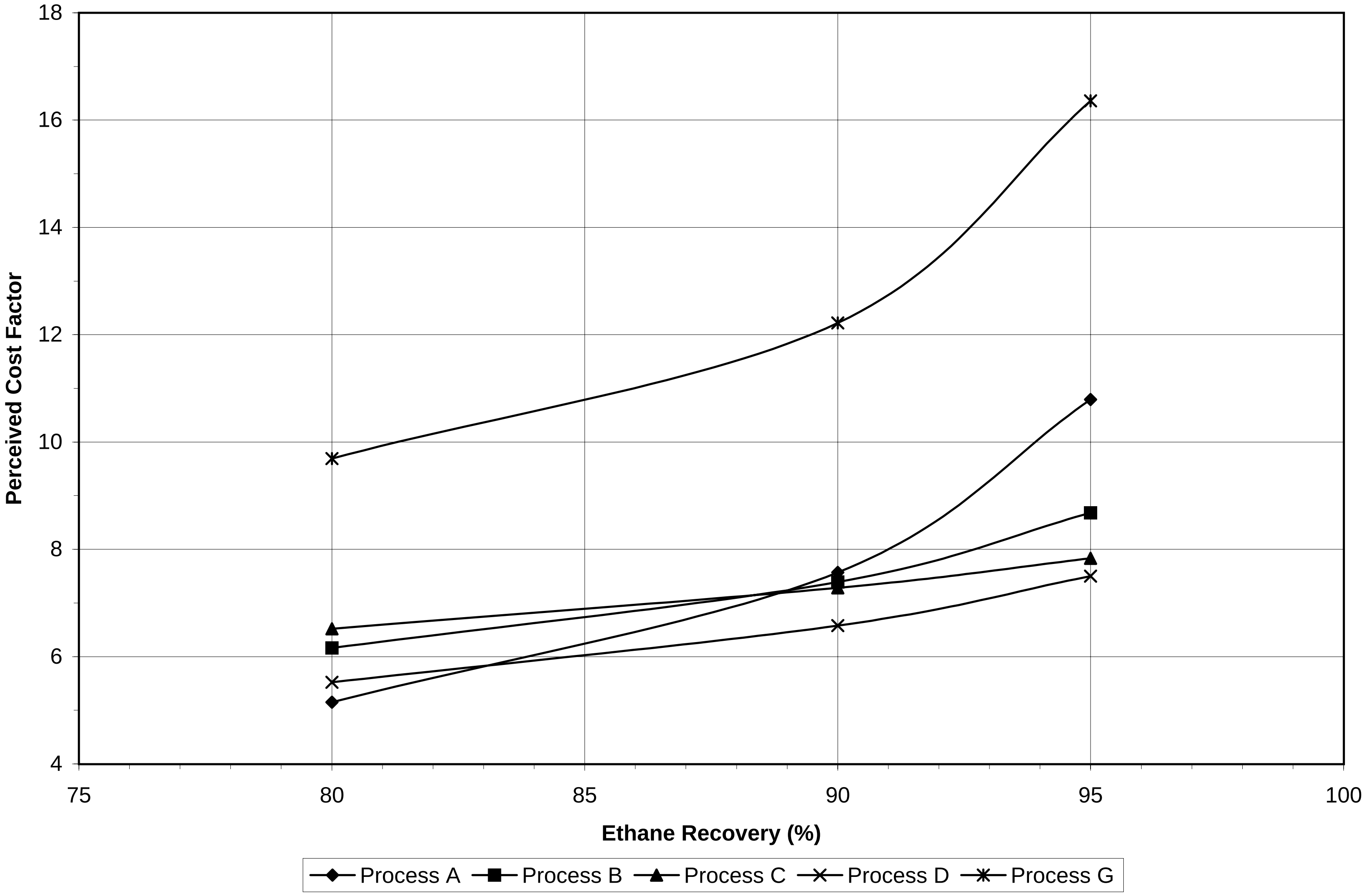


Figure 11: Effect of Inlet Pressure on Process Efficiency Compensated for Inlet Compression
(90% Recovery and 2 gal/MCF)

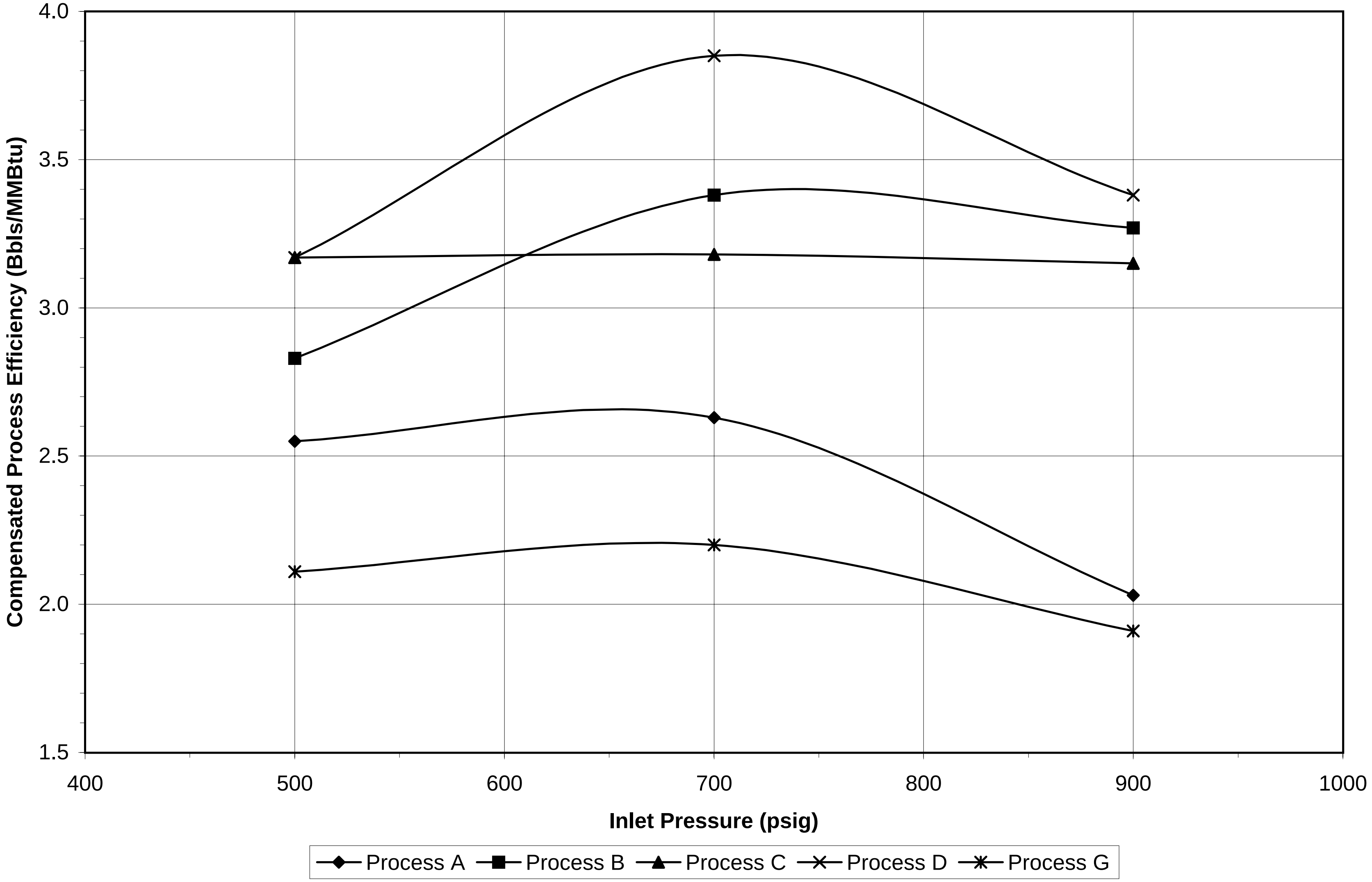


Figure 12: Effect of Inlet Pressure on Capital Costs
(90% Recovery and 2 gal/MCF)