NEW TECHNOLOGY AIDS IN EFFICIENT, HIGH RECOVERY OF LIQUIDS FROM RICH NATURAL GAS STREAMS

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ABSTRACT

Turboexpander technology is the option of choice for the recovery of liquids of natural gas specially ethane and heavier. After more than thirty years, this technology has achieved certain maturity. However, while solutions are available through mature technology, technologists continue to innovate and develop new and more efficient solutions. The investment in units utilizing proprietary/licensed “state of the art” technology pays off in a very short time resulting in a cost effective and efficient unit.

In the Arabian/Persian Gulf area, there are significant quantities of natural gas associated with oil resources. This gas is very rich in heavy components, which most often requires the use of additional external refrigeration to aid in the recovery of liquids. There are many cryogenic turboexpander schemes that use refrigeration, but the unique characteristics of the Arabian Gulf gas require an approach where the right combination of refrigeration and turboexpander cryogenic technologies yield the best results. This paper describes a series of innovative process schemes to efficiently recover liquids from rich or associated natural gas.

Using a mature technology as a base case process, the paper discusses a number of different novel designs showing savings in capital expenses (CAPEX) and operational expenses (OPEX) up to 30% reduction in energy consumption without sacrificing the level of recovery of liquids, optimizing equipment count and layout requirements. A key element of these efficient technologies is its use of true refluxed demethanizers to recover ethane and heavier components. An economic basis is also presented to compare the different cases. Additionally, a simple scheme applicable to revamps is shown as a candidate to upgrade existing plants.

Introduction - Processing heavy gas

After more than thirty years of continuous improvements and innovations, turboexpander technology has become the option of choice for the recovery of natural gas liquids especially ethane and heavier. While the technology in this field is becoming mature, the leading gas processing experts continue to develop solutions that reduce energy usage, mainly compression, usually defined by demethanizer operating pressure. Manipulation of this variable is limited by the richness of the feed gas. Operating companies are relying more on project management contractors to select technology through the front-end engineering phases, where "life cycle cost" are used to evaluate the merit of different processes. It is important to highlight that the use of proprietary design technology is economically justified when it is necessary to achieve an optimum "life cycle cost".

This paper also demonstrates that, when looking for processing options, public domain process schemes cannot be considered generic, because each process has characteristics and qualities that need to be well understood for its effective application.

Influence of Gas Composition

Gas compositions vary as a function of the source of the gas. Associated gas, that is, gas produced with crude oil, tends to be richer in composition than that from the natural gas field.

Natural gas is a mixture of hydrocarbon gases and impurities. There is no one composition or specification that can be referred to as natural gas. Each gas stream has its own distinctive composition. Even two gas wells from the same reservoir may have different compositions. Examples of some typical naturally produced natural gas streams are shown in **Table 1.** [**1**]

Well Stream 1 is typical of an associated gas. Well Streams 2 and 3 are typical low pressure and high pressure gases from natural gas fields. Not only is there a wide variety of natural gas compositions, but each gas stream produced from a natural gas reservoir can change composition as the reservoir is depleted.

A convenient method of expressing "richness" of a gas is by use of "gallons per thousand standard cubic feet of gas" (GPM). This method allows comparisons of gas compositions with a single figure, and is obtained by multiplying the mol percent of each component by the factors shown in **Table 2**, based on the pressure base of 14.65 psia and 60°F.

A casing head "rich" gas may have a GPM content of 9, whereas, a "lean" gas from offshore U.S.A. Gulf Coast has a typical GPM content of 0.8.

Table 1 – Typical Natural Gas Analysis

	Well No. 1		Well No. 2		Well No. 3	
Component	Mol%	GPM	Mol%	GPM	Mol%	GPM
Methane	27.52	-	71.01	-	91.25	-
Ethane	16.34	4.36	13.09	3.50	3.61	0.96
Propane	29.18	8.02	7.91	2.18	1.37	0.38
i-Butane	5.37	1.76	1.68	0.55	0.31	0.10
n-Butane	17.18	5.41	2.09	0.66	0.44	0.14
i-pentane	2.18	0.80	1.17	0.43	0.16	0.06
n-pentane	1.72	0.62	1.22	0.44	0.17	0.06
Hexane	0.47	0.19	1.02	0.42	0.27	0.11
Heptanes+	0.04	0.02	0.81	0.37	0.4	0.18
Total	**100.00**	**21.19**	**100.00**	**8.54**	**97.98**	**2.00**
MW	**38.56**		**24.42**		**17.63**	

Table 2 – GPM Factors

Component	**Factor**
Ethane	0.267
Propane	0.275
i-Butane	0.327
n-Butane	0.315
i-pentane	0.366
n-pentane	0.362
Hexane	0.411
Heptanes+	0.461

Typical gas streams in the Arabian Gulf area are considered “rich gases”. Typical compositions and corresponding GPM’s are shown in **Table 3.**

Table 3 – Typical Gas Analysis in Arabian Gulf Area

	Gas No. 1		Gas No. 2		Gas No. 3		Gas No. 4		Gas No. 5	
Component	Mol%	GPM	Mol%	GPM	Mol%	GPM	Mol%	GPM	Mol%	GPM
Methane	63	-	81	-	83	-	85.72	-	90.24	-
Ethane	20	5.34	9.5	2.54	7.5	2.00	6.98	1.86	7.09	1.89
Propane	9	2.48	4.5	1.24	4.2	1.16	3.89	1.07	1.42	0.39
i-Butane	2.8	0.92	1.2	0.39	1	0.33	0.93	0.30	0.40	0.13
n-Butane	2.5	0.79	2.2	0.69	2	0.63	1.39	0.44	0.39	0.12
i-pentane	1.5	0.55	0.42	0.15	0.35	0.13	0.31	0.11	0.16	0.06
n-pentane	0.55	0.20	0.45	0.16	0.4	0.14	0.48	0.17	0.15	0.05
Hexane	0.4	0.16	0.5	0.21	0.2	0.08	0.27	0.11	0.10	0.04
Heptanes+	0.25	0.12	0.23	0.11	1.35	0.62	0.03	0.01	0.05	0.02
Total	**100**	**10.55**	**100**	**5.49**	**100**	**5.09**	**100**	**4.09**	**100**	**2.71**
MW	**25.24**		**21.1**		**21.23**		**19.74**		**18.05**	

Issues related to rich gas composition

The design of a gas plant to process rich gas is impacted by:

- A large amount of liquid condensation during the cool down, which impacts the shape of the cooling curves and promotes pinch points.
- A large amount of methane condensed with the liquid stream, which reduces the amount of gas available for the turboexpander.

The formation of liquid during the cooling process needs to be carefully evaluated as the densities, flow patterns, pressure drops and, volumes of equipment are significantly affected by these parameters.

Table 4 shows the effect of temperature on the vapor fraction for the different gases of **Table 3**, and the percent of methane occluded in the liquid condensed.

Table 4 – Effect of temperature on vapor fraction and methane condensed

Gas	120° F	40° F	-40° F	% C1@-40°F
Gas No.1	1	0.76	0.31	51
Gas No.2	1	0.94	0.75	49
Gas No.3	1	0.93	0.78	47.5
Gas No.4	1	0.98	0.84	49.7
Gas No.5	1	0.99	0.95	45.9

Figure 1 shows an example of the cooling curve and vapor fraction change for Gas No.1(800 psia & 120° F)

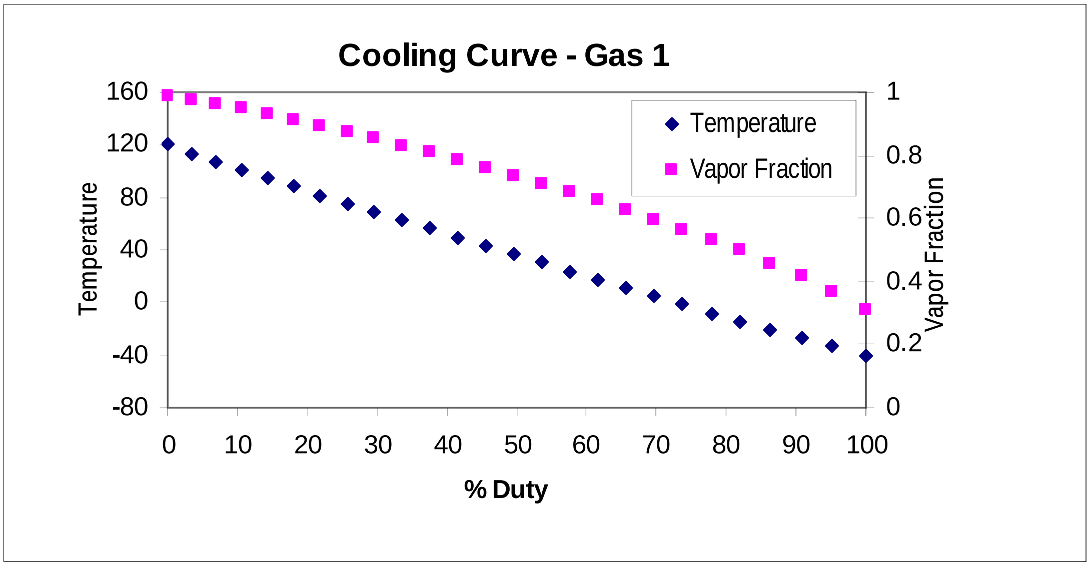


Fig. 1- Cooling Curve and Vapor Fraction

- Condensation of reflux streams alters the shape of the cooling curves and promotes pinch points at very cold temperatures.
- Heavies could limit the operating pressure due to the approach to critical conditions in the bottom of the demethanizer column.
- Warmer demethanizer lower section, affecting the thermal integration of the process
- Warmer bottom of the demethanizer; reboiling with inlet gas may not be possible, requiring external heat supply or other heat media.
- Use of refrigeration

How much energy should be spent per gallon of liquid recovered? **Figure 2** is a generic graph that represents horsepower per gallon per minute (gpm) of liquid recovered, as a function of molecular weight and for a certain level of recovery. *[Note: note difference between GPM (gallons /Mscf) and gpm (gallons per minute)]*. The graph represents a good target to optimize and balance the overall energy used in inlet compression, residue compression, and refrigeration.

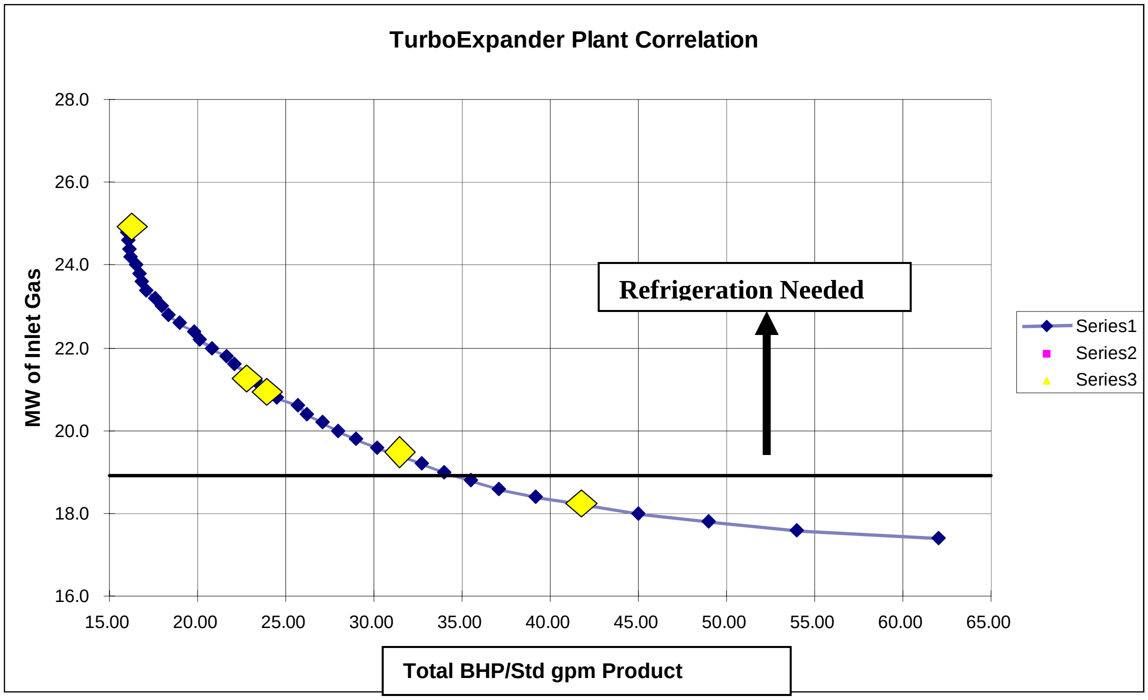


Fig..2 – BHP vs. gallon per minute recovered

The curve is for high recoveries of ethane (95%). Representative points for the gases of **Table 3** are plotted over the curve, and it can be noticed that most of the gases of the Arabian Gulf Region fall in the zone where refrigeration is recommended.

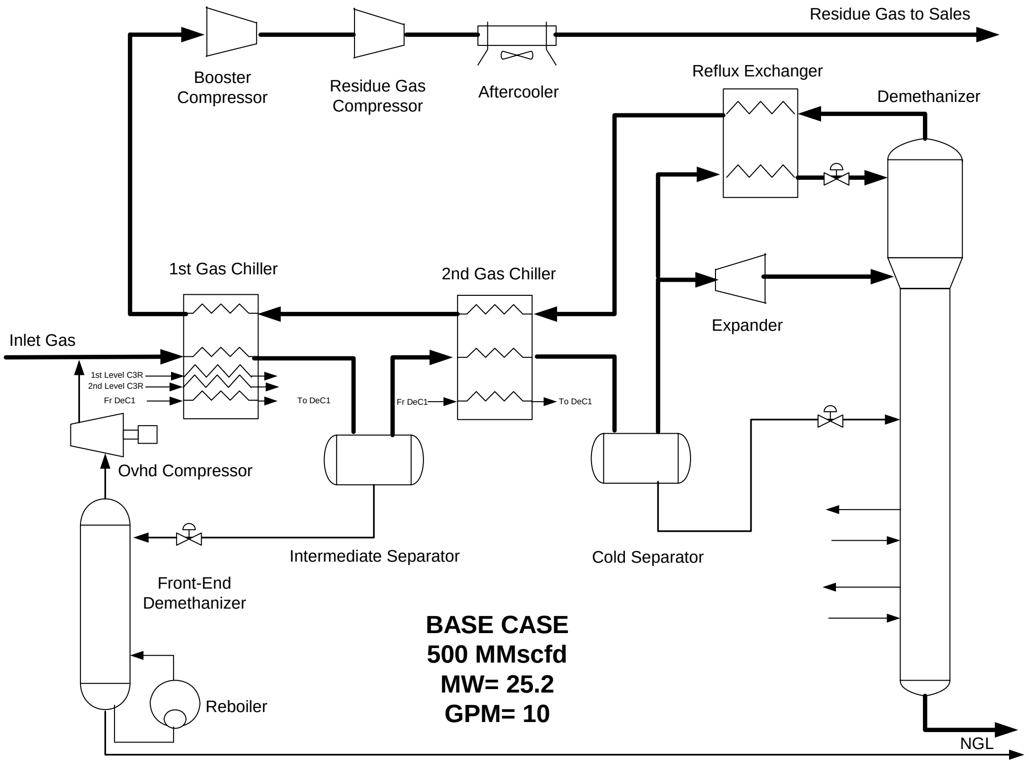
Case Study

As an example of the use of mature technology, **Fig. 3** shows a typical sub-cooled reflux turboexpander process, shown here with refrigeration in the gas-gas exchanger and side-reboilers. This process will be our Base Case.

The basis of the study is:

Plant Gas Flow : 500 MMscfd
Inlet/Outlet Pressure: 785 psig
Inlet Temperature: 80^{o} F
Gas composition is similar to Gas No.1, of Table 3
Electric power is 0.03 $/kWh.
Cost of installed horsepower: 435 $/hp
Cost of installed UA (for plate fins): 0.0815 $/UA

Fig. 3 – Base Case Process Scheme



Treated and dehydrated gas is fed to the cryogenic section at 785 psig and 80^{o} F, and is cooled in the first gas chiller up to – 30^{o} F, and sent to the intermediate separator. The gas separated is sent to the second gas chiller and cooled to $–50^{o}$ F and then sent to the cold separator. Gas from the cold separator is divided into two streams, the first directed to the turboexpander, and the second sent to the reflux exchanger. The reflux stream feeds the demethanizer tower at the top, while the stream from the turboexpander feeds it a few stages below. *(Note: for the sake of clarity, the so-called "reflux" is not in reality a true reflux. It is a design technique that uses same composition, different enthalpy in a section of a column to enhance separation.)*

In the turboexpander the pressure is lowered to 280 psig, and the gas temperature descends to –119^o F by virtue of the isoentropic expansion, extracting work from the process.

The demethanizer column operates at 275 psig and –150^o F in the top, and 280 psig and 26^o F in the bottom.

Demethanizer overhead gas is directed to the reflux exchanger, the second gas chiller and the first gas chiller to provide refrigeration to the process. Low pressure residue gas leaves the first gas chiller at 43^o F and is directed to the booster compressor driven by the turboexpander, and then to the residue gas compressor where pressure is raised to 795 psig. Residue gas is sent to sales pipeline at 785 psig and 100^o F.

The liquid removed from the cold separator is fed into the demethanizer column. The liquid obtained in the intermediate separator, instead, is fed to a front-end demethanizer where predominantly methane is removed by stripping action. This gas is compressed and sent to the front- end of the cryogenic unit. The demethanized liquid is sent as feed to fractionation, together with the demethanizer bottoms.

The process is supported with external propane refrigeration, in the first chiller, at two different levels, one at 0^o F, and the other at –35^o F.

A summary of the performance of this process follows:

Gas processed:	500 MMscfd
Refrigeration (eff: 75%) :	Sub-total 32,300 BHP
Compression (eff: 82% ad.):	Sub-total 19,867 BHP
Total compression:	52,167 BHP
NGL recovered:	2,991 gpm
BHP/gpm index:	17.44 hp/gpm
Ethane recovered:	95% Total

By examining the flowsheet one could question the presence of the front-end demethanizer, since it does not contribute to the overall efficiency of the process, mainly because it recycles methane and ethane constantly, adding energy compression, and hydraulic and thermal load to the first chiller, adding load to the refrigeration system. The recycled stream amounts to 25% of the combined stream, requiring 3720 BHP for the overhead compressor.

Figure 4 shows the heating-cooling composite curves for the base case process. This graphic is a very useful tool to analyze opportunities in heat network optimization and design strategies. We observe:

Observation	Impact
Side-reboiler misplacement	Poor heat integration
Refrigeration load distribution	Higher energy consumption
Close temperature approaches	Pinch
Hot end too open	Opportunity to save refrigeration
Cool NGL product (26° F)	Opportunity to save refrigeration

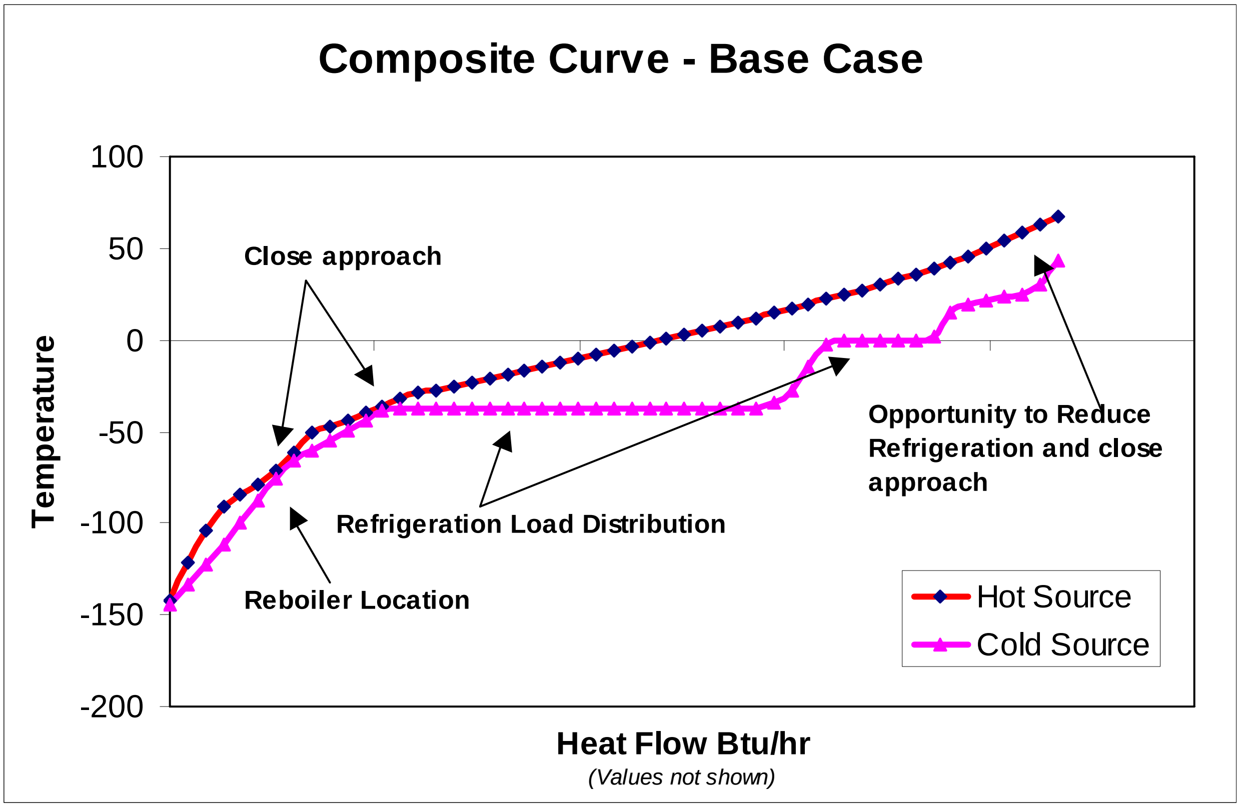


Fig. 4 – Composite Curve – Base Case

If we compare the hp/gpm obtained for this process with the value estimated from the curve (see **Figure 2)**, we notice that the point falls on the right of the corresponding point on the curve, indicating that there are opportunities to reduce the energy consumption.

We develop an Alternate Case and introduce the following changes to optimize the performance of the Base Case:

- Change side-reboiler location
- Balance refrigeration loads

- Open temperature approaches
- Eliminate front-end recycle and re-route stream as reflux to demethanizer column (front-end demethanizer).

We obtain the following results:

Gas processed:	500 MMscfd
Refrigeration (eff: 75%):	Sub-total 24,898 BHP
Compression (eff: 82% ad.):	Residue gas 21,220BHP
Total compression:	46,118 BHP
NGL recovered:	2,991 gpm
BHP/gpm index:	15.41 hp/gpm
Ethane recovered:	95% total
Compression savings:	$ 2,631,315
Exchanger savings:	$ 644,000
Total CAPEX savings:	$ 3,191,380
OPEX savings:	$/yr 1,170,000

With the changes introduced we are able to:

- redistribute refrigeration, and save energy
- efficiently utilize side-reboiler
- eliminate overhead compressor and replace with second turboexpander, recovering 1345 hp from the process
- use cold gas available at front-end and reduce refrigeration load
- reduce the energy index by 11.6%
- introduce savings in CAPEX and OPEX

Figure 5 shows the Alternate Case process.

Fig. 5 – Alternate Case – Process Scheme

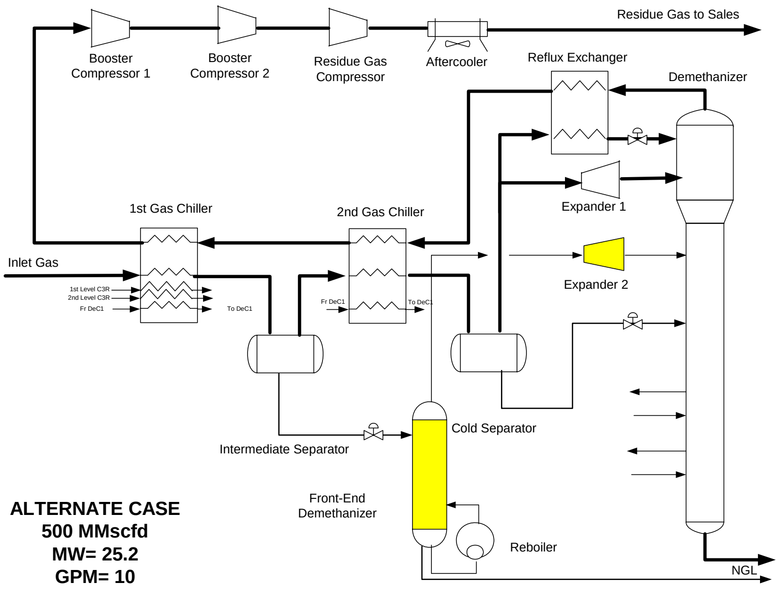


Figure 6 shows the heating-cooling composite curves for the Alternate Case 1 process. The curves reflect the changes introduced in the process.

Can we continue optimizing? There could be potentially minor further changes, like using the refrigeration available from the NGL stream, which we excluded to keep the comparison on the same basis. We could also raise the pressure of the demethanizer to save compression, but to keep the recovery at the same level, we will have to cool more and reflux more which will lead to loss expander work.

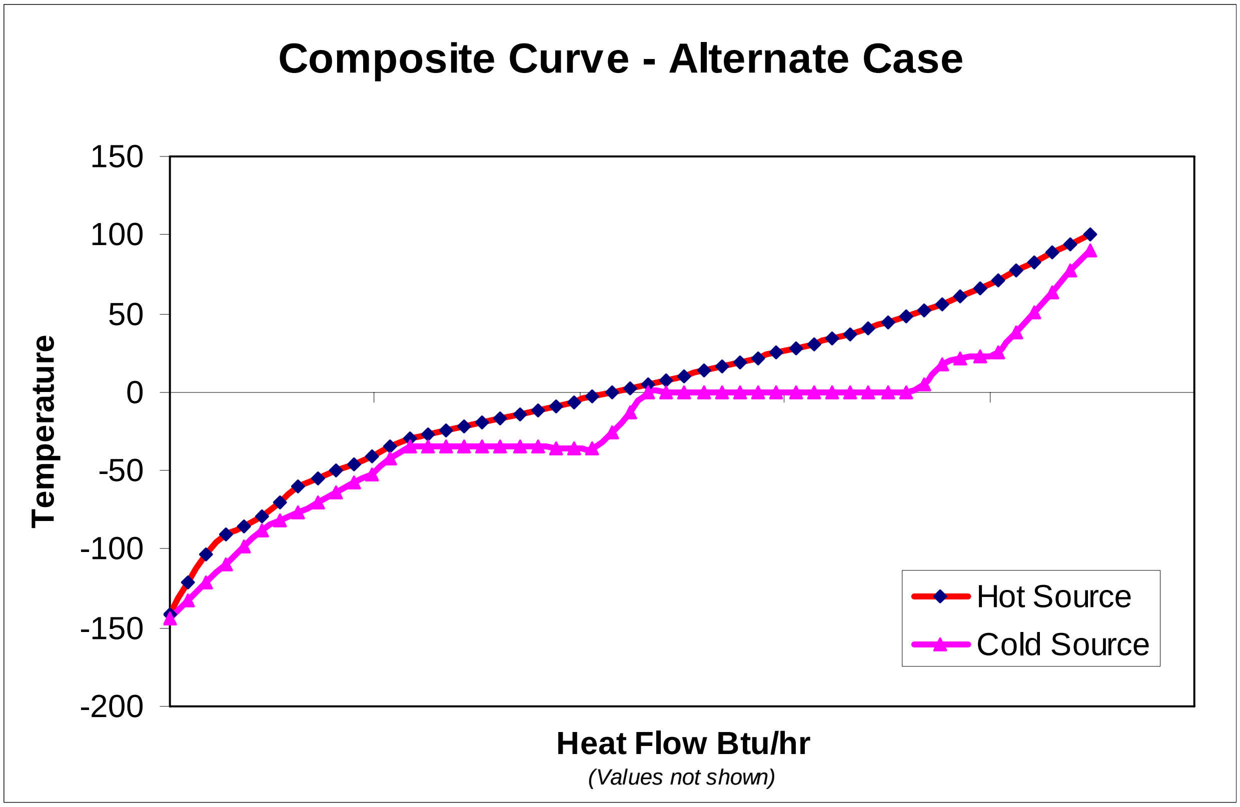


Fig. 6 – Composite Curve – Alternate Case

To achieve 95% recovery, true reflux processes are needed, instead of a “pseudo” reflux process like the sub-cooled reflux, in which we are limited by equilibrium.

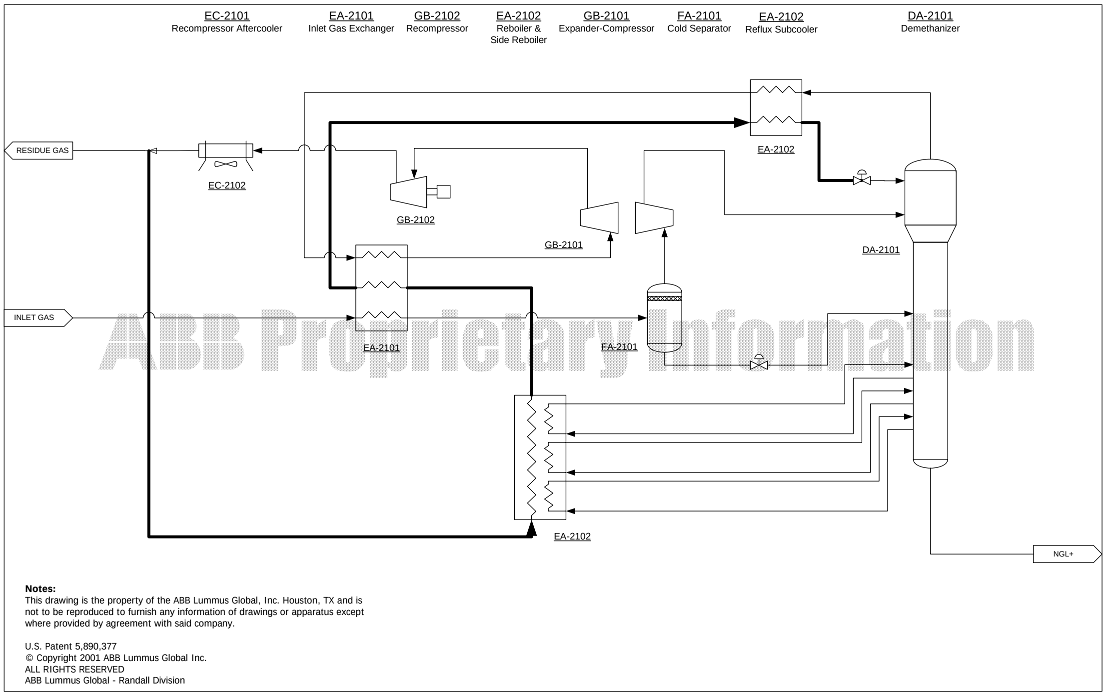
New Technology

Randall Gas Technologies, a division of ABB Lummus Global Inc., with a charter to focus on the development of gas processing technology and to capitalize on more than 30 years of experience as a pioneer and leading supplier of cryogenic gas processing solutions, has been developing a portfolio of high performance processes, recognizing the importance of flexibility and adaptability of processes to different operational scenarios and different qualities of gas feeds. These processes feature true reflux feeding the demethanizer column or multiple refluxes. In March of 2000 we introduced the first of these processes, the ***NGL-PRO***^{SM} ***Process*** . This is a process characterized for an inlet gas feed without split, reflux recycle through side reboilers and other technical features. The advantage of this process relies in its simplicity, minimum piece count, adaptability for revamps, and competitive energy efficiency. This process has been granted a US patent. (U.S. Pat 5,890,377) (**See Figure 7**) [**2**]. The ***NGL-PRO***^{SM} process is very simple to operate and control. [**3**]

We applied the conditions of Gas No.1 to the ***NGL-PRO***^{SM} ***Process*** and the following are the results:

Gas processed:	500 MMscfd
Refrigeration (eff: 75%):	9,475 BHP @ -20^{o} F with economizer
Compression (eff: 82% ad.):	Residue gas 30,090BHP
Total compression:	39,565 BHP
NGL recovered:	2,991 gpm
BHP/gpm index:	13.22 hp/gpm
Ethane recovered:	95% total
Compression savings:	$ 5,481,870
Exchanger savings:	$ 221,290
Total CAPEX savings:	$ 5,703,160
OPEX savings:	$/yr 2,437,490

The ***NGL-PRO***^{SM} ***Process*** adapted for these conditions is shown in Figure 8. Heat curves are shown in figure 9.



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U.S. Patent 5,890,377

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Fig. 7 - *NGL-PRO*^{SM} Process

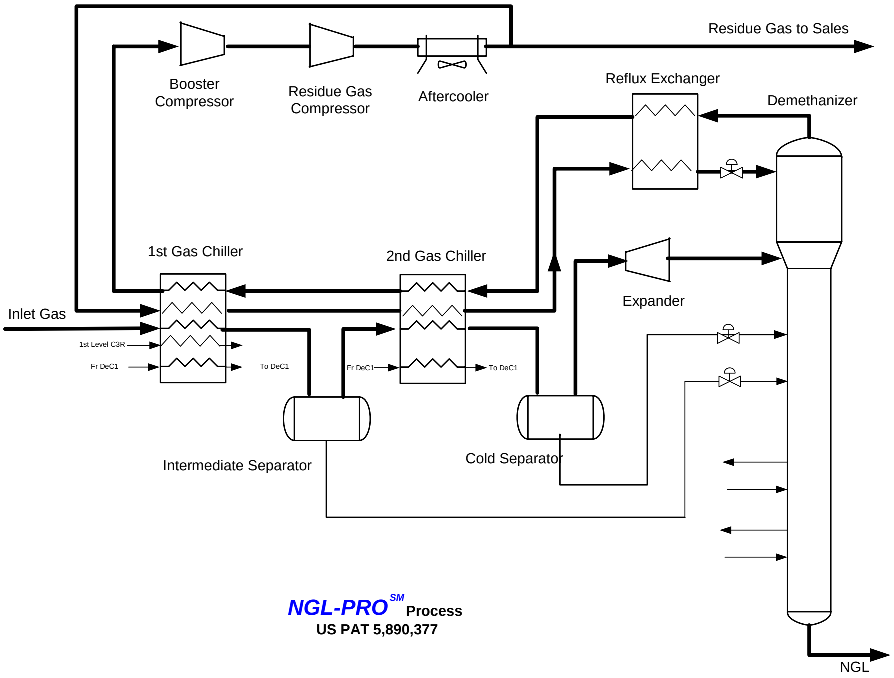


Fig. 8 - ***NGL-PRO***^{SM} **Process adapted for Rich Gas**

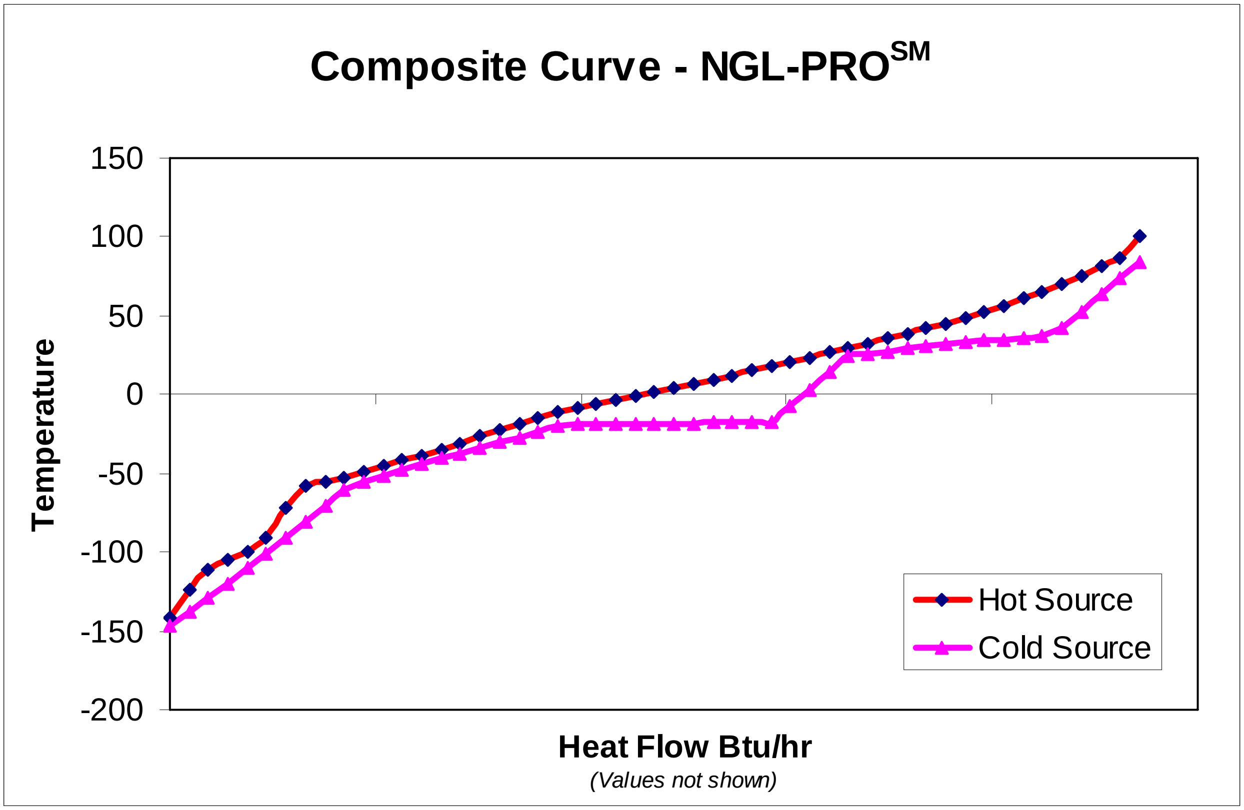


Fig. 9 - ***NGL-PRO***^{SM} **Process Heat Curves**

Although the ***NGL-PRO***^{SM} process represents a great improvement in energy consumption, there is still the possibility to improve it. This is achieved in the new suite of processes presented here with the addition of strategic secondary refluxes. The new processes are:

- ***NGL-FLEX***^{SM} ***Process***
- ***NGL-RGP***^{SM} ***Process***
- ***NGL-MAX***^{SM} ***Process***

Each one of these processes feature in one way or other means to provide a true reflux as well as a secondary mean of refluxing the demethanizer. Other means are also used to reduce the energy consumption like the use of high pressure demethanizers, although this option should be carefully evaluated.

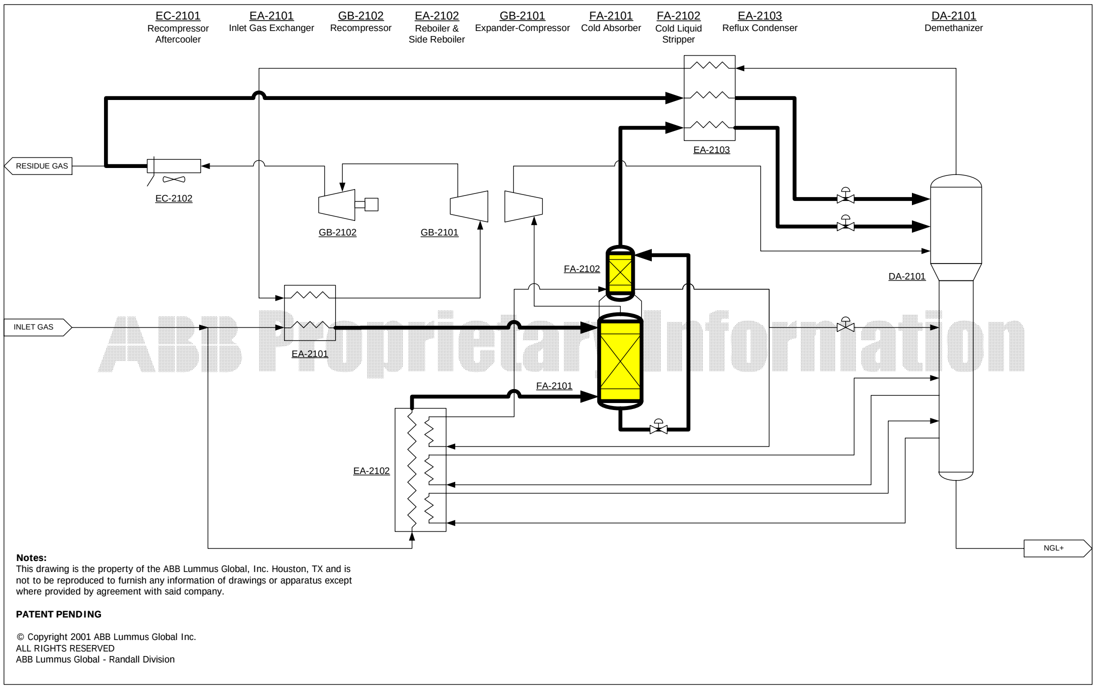
The base case gas, Gas No.1, was run through each one of these processes to determine the best fit for the process conditions, and the result is shown below. For the sake of brevity we will focus only in the process whose performance outstands.

Table 5 – Performance Parameters

	NGL-PRO^{SM}	***NGL-FLEX***^{SM}	***NGL-RGP***^{SM}	***NGL-MAX***^{SM}
Total BHP	39,565	37,210	35,535	36,910
NGL, gpm	2,991	2,991	2,991	2,991
HP/gpm	13.22	12.44	11.88	12.34
UA/gpm	6,814	8,757	9,028	8,996

The table above indicates that the ***NGL-RGP***^{SM} process performs more efficiently on this feed and the desired recovery objectives. However, only an economic analysis will project the technical features into economical benefits. This will be shown in the next section.

The ***NGL-RGP***^{SM} process (**see Figure 10**) achieves high ethane recoveries with a recycle reflux. To minimize the reflux and save energy, this process also includes a cold high pressure absorber and stripper. As we mentioned before, the liquid condensed from the inlet contains a high amount of methane. The liquid obtained from the cold absorber is sent to the high-pressure stripping step, where it is partially demethanized, producing a methane rich stream that is used as a secondary reflux. This additional reflux helps in reducing the recycle reflux, therefore minimizing the horsepower compression.



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PATENT PENDING

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Fig. 10 - *NGL-RGP*^{SM} Process

Economic Comparison

Since engineering is science-based economics, **Table 6** is a comparison of the cases analyzed in this work. All drivers are considered electric. The net present value (NPV) is shown to demonstrate clearly the impact of the high performance processes.

Table 6 – Economic Comparison
(Base recovery is 95% Ethane)

	Base	**Alt. Base**	***NGL-PRO***^{SM}	***NGL-FLEX***^{SM}	***NGL-RGP***^{SM}	***NGL-MAX***^{SM}
Total BHP	52,167	46,118	39,565	37,210	35,535	36,910
NGL, gpm	2,991	2,991	2,991	2,991	2,991	2,991
HP/gpm	17.44	15.41	13.22	12.44	11.88	12.34
OPEX Savings $/yr	Base	1,170,000	2,437,490	2,892,995	3,216,975	2,951,020
CAPEX Savings, $	Base	3,191,380	5,703,160	6,261,510	6,925,290	6,334,823
NPV, MM$	Base	9,802	19,745	22,608	25,102	23,010

The CAPEX row has been adjusted for the difference in BHP of each process, the difference in exchanger area, and main equipment of each scheme.

The table above shows the economic performance of the processes presented here against the study base case using mature technology. It is very important to point out that the high performance processes perform all on the same level. The particular conditions of this study, indicates that the ***NGL-RGP***^{SM} process has a slight economical advantage against the other two processes. This only emphasizes our criteria that each scenario needs to be evaluated carefully. Perhaps a more general statement is that the new generation of processes presented in this work will perform significantly better than the mature technology.

Conclusion

Cryogenic extraction of liquids has existed for more than 35 years, and there has been a continuous flow of innovations, as demonstrated by the enormous body of intellectual property developed in this field. However, we continue to gain experience and learn new lessons. As technologists, our task is to create new and competitive solutions. We have introduced a new generation of cryogenic high performance technologies, specifically tailored for flexible handling of gas compositions, and efficient use of energy. One technology will not be the best in all different gas applications; a suite of technologies is needed to satisfy the diverse requirements of the natural gas industry.

We believe that the value of new technologies contributes differentiating process efficiency, which translates into economy of the facility life cycle cost. That is the aim of the experts. Technology has the mission of enabling business and to elevate its value. Market conditions, business envelope, and value differentiation to the business will dictate whether a certain technology has applicability and chances to succeed.

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2. US Patent 5,890,377 Hydrocarbon Gas Separation Process
3. New Recycle Process Scheme for High Ethane Recovery- GPA 2000