SIMULATION OF TURBO-EXPANDER PROCESSES FOR RECOVERING OF NATURAL GAS LIQUIDS FROM NATURAL GAS

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ABSTRACT

The composition of natural gas is an important factor in deciding what process configuration to employ for recovering natural gas liquids (NGLs). The production of NGLs from natural gas was studied. The study was conducted using HYPROTECH's HYSYS.Process (HHP) simulation software. Natural gases of wide-ranging compositions available both in literature and at three gas fields in Saudi Arabia were tested for different turbo-expander process configurations. These configurations are based on energy integration of the processes - Basic, Gas Subcooled (GSP), Liquid Subcooled (LSP) and Gas-Liquid Subcooled (GSLP). The effects of increasing the amount of C2+ in the feed stream on the efficiency of energy utilization and C2+ recovery are presented. GLSP configuration was observed to have the highest overall average C2 recovery while GSP exhibited the highest C2 recovery for medium C2+ composition. The cryogenic process configuration to choose depends on the relative amount of heavy components in the feed stream. For processes that may use a range of natural gas compositions, GLSP offers advantages in C2 recovery over other turbo-expander configurations. Using GLSP, for all compositions, ethane recoveries of not less than 74% were achieved.

INTRODUCTION

There is worldwide drive toward increasing the utilization of natural gas and the need to minimize energy consumption associated with the process. An important requirement in natural gas processing is that the process should be designed to be flexible to accommodate a range of natural gas compositions. The process choice is also guided by the cyclical nature of the market preference for ethane and propane. Traditionally, the ethane-plus richness determines the type of the process to be employed. The NGLs may be recovered by many methods. Some of them are: Compression, Straight Refrigeration, Cascade Absorption, Ambient Temperature Absorption, Adsorption, Joule-Thomson Expansion and Expander. Lean natural gas usually is processed by a cryogenic turbo-expander (TE) process while rich gas is separated using a non-cryogenic adsorption process.

The TE process has decided advantages over adsorption for processing lean gas. TE may be combined with Joule-Thomson (J-T) valve and external refrigeration. The combination is necessary to improve the energy efficiency or to obtain greater recoveries. For a middle-of-the-road gas composition the choice becomes more challenging. A recent report has shown that the adsorption process has a lower cost (32%) than the gas-subcooled version of the turbo-expander process for processing a middle-of-the-road composition (1).

In the present study, different process configuration strategies for the gas processing based on the TE were conducted. Natural gas of C2+ composition range of 16 – 72% was used for the analysis. A simulation-software (HHP) was employed for the study to establish the optimal TE process configuration for natural gas of

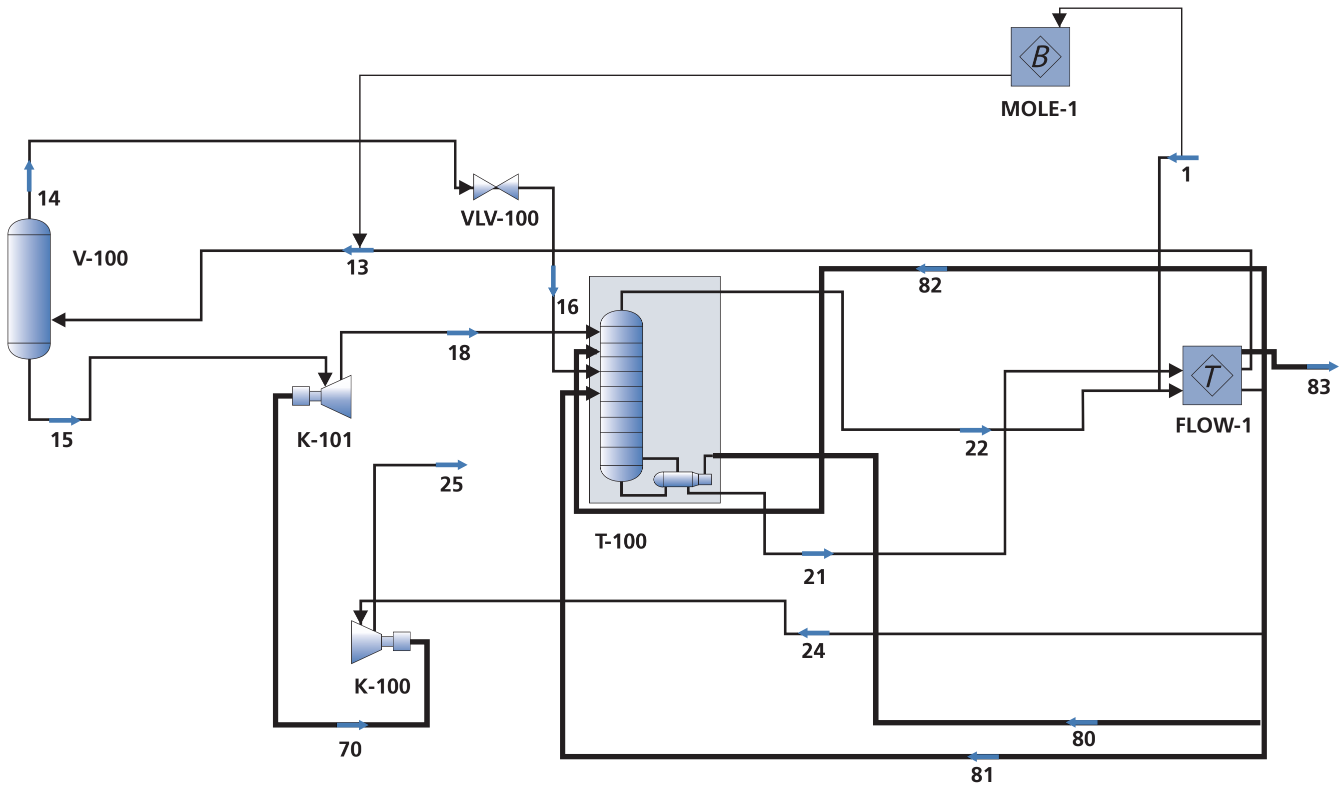

Fig. 1a. Process Flow Diagram for the Basic Configuration

wide-range composition. This work has shown that the optimum heat integration and recompression duty depend strongly on feed composition.

PROCESS DESCRIPTION

TE plants are often used for the recovery of lighter gases (methane, ethane) from a natural gas stream. The Natural Gas is cooled to extremely low temperatures through a network of heat exchangers and valves. The cooling results in partial liquefaction of the stream and enhances ethane recovery. The cold liquid and vapor are then separated in the Low Temperature Separator (LTS). The liquid stream from LTS is flashed across a J-T valve (in most TE processes) for additional chilling. The J-T effect is defined as the cooling that occurs when a highly compressed gas is allowed to expand in such a way that no external work is done.

Expanders are known to be applied at the lowest temperature levels of configurations, as this is where they are thermodynamically more efficient (2, 3). Therefore, vapor from the LTS is fed into the expander unit where the process temperature is further reduced and also produces work, which is utilized for recompression. The liquid product of the expander and the valve outlet both feed to the demethanizer tower. Heat integration allows for pre-cooling of the hot feed, which is thermodynamically more efficient. This approach is used in this design to pre-chill the feed to the LTS by the use of the demethanizer overhead stream and side reboilers.

Building the Model

All models were designed using the HHP Simulation Software. Fig. 1a shows the flow sheet for one of the configurations (Basic Process). The figure has one separator (V-100), one demethanizers (T-100), expander (K-101), compressor (K-100) and a J-T valve (VLV-100). The Peng Robinson thermodynamic property package was used. This property package is adequate for the composition investigated (4). Much of the chilling section is shown as a sub-flow sheet (FLOW-1) with a cascade of heat exchangers using the duties (81 and 82) from the column as shown in Fig. 1b. This is where all the heat integration and recoveries are done. The exchanger network was built as a subflow sheet. A special feature of the HHP simulation software in the subflow sheet environment was used to connect the main flow sheet to the sub-flow sheet, Fig. 1b.

Different configurations of the expander process were used to achieve the production of NGLs and the results were compared. These configurations include the Basic Process (shown in Fig. 1a), Gas subcooled Process (GSP), Liquid Sub-cooled Process (LSP) and the Gas Liquid Subcooled Process (GLSP). These configurations were

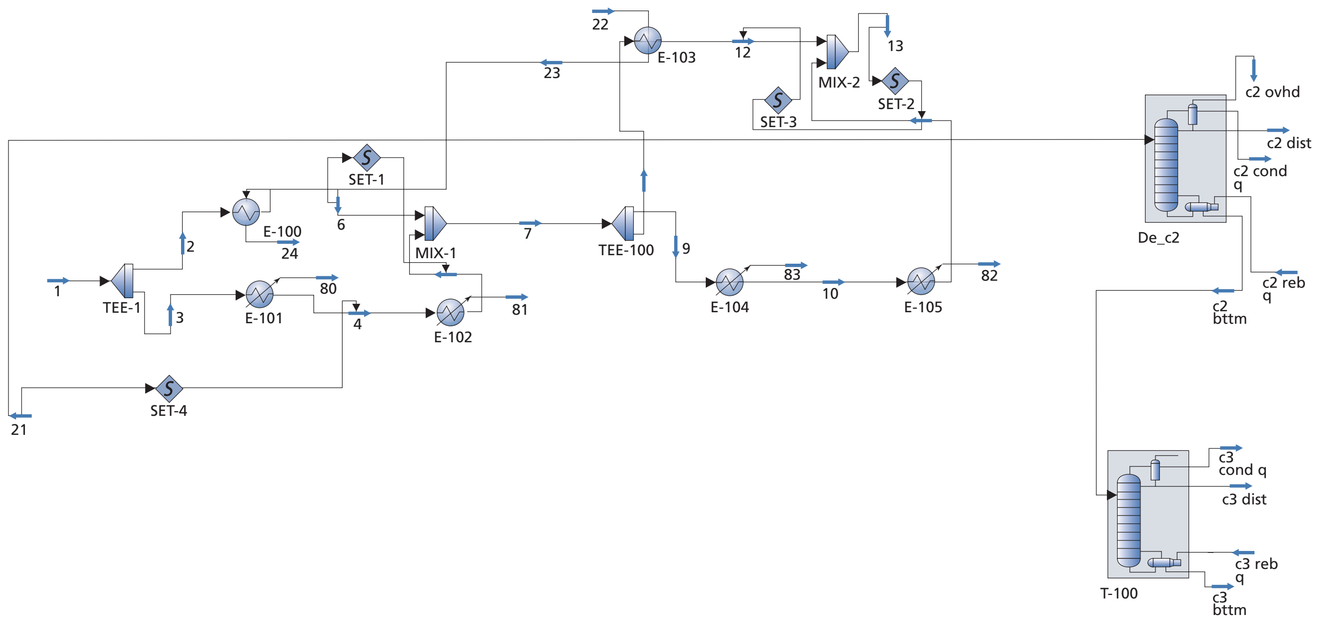

Fig. 1b. Energy Recovery Section for the Basic Process (Subflow sheet)

further studied with modification for the down stream separation of ethane and propane. The configurations are discussed further in the following paragraphs.

Basic: One-Stage Separator Process

Fig. 1a shows the flow sheet for one of the configurations (Basic Process). The figure has one separator, one demethanizer, expander, compressor and a J-T Valve. Much of the chilling section is shown as a subflow sheet (FLOW-1) with a cascade of heat exchangers using the duties (stream numbers 81 and 82) from the column as shown in Fig. 1b. This is where all the heat integration and recoveries are done. The exchanger network was built as a subflow sheet. A special feature of HHP in the subflow sheet environment was used to connect the main flow sheet to the subflow sheet, Fig. 1b.

Gas Subcooled Process (GSP)

In this process, the gas from the main demethanizer column is used for pre-cooling. The feed gas that goes into the LTS is pre-cooled through a series of external refrigeration using Heat Exchangers E-101 to E-105. The colder gas is flashed in the separator to produce a gaseous overhead product and a liquid bottom product. Part of the overhead gas is then routed to be cooled by the demethanizer overhead. By this process the gas is condensed and subcooled before being flashed into the top of the demethanizer. This process provides a cold top stream rich in heavier hydrocarbons.

The other part of the overhead gas stream enters the expander. The expander operates isentropically and lowers the feed pressure. More horsepower is recovered through the expansion process and thus reduces or compensates for the energy requirement in the compressor. Expansion efficiency is thermodynamically a function of temperature. Therefore, the inlet temperature to the expander is critical to the determination of the expander performance. The outlet of the expander is then routed to the middle of the column. The separator liquid is also flashed through a J-T valve into the demethanizer column at an intermediate feed point.

Liquid Subcooled Process (LSP)

In this process, the liquid from the LTS containing most of the heavier hydrocarbons is subcooled and split into two. After the split, the first part is flashed through a J-T valve for further cooling before entering the demethanizer at the top of the column. The other part is also flashed and returned against the separator liquid. This part then goes through a second J-T valve before entering the demethanizer column at a lower point. This alternate design is expected to offer further reduction in energy consumption. It also provides cold heavy hydrocarbon top feed which will act as scrubber for the incoming gas. The gaseous overhead is routed to the expander after which it is fed at the intermediate part of the demethanizer.

Gas Liquid Subcooled Process (GLSP)

This combines the expected advantages of GSP and LSP mentioned above. In this process the liquid from the low temperature separator is pre-cooled before it is split into

	1	2	3	4	5	6	7	8
N_2	0.0055	0.0540	0.0000	0.0000	0.1297	0.0349	0.0623	0.0464
CO_2	0.0091	0.0000	0.0000	0.0000	0.0358	0.0270	0.0171	0.0302
C1	0.8457	0.8400	0.5952	0.9717	0.7109	0.6507	0.8086	0.6539
C2	0.0820	0.0760	0.0536	0.0189	0.0484	0.1050	0.0698	0.0504
C3	0.0340	0.0200	0.0471	0.0029	0.0172	0.0497	0.0261	0.0297
I-C4	0.0058	0.0000	0.0203	0.0013	0.0037	0.0095	0.0043	0.0090
n-C4	0.0086	0.0000	0.0239	0.0012	0.0066	0.0187	0.0074	0.0172
I-C5	0.0028	0.0070	0.0180	0.0007	0.0030	0.0077	0.0018	0.0085
n-C5	0.0021	0.0000	0.0161	0.0005	0.0030	0.0078	0.0015	0.0084
n-C6	0.0018	0.0030	0.0260	0.0004	0.0045	0.0125	0.0006	0.0160
n-C7	0.0012	0.0000	0.1998	0.0024	0.0164	0.0149	0.0000	0.0214
n-C8	0.0005	0.0000	0.0000	0.0000	0.0000	0.0156	0.0000	0.0243
n-C9	0.0004	0.0000	0.0000	0.0000	0.0000	0.0108	0.0000	0.0194
n-C10	0.0005	0.0000	0.0000	0.0000	0.0000	0.0078	0.0000	0.0145
C10+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0274	0.0000	0.0507
TOTAL	1.0000	1.0000	1.0000	1.0000	0.9792	1.0000	0.9995	1.0000

Table 1. Natural Gas Compositions (mole fractions) used in the Simulation

two. The first part goes through a J-T expansion to be cooled further before entering the middle part of the column. The other part is expanded and returned against the liquid from the LTS that is desired to be cooled. The gas part of the LTS is again split into two. One part is cooled by the sales gas of the demethanizer. The other part of the gas from the LTS then goes through the expander K-101 for further cooling before entering the demethanizer at the top of the column.

RESULTS AND DISCUSSION

Table 1 shows the compositions of the inlet gases used for the study. Eight gas types were used based on the typical compositions from various sources of natural gas (5 – 9). The composition of the gas is important in determining the type of separation process to be employed. For instance, gases found in the Arabian Gulf region are richer in heavier components compared with those in North America. Gases that have the so-called middle-of-the-road composition need to be studied carefully to determine the most beneficial configuration for NGL recovery.

To assess the relative advantage of the alternatives, various runs were made under different configurations and compositions at operating conditions shown in Table 2. The ethane recoveries achieved, the load on the compressor/expander, the reboiler energies, are all parameters that not only represent a significant part of the capital requirement but also indicative of the energy utilization within the facility. More than 50 runs were generated, and summaries of the results are shown in the figures. Emphasis has been laid on energy values and ethane recoveries from demethanizer (with increasing amount of C2+ components in a particular gas stream). For each of the Process Configurations HHP simulation software runs were

Flow	10,980 lbmole/hr.
Plant inlet gas pressure	850 psi
Inlet gas temperature	100°F
Product Specifications	C1/C2 in reboiler liquid (0.02)
Demethanizer	Twelve theoretical trays including the reboiler
De-ethanizer	Sixteen theoretical trays including reboiler and condenser
Depropanizer	Twenty Six theoretical trays including reboiler and condenser
Sales gas outlet pressure	280 psi
Heat exchangers	E100, E-101, E-102, E-103, E-104, E-105
Compressors/Expanders	75%/80% efficiency
Property Fluid Package	Peng Robinson Equation of State

Table 2. Simulation Operating Conditions

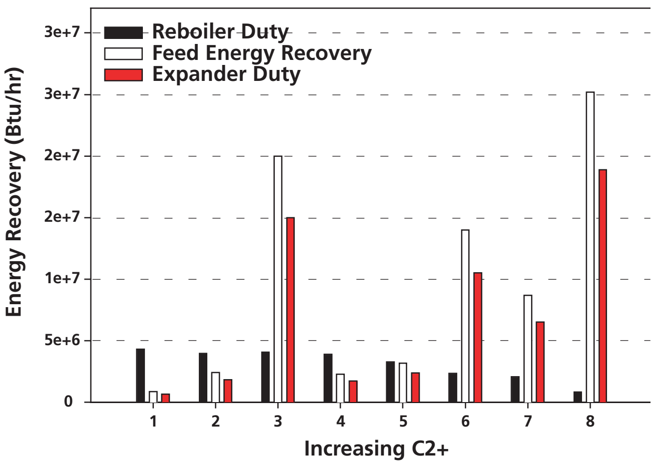

Fig. 2. Energy recovery with increasing C2+ in the feed (Basic Configuration)

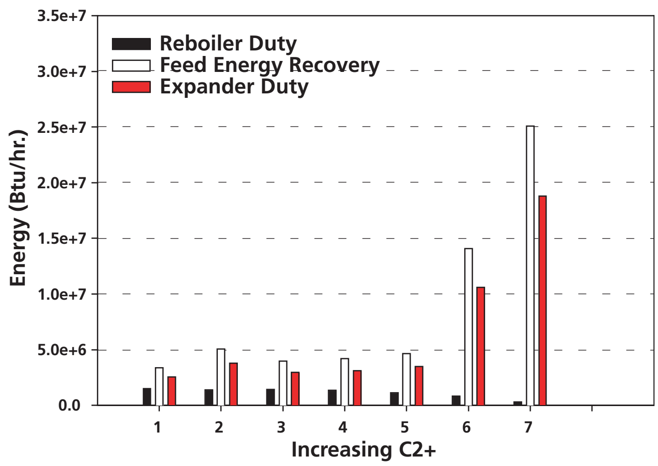

Fig. 5. Energy recovery with increasing C2+ in the feed (GLSP Configuration)

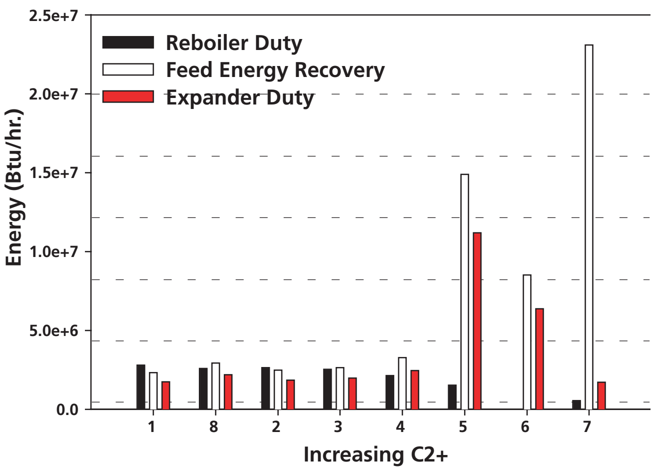

Fig. 3. Energy recovery with increasing C2+ in the feed (GSP Configuration)

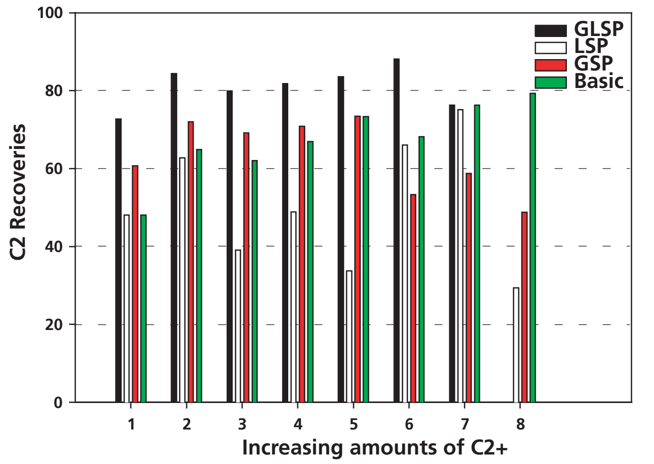

Fig. 6. C2 recovery with increasing C2+ in the feed for different configurations

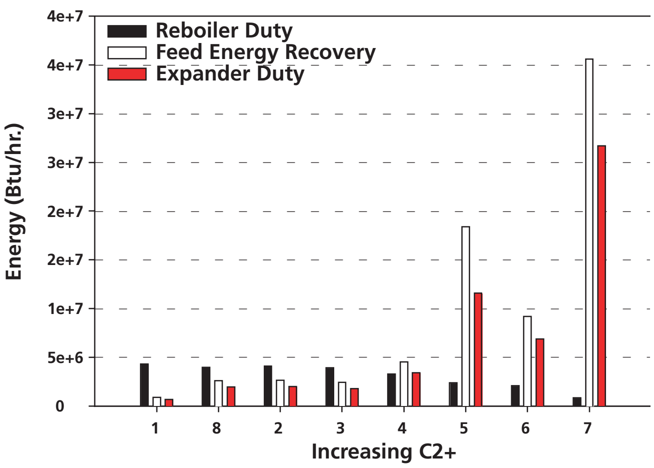

Fig. 4. Energy recovery with increasing C2+ in the feed (LSP Configuration)

carried out for all eight compositions.

Figures 1a and 1b show the basic configurations as described in the introduction. In Fig. 1a, the main energy recovery is from the expander, which is then utilized in the sales gas compression. Figure 1b shows the streams integration made to recover energy from the process gas, which is then utilized in the column. As these parameters change so do the quantities of recoverable NGLs. Figs. 2-5 show the reboiler duties, feed energy recoveries and expander duties respectively numbered as 80, 81 and 70 in the configurations. For the basic configuration, Figs. 1a and 1b, the energies show no clear trend with increase in C2+ in the feed stream. The subcooling of the feed stream; either with gas or liquid is higher for rich natural gas. Among the configuration, LSP, Fig. 4, shows the highest energy recovery.

Figure 6 shows the C2 recoveries for the configurations with increasing amounts of the C2+ in the feed stream. For the basic configuration, recovery as high as 80% was obtained for the feed with the highest amount of C2+. It appears that the higher the C2+ the higher the recovery. This is not the case for GSP where the highest recovery is just about 70%. The highest C2 recovery occurred when the feed had a medium amount of C2+. The LSP shows lower recoveries than the Basic and GSP. GLSP shows the highest average recoveries among all of the configurations when using a combined configuration. Irrespective of the nature of the feed, the GLSP shows the highest C2 recovery as shown in the figure.

CONCLUSION

Simulation of the production of NGLs from natural gas has been performed using HYPROTECH's HYSYS.Process Simulation software. Natural gases of wide range compositions were tested for different turbo-expander process configurations - Basic, Gas Subcooled (GSP), Liquid Subcooled (LSP) and Gas-Liquid Subcooled (GSLP). For all configurations, ethane recoveries of not less than 74% were achieved. GLSP was observed to have the overall average C2 recovery of about 80% independent of the nature of feed composition. GSP exhibited the highest C2 recovery for medium C2+ composition. This study has shown that the question of which cryogenic process configuration to choose depends on the relative amount of heavy component in the feed stream, but in the case of a location with variable feed compositions, GLSP would give the highest average ethane recovery.

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