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A Feasibility Study of the Technologies for Deep Ethane Recovery from the Gases Produced in One of the Iran Southern Fields

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Abstract

Recently, due to the very good market in ethane as a feedstock for petrochemical complexes, there are some plans to make a deep ethane recovery from the gases produced in Iran southern fields. In this work, the feasibility of different technologies for deep ethane recovery from a specified feed gas produced in one of the Iran southern fields is reviewed. Three different processes are selected and simulated for the specified feed gas. These processes are compared from technical and economic viewpoints and the advantages and disadvantages are discussed. The results show that RSV and CRR processes are technically more feasible for high levels of ethane recovery (greater than 95%). The economic evaluations show that the CRR process is the most appropriate one for the feed gas specified in this study.

Keywords: Natural Gas Liquid, Ethane Recovery, GSP, RSV Process, CRR Process

1. Introduction

Natural gas liquid (NGL) is a general term applied to all the liquids recovered from natural gas and refers to ethane and heavier products. The price difference between selling NGL as a liquid and as a fuel, commonly referred to as “shrinkage value,” often dictates the recovery level desired by the gas processors (Lee et al., 1999). Several methods such as lean oil absorption, gas adsorption, cryogenic processes, membrane processes, and supersonic processes have been used for liquid recovery from natural gas.

The methods using membrane and supersonic technologies are modern processes recently introduced as alternatives for liquid recovery in gas processing industry. The advantages of membrane processes include their flexibility, low total investment, and compactness (Lokhandwala, Jacobs, 2000). The supersonic technology is simple and environmentally friendly and does not require many chemicals; additionally, it is not labor-intensive (Machado et al., 2012; Schinkelshoek, Epsom, 2008). However, this technology has not been commercialized for NGL recovery processes yet (Ambari, 2004).

The cryogenic processes are categorized into turbo-expansion, Joule-Thomson (J-T) expansion, cascade refrigeration, and multi-component refrigeration in the gas processing industry. Due to the operating and economic advantages of turbo-expander plants, gas processing industries mainly employ the processes based on turbo-expander plants for ethane recovery at different levels (Lee et al., 1999;

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Chebbi et al., 2004). A comparative study between different processes based on turbo-expanders with a typical natural gas feed is performed by Diaz et al. (Diaz et al., 1996). Based on the de-methanizer column pressure and the gas composition of the inlet feed, Chebbi et al. optimized a conventional turbo-expander process to attain the highest level of process profit (Chebbi et al., 2010). Recently, Tirandazi et al. surveyed processes using refrigeration cycles in ethane recovery plants by performing energy analysis (Tirandaz et al., 2011).

Among the turbo-expander-based methods, the industry standard single stage (ISS), gas sub-cooled process (GSP), cold residue-gas reflux (CRR), and recycle split-vapor process (RSV) are known as common processes in this category. These processes are described in more detail in the following sections.

2. Processes and methods

2.1. A typical NGL recovery plant

Many of the NGL recovery plants built during the last thirty years use industry-standard single-stage (ISS) turbo-expander technology for moderate to high ethane recovery (Hudson, Wilkinson, 1992). ISS plants are usually designed for ethane recoveries of 70-80%. Higher recoveries with this process will usually increase the compression requirements disproportionately due to the nature of the process (Hudson, Wilkinson, 1992).

2.2. High ethane recovery processes

Since late 1970’s, improvements have been made to ISS scheme (Lee et al., 1999). To achieve these improvements, different concepts such as split-vapor feed, lean reflux, flexible reflux, recycle split vapor, etc. have been used. The split-vapor feed concept was first used by Ortloff Corporation in a plant in 1979 and is now recognized as one of the most efficient processes for high ethane recovery (Pitman et al., 1998). This design and its three various improvements described below can provide significant plant operating flexibility. These designs are suitable for both new projects and revamping existing plants. Due to employing a lower compression, these processes usually require less capital investment (Hudson, Wilkinson, 1992). Therefore, these three technologies are selected to be compared in this study.

a. Gas sub-cooled process (GSP)

Gas sub-cooled process (GSP) is one of the methods which uses split-vapor feed concept (Lee et al., 1999). In this process, a small portion of the non-condensed vapor after substantial condensation and sub-cooling is used as a reflux to the top of the tower. The main portion, typically in the range of 65-70%, is subjected to turbo expansion as usual. In spite of less flow being expanded via the expander, this colder reflux permits an improved ethane recovery even at a higher column pressure. Therefore, in comparison to ISS process, inlet separator can operate at a higher temperature, providing a net increase in power recovery from turbo-expander and reducing recompression power requirements. It also reduces the risk of CO_2 freezing in the tower (Lee et al., 1999).

b. Cold residue-gas reflux (CRR)

Use of a leaner top reflux has been attempted for higher recovery levels in the next generation of split-vapor processes. The cold residue gas reflux (CRR) is one of these schemes incorporated into the original GSP design to improve ethane-recovery efficiency (Lee et al., 1999). In this scheme, the sub-cooled split-vapor stream is introduced to the middle part of the rectification section of the tower, while the main reflux comes from the expander discharge. A very high level of ethane recovery (in excess of 99%) is economically achievable with this process; however, the cryogenic compressor can be very expensive (Lee et al., 1999). Another advantage of this process is that it can be operated to almost completely reject ethane, while it maintains propane recovery in excess of 99%. It also has better CO_2 tolerance than the GSP design (Pitman et al., 1998).

c. Recycle split-vapor process (RSV)

In this process, the warm methane reflux stream is used by withdrawing a small portion of the recompressed residue gas. The compression requirements of the recycle residue gas are accomplished by the main residue-gas compressor, thereby eliminating the need for a booster compressor and reducing capital investment in most cases. A single plate-fin exchanger is usually used to cool both the reflux stream and split-vapor feed. In these cases, the incremental investment in GSP design is almost insignificant. A very high level of ethane recovery is attainable with this scheme. Compared to GSP design, it has better CO_2 tolerance for the same ethane recovery (Pitman et al., 1998).

3. Results and discussion

3.1. Comparison of different processes

GSP, CRR, and RSV processes are used for the comparison purposes. The composition and specifications of the feed gas which is a gas produced from one of the Iran southern fields are shown in Tables 1 and 2 respectively. Variable and fixed parameters used in the simulations are shown in Table 3.

All the simulations are carried out using Aspen Hysys package V. 7.3. The Peng-Robinson equation of state (EOS) property package is used to calculate the thermodynamic properties required. The pre-treatment processes including sweetening and dehydration are designed and simulated first. The required information on all the process simulations is gathered from patents and references in the open literature (Campbell, Wilkinson, 1979; Campbell et al., 1996a; Campbell et al., 1996b).

Table 1
Inlet gas composition

Component	Mole Percent	Component	Mole Percent	Component	Mole Percent
CH_4	78.72	i-C_5H_{12}	0.73	N_2	0.06
C_2H_6	4.56	n-C_5H_{12}	0.5	CO_2	4.23
C_3H_8	2.07	n-C_6H_{14}	0.72	H_2S	0.79
i-C_4H_{10}	0.46	C_7^+	5.56	H_2O	0.49
n-C_4H_{10}	0.93				

Table 2
Inlet gas main characteristics

Characteristics	Value
Inlet gas pressure (MPa)	10.498
Inlet gas temperature (K)	327
Inlet gas flow rate (MMstdm^3/d)	5.66
C_7^+ MW	172
C_7^+ specific gravity	0.8044

Table 3
Fixed parameters used in all the process designs

Parameter	Value
Outlet gas pressure (MPa)	10.40596
Product C_1/C_2 ratio (molar)	0.025
Expander adiabatic efficiency	85%
Residue gas compressor polytropic efficiency	75%
Booster compressor polytropic efficiency	75%
Cryogenic gas compressor polytropic efficiency	75%
Pump adiabatic efficiency	75%
Exchanger minimum temperature approach (K)	5.55
Exchanger and air cooler pressure drop (kPa)	34.5
Ambient temperature (K)	328

3.2. Comparison criteria

Total required compression, process efficiency, process minimum temperature, and CO_2 freezing temperature margin are used as comparison criteria for the selected processes. These parameters are proposed by Pennybaker et al. for comparing the different ethane recovery processes (Pennybaker et al., 2000). The CO_2 freezing temperature margin is considered as risk-assessment effective parameter in the simulation of GSP process (Esmaeili, Ghabouli, 2011).

For economic evaluations, the effects of total capital investment, total product cost, and the rate of return on investment are studied. Some important characteristics such as process flexibility, attainable ethane recovery level, and the effects of low temperature on material selection should also be taken into consideration during comparison (Lynch et al., 2007).

3.3. Technical evaluations

De-methanizer tower as an important piece of equipment in the processes selected in this study (CRR, RSV, and GSP) is simulated. The specifications of this tower for different processes are shown in Table 4. The tray efficiencies are taken from Mokhatab (Mokhatab et al., 2012).

Table 4
The specification parameters and heat duty in de-methanizer tower

Process	Operational Parameters			Tray Specifications				Column Duty (kJ/hr)	
	P (kPa)	**T_{min} (K)**	**D (m)**	**No**	**Type**	**Efficiency**	**Space (m)**	**Reboiler**	**Condenser**
GSP	1999	172.05	1.5	30	Sieve	0.525	0.5	1.18×10^7	0
CRR	1931	164.6	1.5	30	Sieve	0.525	0.5	7.25×10^6	0
RSV	2103	171.3	1.5	30	Sieve	0.525	0.5	9.55×10^6	0

The temperature profiles of the de-methanizer tower obtained from the simulation of all the processes are shown in Figure 1. A reduction in temperature is occurred in the middle of the tower, especially for CRR and RSV processes, which is attributed to the addition of the recycled cooler streams to the tower.

Figures 2 and 3 show the distribution of the mole fractions of liquid ethane and liquid methane in the de-methanizer column respectively. The ethane mole fraction decreases from the bottom to the top of the tower, which means that ethane and heavier components are removed from the feed stream.

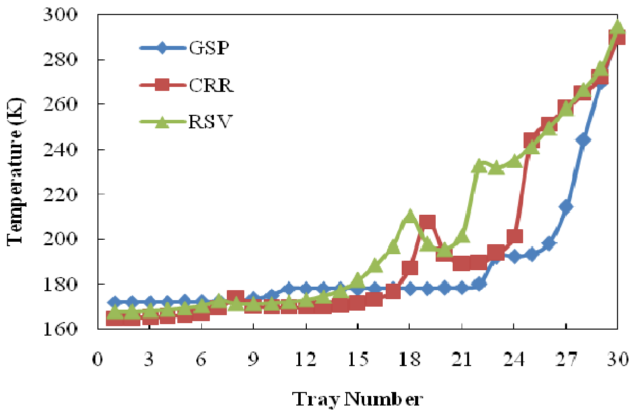

Figure 1
Temperature profile of the de-methanizer tower

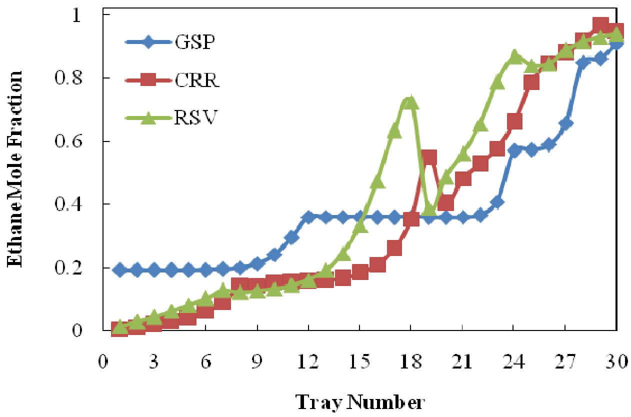

Figure 2
Ethane mole fraction in the de-methanizer tower

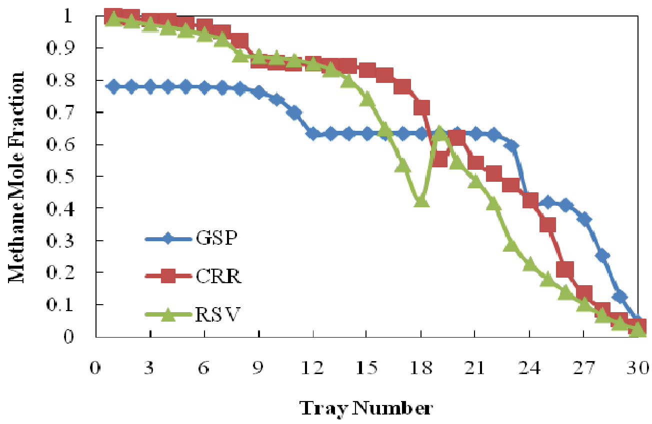

Figure 3
Methane mole fraction in the de-methanizer tower

One of the important parameters in ethane recovery processes is the molar ratio of C_1 to C_2 (C_1/C_2). The specified and obtained (in the simulations) values of this parameter for each process are shown in Table 5. As it is shown, all of the simulations have accurately converged and the CRR process results in the highest level of ethane recovery.

Table 5

The specified and obtained values for C_2+ stream in de-methanizer tower

Process	**C_1/C_2 (molar)**		**C_1 mole fraction at the bottom**		**Ethane Recovery**
	Specified Values	Obtained Values	Specified Values	Obtained Values	
GSP	0.025	0.025	0.010	0.012	92%
CRR	0.025	0.020	0.010	0.010	99%
RSV	0.025	0.020	0.010	0.010	98%

The results for the sensitivity analysis of the minimum temperature, CO_2 freezing temperature margin, and de-methanizer column pressure are shown in Figures 4, 5, and 6 respectively. In these figures, the vertical axes are the variation of ethane recovery level, which is represented by %ΔRF. These figures show that all of the three parameters used in this study, namely T_{min}, ΔT_{CO2}, and de-methanizer pressure, are of significant importance.

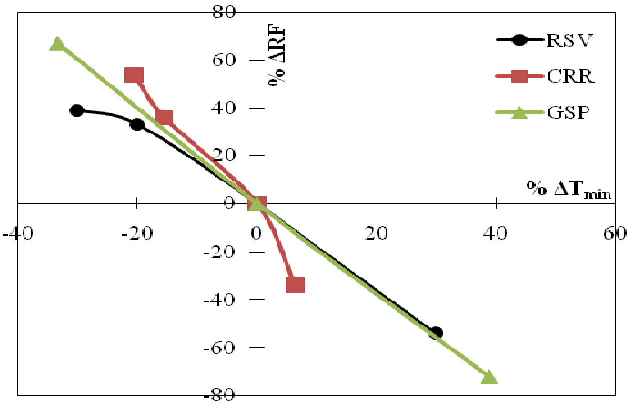

Figure 4
Sensitivity analysis of the process minimum temperature

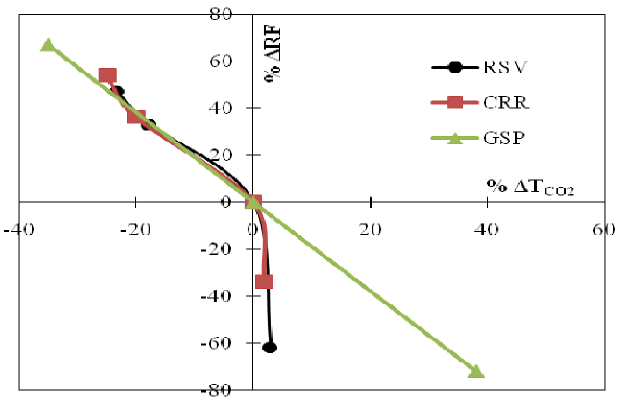

Figure 5
Sensitivity analysis of CO_2 freezing temperature margin

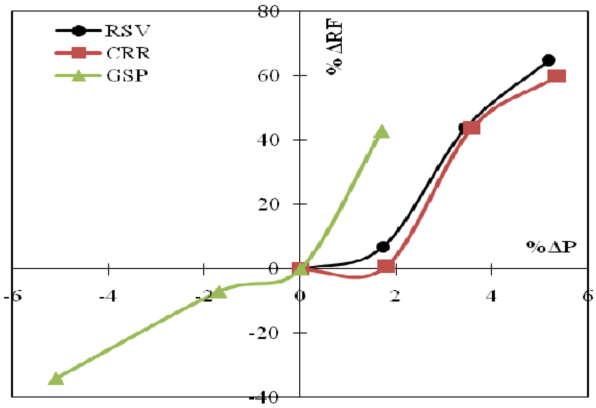

Figure 6
Sensitivity analysis of de-methanizer column pressure

Figure 7 illustrates the effects of the total compression horsepower required on ethane recovery level. In general, by increasing the amount of external power supplied to the gas, the ethane recovery level increases (Lynch et al., 2007). As this figure depicts, CRR and RSV processes show an asymptotic approach and are more efficient than the standard GSP process at higher levels of ethane recovery. It can also be seen that increasing horsepower does not affect ethane recovery at very high ethane recovery levels.

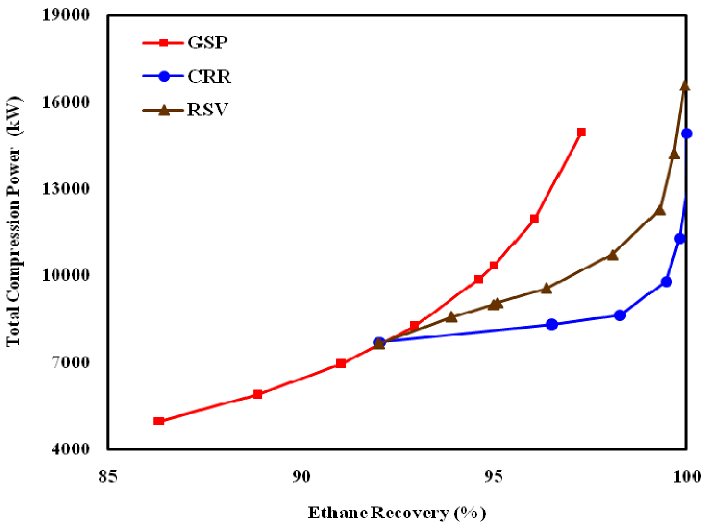

Figure 7
Effect of total compression power on ethane recovery level

Herein, a term is defined as *process efficiency* (PE) which is a measure of the process energy. It is given by:

$$PE = \text{Product Rate} \Big/ (\text{Compression Energy} + \text{Pump Energy}) \tag{1}$$

This term is calculated for each process and its effect on ethane recovery level is compared in Figure 8. This figure shows that the process efficiency of all the processes declines as recovery level rises. Regardless of recovery level, CRR is the most efficient process under these conditions.

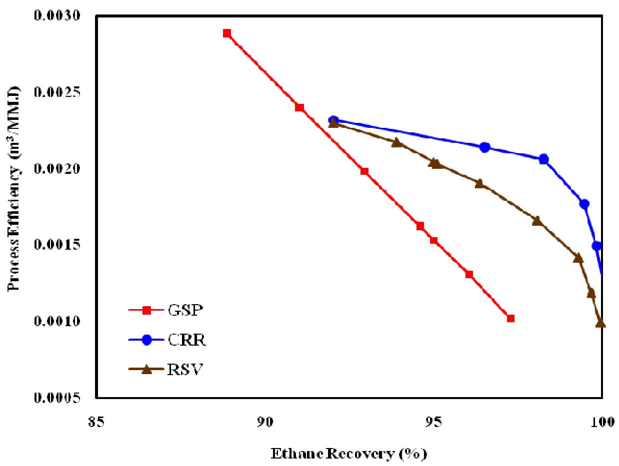

Figure 8
Effect of process efficiency on ethane recovery level

Another important parameter in the ethane recovery process is the minimum temperature required in the process. To attain lower temperatures, more energy is required. The effect of this parameter on the performance of the selected processes is shown in Figure 9. According to this figure, higher recovery levels require lower temperatures. It is shown that RSV and CRR processes have almost the same performance and GSP process requires the lowest temperature. In expander-based processes, the minimum temperature of the process determines material selection.

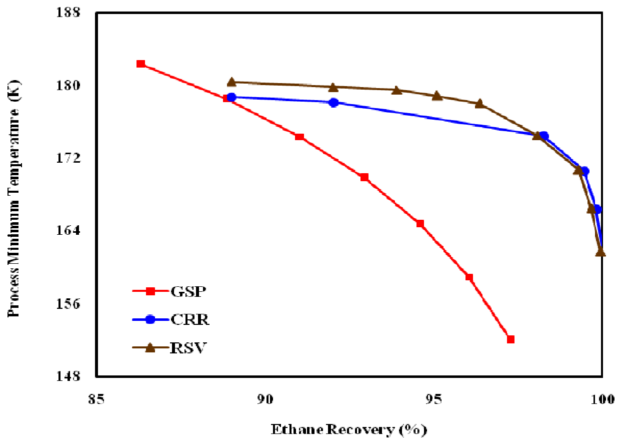

Figure 9
Effect of process minimum temperature on ethane recovery level

Most ethane recovery processes work at very low temperatures. At these low temperatures, there is the risk of CO_2 freezing. One of the parameters used herein to compare the processes is CO_2 freezing temperature margin. This parameter is defined as follows:

$$\Delta T_{CO_2} = T_{\min} - T_{CO_2,\ Freezing} \tag{2}$$

The effect of this parameter on the performance of the three selected processes is shown in Figure 10. According to the results, RSV process has more flexibility for CO_2 freezing than the others. The temperature is usually minimized at the expander outlet or de-methanizer overhead in these processes, and these two points are thus the most dangerous points for CO_2 freezing (Peters, Timmerhaus, 1991).

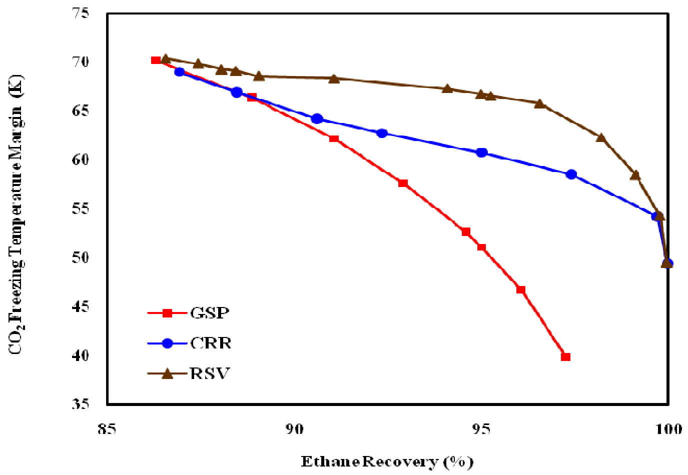

Figure 10
Effect of CO_2 freezing temperature margin on ethane recovery level

3.4. Economic evaluations

Equipment sizes are needed to calculate the initial required investments. All of the equipments are sized using Aspen Hysys software for all of the processes selected in this study. Total capital investment, total product cost, and the rate of return on investment are three parameters used for the economic evaluations. Total capital investment is the sum of the fixed and working capital investments required (Peters, Timmerhaus, 1991). The fixed capital investment is related to direct and indirect costs and the working capital costs are considered to be 15% of total capital investment. The components of direct and indirect costs are listed in Table 6. The costs of all the purchased equipment required for the economic evaluations are calculated based on the 2012 cost indexes using the correlations and methods described elsewhere (Peters, Timmerhaus, 1991; Douglas, 1998). The total product cost is considered to be the sum of manufacturing costs and general expenses (Peters, Timmerhaus, 1991). The elements used for manufacturing costs and general expenses along with their values are given in Table 7. The annual percentage return on total investment is calculated as the ratio of the annual profit to the total capital investment. The annual rate is obtained using the difference between the annual income and the annual expenses (Peters, Timmerhaus, 1991).

Table 6
The components of direct and indirect costs (Pennybaker et al., 2000)

Cost	Used Values
Direct Costs (DC)	
Purchased equipment cost (PEC)	Taken from [19].
Installation	25% of PEC
Instrumentation and controls	6% of PEC
Piping	10% of PEC
Electrical	10% of PEC
Service facilities	40% of PEC
Land	4% of PEC
Indirect Costs	
Engineering and supervision	5% of DC
Construction	6% of DC

The effects of total capital investment, total product cost, and the rate of return on investment are calculated and shown in Figures 11 to 13 respectively. The results show that CRR and RSV processes perform better than GSP; however, CRR is the most economically feasible process.

Table 7

The elements of total product cost (Pennybaker et al., 2000)

Cost	Used values
Manufacturing cost (MC)	
Raw materials	10% of total product cost
Operating labor (OL)	10% of total product cost
Direct supervisory (S)	10% of OL
Utilities	10% of total product cost
Maintenance and repairs (M)	5% of fixed-capital investment
Operating supplies	1% of fixed-capital investment
Laboratory charges	10% of OL
Depreciation	10% of fixed-capital investment
Local taxes	1% of fixed-capital investment
Insurance	1% of fixed-capital investment
Plant-overhead costs	70% of cost for OL, S and M
General expenses	
Administrative costs	15% of cost for OL, S and M
Distribution and selling costs	2% of total product cost
Research and development costs	5% of total product cost

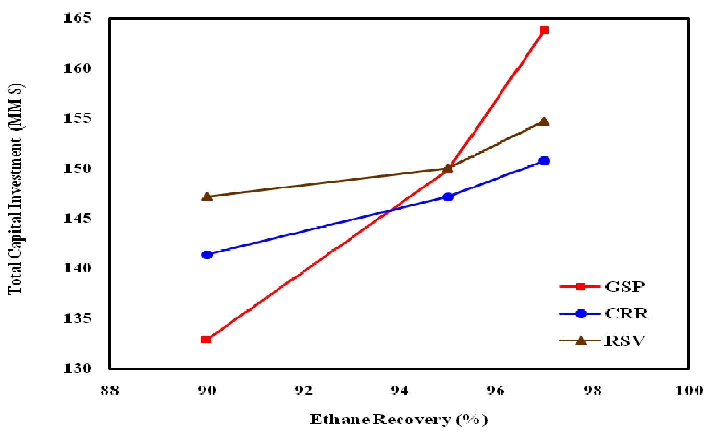

Figure 11

Effect of total capital investment on ethane recovery level

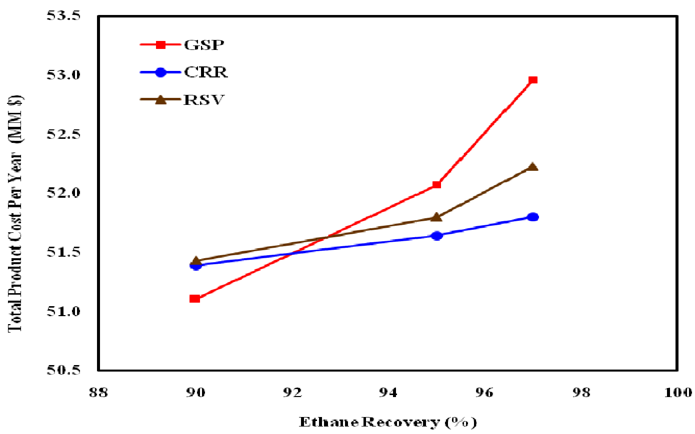

Figure 12
Effect of total product cost on ethane recovery level

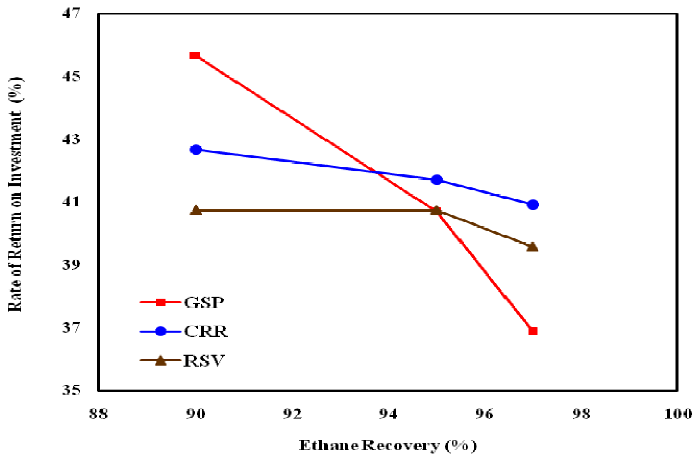

Figure 13
Effect of the rate of return on investment on ethane recovery level

4. Conclusions

The feasibility of NGL recovery from the gases produced in one of the Iran southern fields is studied by three different processes, namely GSP, RSV, and CRR. These processes are compared from technical and economic points of view for the specified feed gas. Moreover, several parameters are defined and employed for this comparison. The results show that RSV and CRR processes are technically more feasible for ethane recovery levels higher than 95%. Finally, economic evaluations show that CRR process is the best one for the feed gas specified in this study.

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