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Simulation and Optimization Analysis of Natural Gas Liquid (NLG) Recovery Process from Natural Gas

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Abstract

Recently due to the growing demand of natural gas liquids (NGL), there are many processes are existing to make a deep NGL recovery from natural gas. The present study describes the simulation and optimization analyses of NGL recovery for two different processes. The simulation is employed to assess and compare an existing NGL recovery unit at Port Said (EGYPT) in United Gas Derivatives Company (UGDC) which was designed as Improved Overhead Recycle Process (IOR) with anther recovery technology known as the Single Column Overhead Recycle Process (SCORE). The simulation results show that IOR process is more flexible than that SCORE process in the case of changing natural gas feed composition from very rich to very lean gas. Since IOR process can accommodate change in feed gas composition from lean gas range (0.91806 – 0.9620) to rich gas range (0.91806 – 0.85511) based on methane mole fraction. At normal operating condition the fixed capital investment and operating cost for SCORE process is less by $ 25.67E+06 / year than that of IOR process. Also the total production profit for SCORE is more by $ 10.787E+06 / year than total production profit for IOR process. So SCORE process is the technology of choice for plants where high propane recovery and maximum efficiency are of great importance.

Keywords

Natural Gas Processing, NGL Recovery Process, Propane Recovery Processes, SCORE Process, IOR Process, Energy Saving.

Introduction

In today's oil and gas industry, companies are demanding more in terms of operational flexibility, plant automation, reduced project cycle and optimization. Natural gas is valuable both as a clean source of energy and as a chemical feedstock. Before reaching the customer, it has to pass several processing steps. These steps are partly necessary to be able to transport the gas over long distances and partly necessary for the recovery of valuable components contained in the gas. (1,2). Recently in business climate, the successful gas processors will be those who can tailor the performance of their NGL / LPG recovery plant to maximize product margins as market conditions change, while still maintaining efficient operation. The gas plant in bottle NGL / LPG recovery processes described are the next generation of processes for reducing capital costs and operating costs while still maintaining maximum process flexibility, efficiency and product recovery(3). Besides other approaches, Process Simulation using HYSYS Software is also being employed as a technology enabled solution to meet these challenges(4). Performing engineering studies with simulation is becoming a critical requirement for new liquefied natural gas (LNG) plants (6). Engineering studies with simulation can identify design changes that will significantly improve plant performance and the safety and reliability of plant operations. Furthermore, if such design changes are identified early, they can be implemented at a low cost and provide significant savings during a plant's lifetime (7, 8).

Objective of Study

The objective of this study is to assess and investigate both the existing NGL recovery unit IOR and SCORE and compare between them includes the following performance items:

1. The flexibility of each process for handling different natural gas compositions.
2. Differentiate between total power consumption of the two units for each case under investigation.
3. Estimate the cost of both process repressed by fixed and operating costs.

4. Assess the economic potential of SCORE over the existing IOR unit.

Plan Modeling and Optimization Analyses for IOR and SCORE

The case study will be the NGL recovery unit at Egypt in United Gas Derivatives Company (UGDC) which was operated as Improved Overhead Recycle process (IOR).

United Gas Derivatives Company was established to receive the gas produced from North Port Said, Ras El Bar and Temsah concessions through the gas treatment plants of El Gamil and Ha'py in order to extract the NGL and produce propane, LPG and Condensates as per overall process flow scheme, figure.1.Originally, The liquid propane is stored in the refrigerated tank at Damietta to be exported to the international market through marine vessels. While the LPG and the condensate are pumped to the relevant pipeline network owned by Egyptian General Petroleum Corporation (EGPC) for local consumption.

Currently, the liquid propane is transferred to the Egyptian Propylene & Polypropylene Company (EPPC) for petrochemical industry to maximize foreign currencies returns and added value. EPP is producing Propylene and the UGDC existing Damietta facilities are modified to be utilized to import Propane "The project is under commissioning" in addition to export the excess commercial propane to international market.

NGL recovery unit in UGDC plant (Ortloff's IOR process) is a two column design, incorporating an Absorber (C-02) and a Demethanizer (C-01). The Demethanizer overhead vapor is cooled and partially condensed, with the resulting liquids providing reflux for both columns. The cooling necessary to partially condense the Demethanizer overhead vapour is provided by Absorber overhead vapours. The two columns typically operate at about the same pressure, with pumps providing the energy required for the liquids to transfer between the columns as per figure 2.

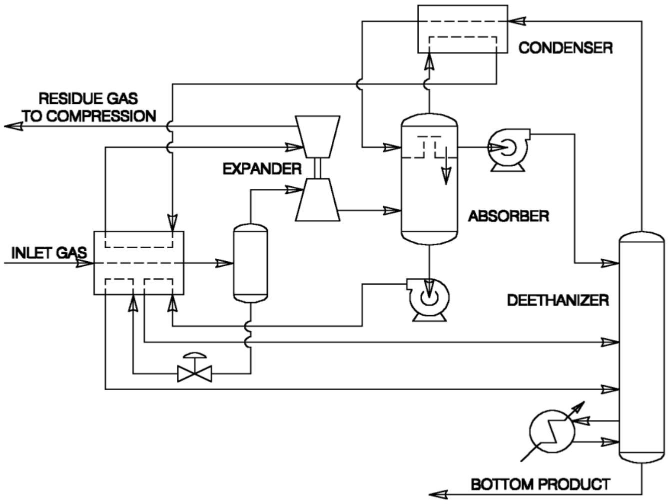

Figure 2 Improved Overhead Recycle process (IOR)

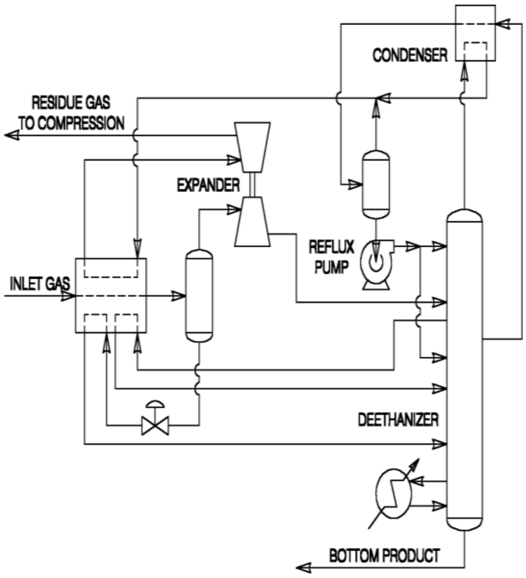

Figure 1 Single Colum Overhead Recycle Process (SCORE)

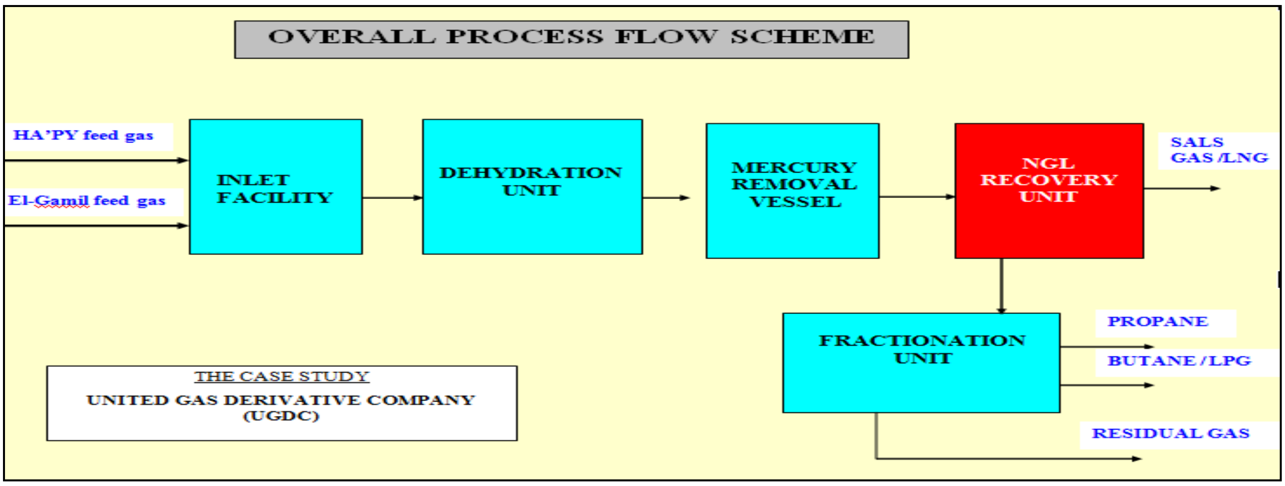

Figure 1 UGDC Overall Process Flow Scheme.

In this study, Modification was done to the UGDC unit which is IOR technology to be designed as per the new technology Single Colum Overhead Recycle Process (SCORE).

Ortloff's Single Column Overhead Recycle (SCORE) process was developed in the late 1990's and first utilized in 2000. A number of plants are now in operation, with others being designed and constructed around the world. SCORE is a cryogenic gas processing technology suited to the recovery of propane and heavier hydrocarbons from a natural gas stream (9, 10).

Although the IOR process have traditionally been employed as two-column system, the two columns in either process can be visualized conceptually as a single composite column with an intermediate vapor side draw. This composite column concept led to the development of the Single Colum Overhead Recycle Process (SCORE) as per figure 3.

The single, larger column and small reflux drum are used in the SCORE process rather than the two columns used in the IOR process. Reflux for the column is generated by condensing vapor side draw stream. A liquid side draw is utilized for process cooling to optimize heat integration.

Simulation of NGL / LPG recovery processes was done to compare between Improved Overhead Recycle Process (IOR) and Single Colum Overhead Recycle Process (SCORE) in:

1) Flexibility of IOR and SCORE Process. (Natural gas feed composition change from lean to rich).
2) Optimization of IOR and SCORE Process. (Fixed and operating cost in addition to total profit of products).

The commercially available software HYSYS was used to model the plant. The first step required when modeling complex processes using HYSYS is the definition of important species which appear in the real processes and, thus, that should be considered in the simulation and the study (11).

The flow diagram of the IOR Process (existing unit) and SCORE Process (modified unit) is shown in the Figure 4 and Figure 5. UGDC Normal Operating Conditions and natural gas feed composition as per Table 1.

Flexibility of IOR and SCORE Process

Changing the composition of the natural gas feed stream

The feed stream to the NGL / LPG recovery process is natural gas coming sometimes from different wells. Always there is a change in this feed gas composition due to different wells gas composition. The NGL / LPG recovery process should be flexible enough to accommodate with this changes in its feed stream composition.

To compare the flexibility of the two processes IOR and SCORE; the composition of the feed stream from natural gas well has been changed to know to which extend the process will be flexible and to know the optimum operating conditions.

Natural gas can be classified to lean and rich gas as per table 2 according to the content of the recoverable liquids in the gas. The amount of potential recoverable liquid is expressed as gallons liquid at 60 degree Fahrenheit, if totally condensed, per 1000 standard cubic feet of the gas (so called GPM, not to confuse with gallon per minute).

A gas termed lean and rich based on ethane and heavier hydrocarbons (C2+) as follows in table 2:

Table 2 Types of natural gas

Types of Natural Gas	Heavier hydrocarbons(C2+)
Lean gas	< 2.5 GPM
Moderately –Rich	2.5-5 GPM
Very Rich	> 5GOM

To determine this extend of flexibility for IOR and SCORE process, the well natural gas feed composition to the process will be changed to ten different feed compositions:

By changing the concentration of methane (C1), the heavier hydrocarbons (C2+) concentration will be changed by normalize the concentration of the pure components.

The concentration of methane in UGDC Natural Gas Feed Composition is 0.91806 (mole fraction) as per table 3

The concentration of methane in natural gas feed composition can be increased (Lean gas) or decreased (Rich gas).

In the case of Lean gas : the concentration of methane will be changed from 0.91806 to 0.9494 which is the extend that the two towers in the case of IOR process cannot handle more the separation within the products specification and the number of feed of that change will be 10 different compositions.

In the case of Rich gas : the concentration of methane will be changed from 0.91806 to 0.8159 which is the extend that the two towers in the case of IOR process cannot handle more the separation within the products specification and the number of feed of that change will be 11 different compositions.

Table 3 UGDC Natural Gas Feed Composition (Original Composition)

UGDC Natural Gas Feed Composition	
Nitrogen	1.06E-03
CO2	7.24E-03
Methane	0.91806
Ethane	4.53E-02
Propane	1.75E-02
i-Butane	3.91E-03
n-Butane	3.59E-03
i-Pentane	1.36E-03
n-Pentane	7.50E-04

Table 1 UGDC Normal Operating Conditions.

Natural Gas Feed			
Stream Specification		Stream Composition	
Phase Fraction	Vapor	Nitrogen	1.06E-03
Temperature [C]	38	CO2	7.24E-03
Pressure [bar_g]	68.5	Methane	0.918061313
Molar Flow [MMSCFD]	210	Ethane	4.53E-02
Mass Flow [tone/d]	4314.197915	Propane	1.75E-02
Std Ideal LiqVol. Flow [barrel/day]	87342.10094	i-Butane	3.91E-03
Molar Enthalpy [kcal/kgmole]	-18490.38306	n-Butane	3.59E-03
Molar Entropy [kcal/kgmol-K]	35.67336397	i-Pentane	1.36E-03
Heat Flow [kW]	-224773.4438	n-Pentane	7.50E-04
Molar Density [kgmole/m3]	3.090132	C6+*	1.18E-03

Result and Discussion

As previously mentioned the simulation of the existing plant for NGL recovery in Port Said (IOR) and (SCORE) was conducted using HYSYS simulation software version 8.4 and applying Peng-Robinson equation of state.

The results of both cases are shown as following;

Flexibility of IOR and SCORE Process

Changing the composition of the feed stream of IOR and SCORE process from lean gas (increase C1 concentration) to rich gas (decrease C1 concentration)to determine the extent of flexibility of each process. In another word, flexibility of

IOR process which contain two columns. Flexibility means to which extent the two columns can handle the required separation with specific product quality during changing feed composition.

Similar for SCORE in which extent can single columns handle the required separation with specific product quality during changing feed composition.

Changing lean feed composition for the IOR and SCORE process

The natural gas feed composition to both IOR and SCORE has been changed of methane mole fraction from 0.9186 mole to 0.9620 illustrated in table 4 A/B.

The analyses of simulation results shows that for the performance of IOR process can accommodate up to 0.9620 mole fraction of methane whoever for SCORE process and lean gas streams the maximum extend of increasing methane mole fraction is 0.9356 in feed stream.

Changing rich feed composition for the IOR and SCORE process

The natural gas feed stream has been changed for both process IOR and SCORE from 0.91806 mole to 0.7840 mole fraction of methane shown in table 5 A/B.

The analyses of changing feed composition shows that for IOR process, the minimum extend of methane concentration is down to 0.784 whoever for single column can (SCORE) process is down to 0.8511 methane mole fraction.

Power cost estimation for feed streams to IOR and SCORE process

Since the power cost represent about 80% of the process cost .so the power of the sales gas compressors for both techniques compressors are estimated at different feed composition. the sales gas compressors are the compressors used to raise the sales gas pressure to that extend required for transferring it to through the gas pipelines to the consumers both houses or industrial plants.

The results show for both techniques IOR and SCORE, the power of compressors increase linear with increasing the methane mole fraction as shown in figure 6.

Similar results were obtained as gas feed composition change from lean to rich as shown in figure 7.

Total power consumption for improved overhead recycle (IOR) is higher than the single overhead cycle (SCORE). Also the total power consumption for lean feed streams slightly higher than that of rich streams for both processes as shown in figure 8. and figure 9.

Products production for IOR and SCORE process

The simulation of feed composition of UGDC (table 1) at normal operating conditions as used for both processes. The comparison between IOR and SCORE processes cost estimation will be focused on the fixed and operating costs, production of each of sales gas, propane, liquefied petroleum gas (LPG) and natural gasoline or condensate .The results of both processes are tabulated in table (6) and (7). The simulation results shows that an increase in the amount of propane for SCORE than the IOR by 256.2 tons /day. Whoever LPG increases for IOR by about 236.2 tons /day.

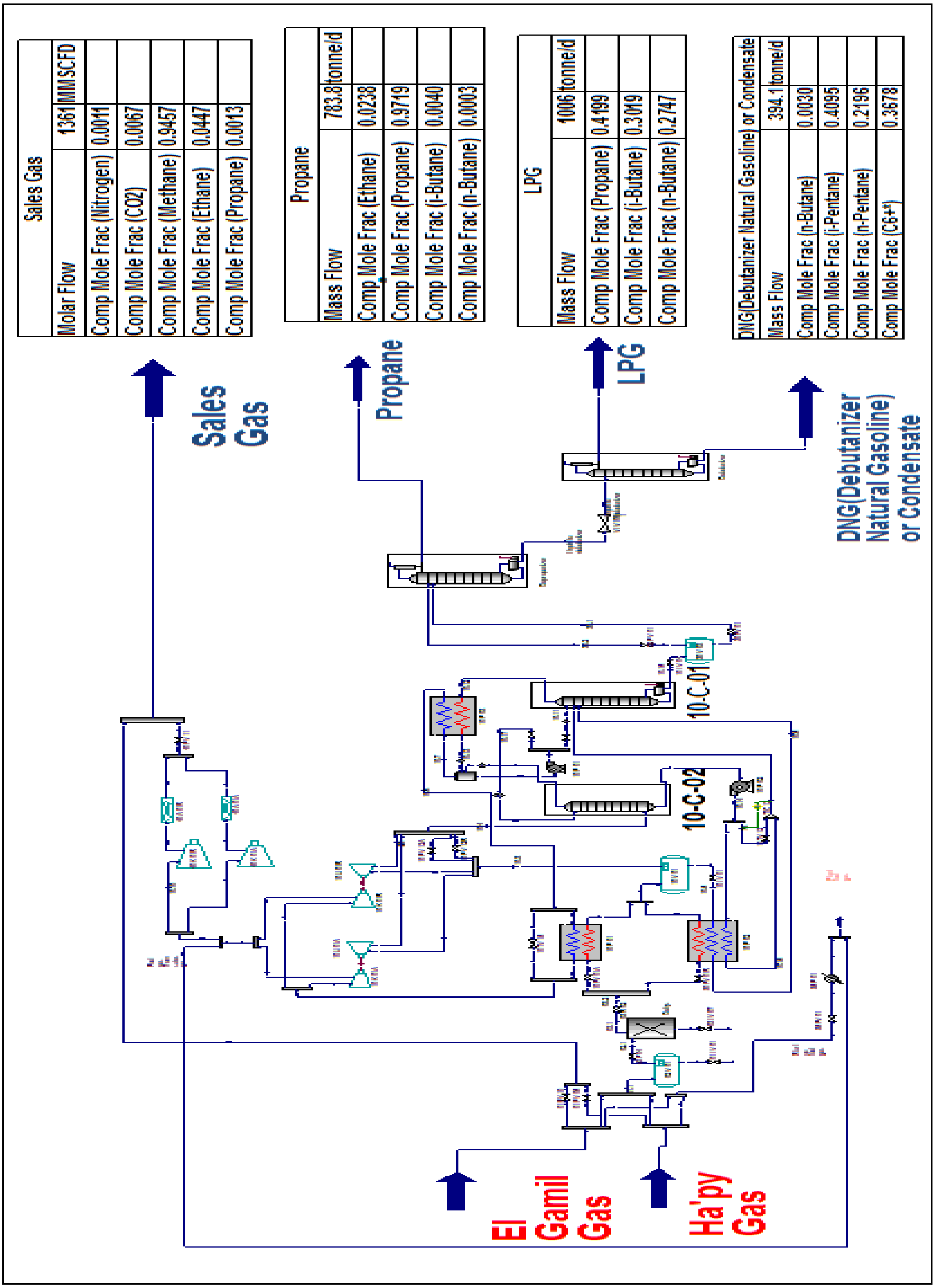

Figure 2 Improved Overhead Recycle Process (IOR)

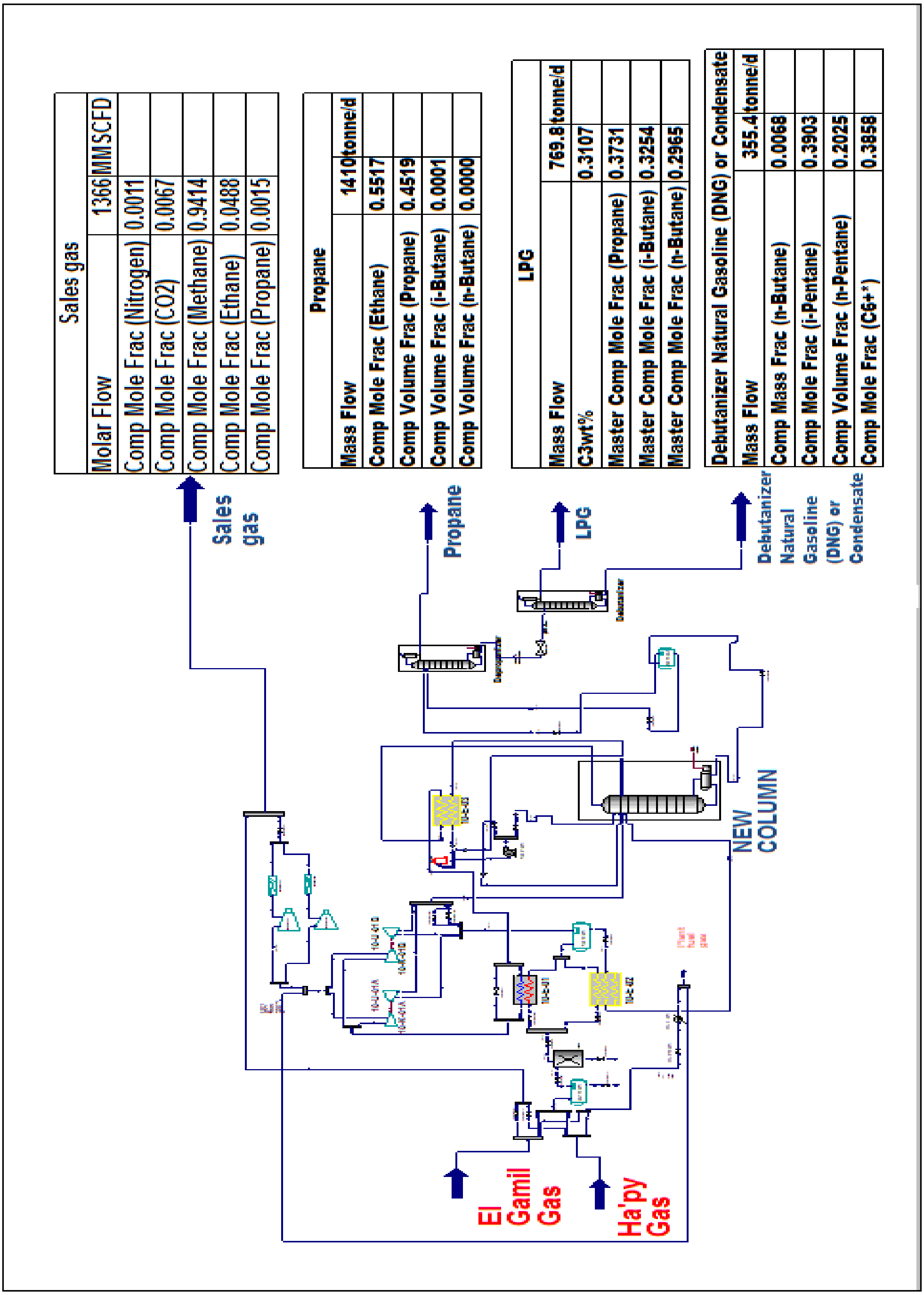

Figure 3 Single Colum Overhead Recycle Process (SCORE)

Table 4A Composition of the Lean Natural Gas Feed (IOR)

Feed	1	2	3	4	5	6	7	8	9	10
Nitrogen	1.06E-03	1.03E-03	9.87E-04	9.63E-04	9.06E-04	8.46E-04	7.94E-04	7.48E-04	6.13E-04	4.91E-04
CO2	7.24E-03	7.01E-03	6.74E-03	6.58E-03	6.19E-03	5.78E-03	5.43E-03	5.11E-03	4.18E-03	3.35E-03
Methane	0.918061	0.920646	0.92369	0.925566	0.929993	0.934573	0.938591	0.942144	0.952644	0.962035
Ethane	4.53E-02	4.39E-02	4.22E-02	4.12E-02	3.87E-02	3.62E-02	3.40E-02	3.20E-02	2.62E-02	2.10E-02
Propane	1.75E-02	1.70E-02	1.63E-02	1.59E-02	1.50E-02	1.40E-02	1.31E-02	1.24E-02	1.01E-02	8.13E-03
i-Butane	3.91E-03	3.79E-03	3.64E-03	3.55E-03	3.34E-03	3.12E-03	2.93E-03	2.76E-03	2.26E-03	1.81E-03
n-Butane	3.59E-03	3.48E-03	3.34E-03	3.26E-03	3.07E-03	2.87E-03	2.69E-03	2.53E-03	2.07E-03	1.66E-03
i-Pentane	1.36E-03	1.32E-03	1.27E-03	1.24E-03	1.16E-03	1.09E-03	1.02E-03	9.60E-04	7.86E-04	6.30E-04
n-Pentane	7.50E-04	7.26E-04	6.99E-04	6.81E-04	6.41E-04	5.99E-04	5.62E-04	5.30E-04	4.33E-04	3.48E-04
C6+*	1.18E-03	1.14E-03	1.10E-03	1.07E-03	1.01E-03	9.42E-04	8.84E-04	8.33E-04	6.82E-04	5.47E-04

Table 4B Composition of the Lean Natural Gas Feed (SCORE)

Feed	1	2	3	4	5	6	7	8	9	10
Nitrogen	0.00106	0.001027	0.000987	0.000963	0.000906	0.000846	0.000794			
CO2	0.00724	0.007012	0.006743	0.006577	0.006186	0.005781	0.005426			
Methane	0.918061	0.920646	0.92369	0.925566	0.929993	0.934573	**0.938591**			
Ethane	0.045312	0.043882	0.0422	0.041162	0.038714	0.036181	0.033959			
Propane	0.017536	0.016983	0.016331	0.01593	0.014982	0.014002	0.013142			
i-Butane	0.00391	0.003787	0.003642	0.003552	0.003341	0.003122	0.00293			
n-Butane	0.00359	0.003477	0.003344	0.003261	0.003067	0.002867	0.002691			
i-Pentane	0.00136	0.001317	0.001267	0.001235	0.001162	0.001086	0.001019			
n-Pentane	0.00075	0.000726	0.000699	0.000681	0.000641	0.000599	0.000562			
C6+*	0.00118	0.001143	0.001099	0.001072	0.001008	0.000942	0.000884			

Table 4A Composition of the Rich Natural Gas Feed (IOR)

Feed	1	2	3	4	5	6	7	8	9	10
Nitrogen	1.06E-03	1.09E-03	1.28E-03	1.36E-03	1.60E-03	1.93E-03	2.30E-03	2.38E-03	2.58E-03	2.80E-03
CO2	7.24E-03	7.45E-03	8.73E-03	9.26E-03	1.10E-02	1.32E-02	1.57E-02	1.63E-02	1.76E-02	1.91E-02
Methane	0.918061	0.915696	0.901232	0.895211	0.875958	0.851123	0.822007	0.815946	0.800819	7.84E-01
Ethane	4.53E-02	4.66E-02	5.46E-02	5.79E-02	6.86E-02	8.23E-02	9.84E-02	1.02E-01	1.10E-01	1.20E-01
Propane	1.75E-02	1.80E-02	2.11E-02	2.24E-02	2.65E-02	3.19E-02	3.81E-02	3.94E-02	4.26E-02	4.63E-02
i-Butane	3.91E-03	4.02E-03	4.71E-03	5.00E-03	5.92E-03	7.10E-03	8.49E-03	8.78E-03	9.51E-03	1.03E-02
n-Butane	3.59E-03	3.69E-03	4.33E-03	4.59E-03	5.43E-03	6.52E-03	7.80E-03	8.06E-03	8.73E-03	9.48E-03
i-Pentane	1.36E-03	1.40E-03	1.64E-03	1.74E-03	2.06E-03	2.47E-03	2.95E-03	3.06E-03	3.31E-03	3.59E-03
n-Pentane	7.50E-04	7.72E-04	9.04E-04	9.59E-04	1.14E-03	1.36E-03	1.63E-03	1.68E-03	1.82E-03	1.98E-03
C6+*	1.18E-03	1.21E-03	1.42E-03	1.51E-03	1.79E-03	2.14E-03	2.56E-03	2.65E-03	2.87E-03	3.12E-03

Table 4B Composition of the Rich Natural Gas Feed (SCORE)

Feed	1	2	3	4	5	6	7	8	9	10
Nitrogen	1.06E-03	1.09E-03	1.28E-03	1.36E-03	1.60E-03	1.93E-03				
CO2	7.24E-03	7.45E-03	8.73E-03	9.26E-03	1.10E-02	1.32E-02				
Methane	0.918061	0.915762	0.901232	0.895211	0.875958	0.851123				
Ethane	4.53E-02	4.66E-02	5.46E-02	5.79E-02	6.86E-02	8.23E-02				
Propane	1.75E-02	1.80E-02	2.11E-02	2.24E-02	2.65E-02	3.19E-02				
i-Butane	3.91E-03	4.02E-03	4.71E-03	5.00E-03	5.92E-03	7.10E-03				
n-Butane	3.59E-03	3.69E-03	4.33E-03	4.59E-03	5.43E-03	6.52E-03				
i-Pentane	1.36E-03	1.40E-03	1.64E-03	1.74E-03	2.06E-03	2.47E-03				
n-Pentane	7.50E-04	7.72E-04	9.04E-04	9.59E-04	1.14E-03	1.36E-03				
C6+*	1.18E-03	1.21E-03	1.42E-03	1.51E-03	1.79E-03	2.14E-03				

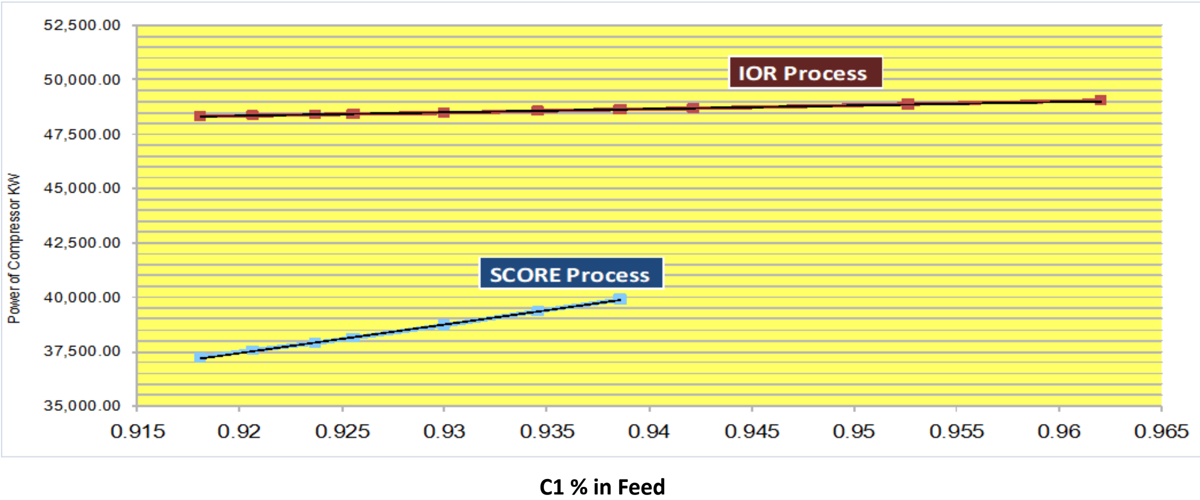

Figure 6 Power of the compressor for Lean Gas in IOR and SCORE Process

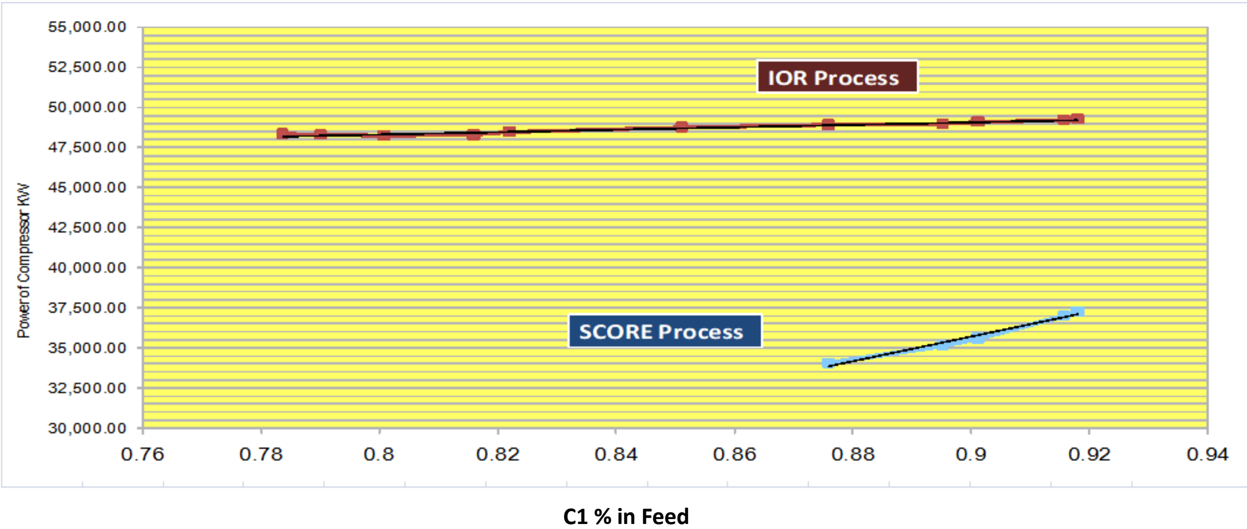

Figure 7 Power of the compressor for Rich Gas in IOR and SCORE Process

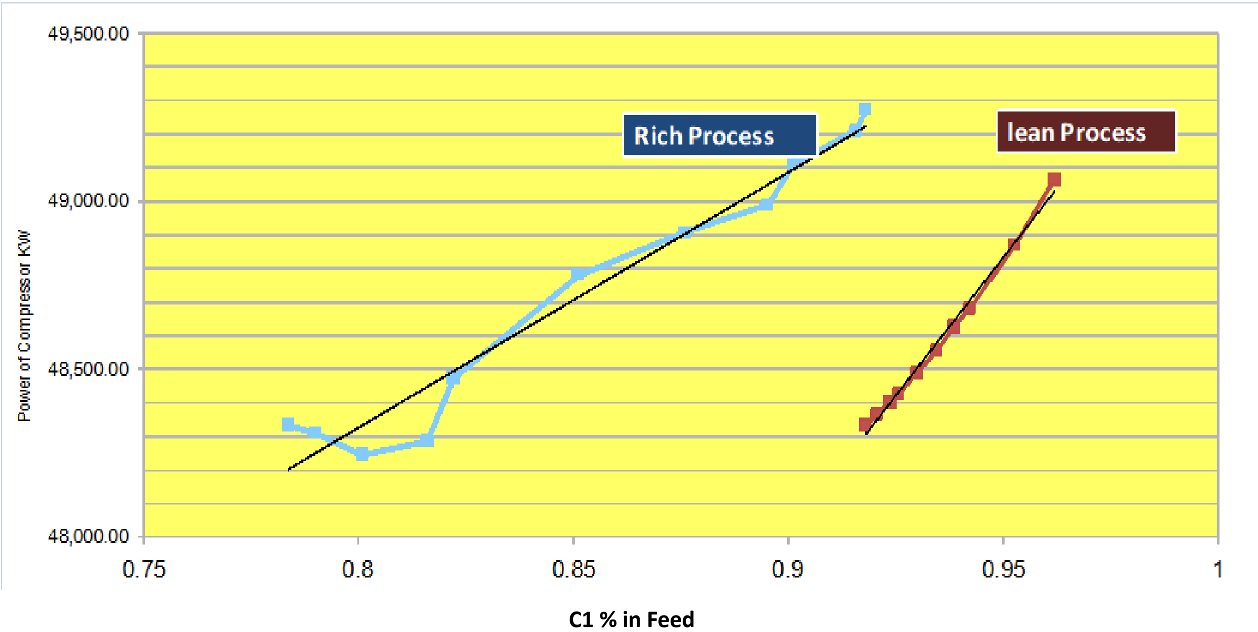

Figure 8 Power of the compressor for Rich and Lean Gas in IOR Process

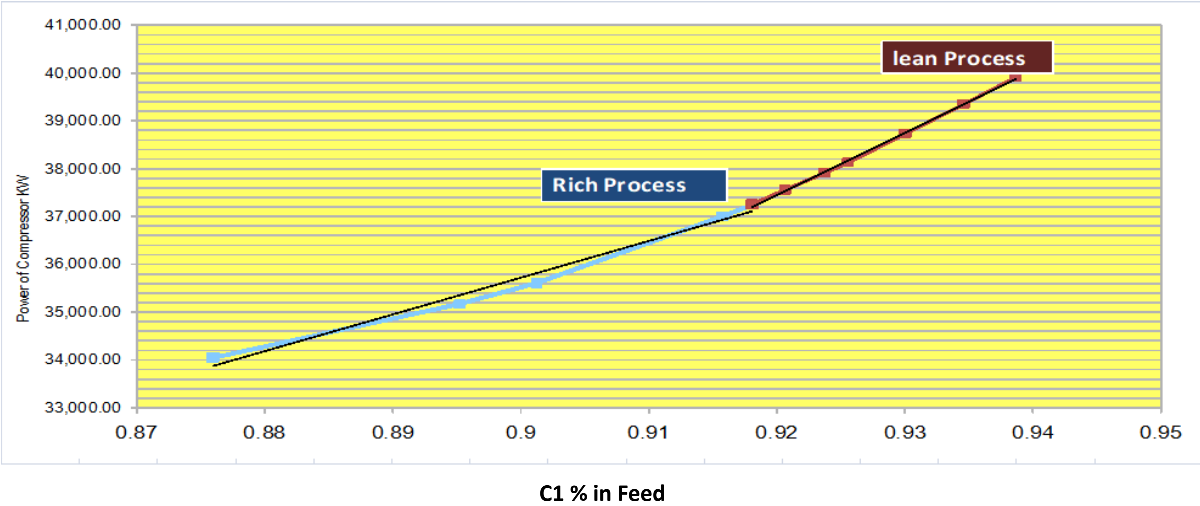

Figure 9 Power of the compressor for Rich and Lean Gas in SCORE Process

Table 6 Simulation Result and Cost Estimation for IOR Process

a-Simulation Result				
		Flow Rate	Composition (Mole Fraction Basis)	
Top Product Composition	Methane (Sales gas)	1361 MMSCFD	Nitrogen CO2 Methane Ethane Propane	1.09e-003 6.65e-003 0.9457 4.4718e-002 1.323e-003
Bottom Product Composition	Propane	783.8 TONNE/DAY	Ethane Propane i-Butane	2.375e-002 0.9719 3.99e-003
	LPG	1006 TONNE/DAY	Propane i-Butane n-Butane	0.41992 0.30192 0.2747
	Debutanizer Natural Gasoline (DNG) or Condensate	394.1 TONNE/DAY	i-Pentane n-Pentane C6+	0.40951 0.21959 0.3678
Number of trays Column	C-01		24 tray	
	C-02		6 trays	
Compressor	Compressor power		48332. Kw	
b- Cost Estimation				
Fixed Capital Investment			Columns cost	66.03 E+0
Operating cost			Compressor Electricity cost	65.54 E+0

Cost estimation for the Production Profit

The cost assessment for IOR and SCORE in which included fixed and operating costs as well cost of the product produced were evaluated in appendix B and as shown in table 8.

Consequently it can seen from the previous simulation results that the overall profit calculation for single column overhead recycle process gained about $ 10.787E+6 per year more than the proved overhead recycle process as presented in table 9.

Figure 10. Demonstrate the differences between IOR and SCORE as total cost, operating and fixed cost.

Table 7 Simulation Result and Cost Estimation for SCORE Process

a-Simulation Result				
		Flow Rate	Composition	
Top Product Composition	Methane (Sales gas)	1366 MMSCFD	Nitrogen CO_2 Methane Ethane Propane	1.094e-003 6.7015e-003 0.9414 4.8794e-002 1.5343e-003
Bottom Product Composition	Propane	1410 TONNE/DAY	Ethane Propane i-Butane	0.55173 0.44409 5.9206e-005
	LPG	769.8 TONNE/DAY	Propane i-Butane n-Butane	0.373139 0.325446 0.29652
	Debutanizer Natural Gasoline (DNG) or Condensate	355.4 TONNE/DAY	i-Pentane n-Pentane C6+	0.390295 0.214439 0.385754
Number of Trays in Column	New Column		10 tray	
Compressor	Compressor power		37246 Kw	

b- Cost Estimation		
Fixed Capital Investment	Columns cost	52.97 E+0
Operating cost	Compressor Electricity cost	52.93 E+0

Table 8 Cost estimation for the Process Production Profit

Plant Design	IOR	SCORE
Sales gas Production, MMSCFD	1361	1366
Incremental Sales gas , MMSCFD	5 (net heating value 1000 btu/scf)	
Average price of Methane ($/t)	3.5 $ / 10E+6 btu	
Incremental Production Profit ($ /year)	+6.205E+6	
Propane Production/day	783.8	1040
Incremental Propane , T/day	256.2	
Average price of Propane ($ /t)	865	
Incremental Production Profit ($ / year)	+80.88E+6	
LPG Production/day	1006	769.8
Incremental LPG , T/day	-236.2	
Average price of LPG ($/t)	885	
Incremental Production Profit ($/year)	-76.298E+6	
Total production profit difference $ /year (SCORE in more than IOR)	10.787E+6	

Table 9 Overall Cost estimation for SCORE and IOR Process.

Plant Design	IOR	SCORE
Fixed Capital Investment $ /year	66.03 E+06 $	52.97 E+06 $
Operating cost $ /year	65.54 E+06 $	52.93 E+06 $
Total cost $ /year	131.57E+06	105.9E+06
Total cost Difference $ /year (SCORE in less than IOR)		
25.67E+06		
Total production profit difference $ /year (SCORE in more than IOR)		
10.787E+6		

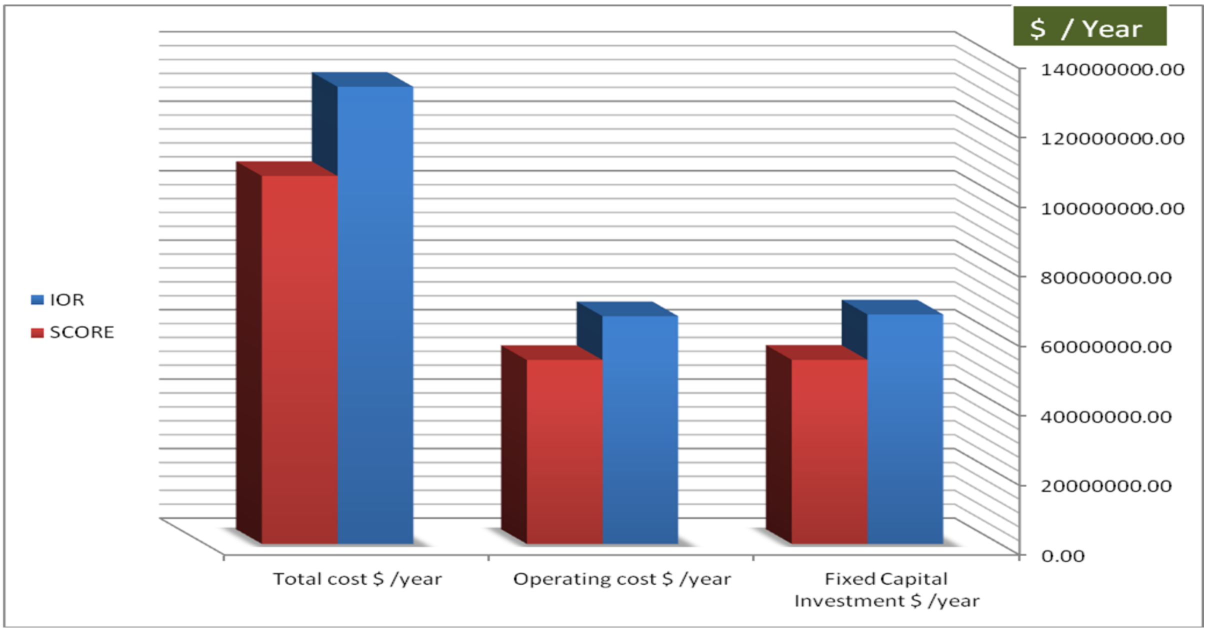

Figure 10 Cost Estimation for IOR and SCORE Process.

Conclusion

The studies describe the simulation and optimization to compare the flexibility and the costs of the existing Improved Overhead Recycle Process (IOR) UGDE in Port Said with the flexibility and the costs of Single Colum Overhead Recycle Process (SCORE).

The conclusion which can be withdrawn from the study is the following:

1. IOR process is more flexible than SCORE process in the case of changing the natural gas feed composition from very rich to very lean gas.
2. IOR process can accommodate change in feed gas composition change from lean gas range (0.91806-0.9620) to rich gas range (0.91806-0.784) although, SCORE process can accommodate only from lean gas range (0.91806-0.9356) to rich gas range (0.91806-0.8511) based on methane mole fraction.
3. At normal operating conditions, the Fixed Capital Investment and operating cost for SCORE process is LESS by 25.67E+06 $ / year than Fixed Capital Investment and operating cost for IOR process.
4. At normal operating conditions, the total production profit for SCORE process is MORE by 10.787E+06 $ / year than total production profit for IOR process.
5. SCORE is the technology of choice for plants where high propane recovery and maximum efficiency are of great importance.

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Appendix (A)

Pang Robinson equation of state

Thermodynamic Properties in HYSYS for the Peng-Robinson Equation Property Package. The Peng-Robinson (PR) model is ideal for Vapor-Liquid Equilibrium (VLE) calculations as well as calculating liquid densities for hydrocarbon systems. Several enhancements to the original PR model were made to extend its range of applicability and to improve its predictions for some non-ideal systems. However, in situations where highly non-ideal systems are encountered, the use of Activity Models is recommended.

The PR property package rigorously solves any single-, two-, or three-phase system with a high degree of efficiency and reliability and is applicable over a wide range of conditions:

1. Temperature Range > -271°C or -456°F
2. Pressure Range < 100,000 kPa or 15,000 psia

The PR property package also contains enhanced binary interaction parameters for all library hydrocarbon-hydrocarbon pairs (a combination of fitted and generated interaction parameters), as well as for most hydrocarbon-non-hydrocarbon binaries. For non-library or hydrocarbon hypo components, HC-HC interaction parameters are generated automatically by HYSYS for improved VLE property predictions.

For Oil, Gas, or Petrochemical applications, the PR equation of state EOS is the generally recommended property package.

Physical properties are predicted by HYSYS using the following thermodynamic based equations

$$\frac{H-H^{ID}}{RT}=Z-1+\frac{1}{RT}\int_{\infty}^{V}\left[T\left(\frac{\partial P}{\partial T}\right)\bigg|_{V}-P\right]dV \quad (1)$$

$$\frac{S-S_o^{ID}}{RT}=\ln Z-\ln\frac{P}{P^o}+\int_{\infty}^{V}\left[\frac{1}{R}\left(\frac{\partial P}{\partial T}\right)\bigg|_{V}-\frac{1}{V}\right]dV \quad (2)$$

Where the Ideal Gas Enthalpy basis (H^{ID}) used by HYSYS is equal to the ideal gas Enthalpy of Formation at 25°C and 1 atm. The Ideal Gas Enthalpy basis (H^{ID}) used by HYSYS changes with temperature according to the coefficients on the Tdep tab for each individual component. An example of the prediction of the enthalpy of a single component is given below where the values of $a=f(T)$ and *b* are from the Peng-Robinson equation of state.

$$\frac{\left(H-H^{ID}\right)}{RT}=Z-1-\frac{1}{2^{1.5}bRT}\left[a-T\frac{da}{dt}\right]\ln\left[\frac{V+\left(2^{0.5}+1\right)b}{V+\left(2^{0.5}-1\right)b}\right] \quad (3)$$

Where

$$a=\sum_{i=1}^{N}\sum_{j=1}^{N}x_i x_j\left(a_i a_j\right)^{0.5}\left(1-k_{ij}\right) \quad (4)$$

$$b_i=0.077796\frac{RT_{ci}}{P_{ci}} \quad (1)$$

$$a_i=a_{ci}\alpha_i \quad (2)$$

$$a_{ci}=0.457235\frac{\left(RT_{ci}\right)^2}{P_{ci}} \quad (7)$$

$$\sqrt{\alpha}=1+m_i\left(1-T_{ri}^{0.5}\right) \quad (8)$$

$$m_i = 0.37646 + 1.54226\omega_i - 0.2699\omega_i^2 \qquad (9)$$

Appendix (B)

Cost estimation methods used

The most important costs that will be needed to compare options are capital equipments cost, operational cost and production profit cost. The following equations were used in the present study where all costs in US dollars and commercial steel materials of consideration.

1-Columns

Vertical cylindrical vessels are used for distillation; Columns can have trays or packing. When trays are used, the tray spacing must be specified. To provide enough room for someone to crawl inside the column for repairs and maintenance, a typical value of tray spacing is 2 ft.

Excel file calculates the diameter of the vessel. Knowing the diameter and the height, the capital cost can be found using the equations given in the following

Capital cost = 17.640 $(D)^{1.066}$ $(L)^{0.802}$

Vessels (diameter and length in meters)

2- Compressors

The power requirements of a compression system depend on the compression ratio and the suction temperature. Compressors are driven by steam turbines (using high-pressure steam) or electric motors. In either case the energy is high level and expensive. Compressor suction temperatures should be kept low. Multistage compression systems use inter cooling to more closely approach isothermal compression. Equal compression ratios are used in each stage. Compressor power requirements are obtained from the simulation (13).

Capital cost = (4293)(517.3)(3.11) $(HP)^{0.82}$/ 280 Compressors (work in horsepower)

3-Pumps, Valves, and Piping

Since the work of pumping liquids is usually small and the cost of a pump is usually much smaller than that the major vessels, pumping cost can usually be neglected in the conceptual design stage. The same is true for valves and piping (14).

4- Energy Costs

Electricity = 16.8$/GJ

5- Products Price

As per Egyptian general petroleum corporation (15):

a) natural gas (sales gas) =5 $ /106 btu , 1000btu/scf

b) propane = 867 $ / T

c) LPG =885 $ / T