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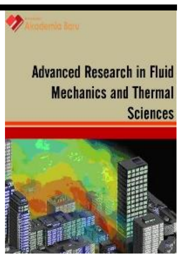

Simulation of Liquefied Petroleum Gas Recovery from Off Gases in a Fuel Oil Refinery

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ABSTRACT

With the growing need and demand for petroleum fuels in the industrial, automotive and domestic sectors, it has become the need of time to address this problem. The important question is, what engineers can do in this regard. There is a simple solution to cater this problem, the production trends worldwide are increasing every year, but still, the demand keeps increasing exponentially. One way is to stress emphasis on reducing the wastage of these precious fuels and, at the same time, implement methodologies and techniques to recover these. The research caters to cope up with the shortage of LPG within Pakistan. Since LPG is a fuel that is being used in the industrial, automotive as well as domestic sector, adequate responsive measures should be taken to meet the market requirements. This research focuses on the technique to recover LPG from refinery off-gases. Since off-gases usually are flared of by most of the refineries leading to potential loss of lighter end fuels like LPG. The article encloses a detailed proposal of a recovery plant that makes use of simple techniques and efficient process accompanied by economical and feasible solutions.

1. Introduction

The liquefied petroleum gas abbreviated as LPG is an efficient nontoxic, odorless, environment-friendly hydrocarbon fuel which comprises propane and butane primarily with some fractions of ethane and pentane [1,2]. As the fuel represents the family of lighter hydrocarbons from C_1-C_5, it is also termed as gas liquids. The concentration of propane and butane in LPG varies by the season. That is, the fuel sold includes more propane in winter while butane is a prime component in summer. Powerful odorant ethanol is added in an odorless fuel for leakage detection. The international standard of LPG is EN 589. The LPG was developed at the beginning of the 20th century, which is indeed very late in the oil and gas business [1,2].

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It was developed when the scientist was working on the problem of quick gasoline evaporation. In 1911, an American scientist found that there are two gases propane and butane in gasoline, which causes its quick evaporation so they should be removed. He found methods to remove these gases from gasoline and these removed gases are LPG. LPG was initially presented in Pakistan in 1966. At first, the Pakistan LPG market was a completely directed one, where supply was confined to just indigenously delivered LPG and where the Government of Pakistan controlled evaluating. A change happened in 1994-1995 when imports were permitted, prompting total industry deregulation by April 2001. Even though LPG's offer in the nation's energy prerequisites has been nominal to date, over the previous decade, development by volume has been at a pace of around 14% per annum. This is required to keep developing fundamentally with expanding LPG supplies accessible from both imported and local sources [3,4].

LPG’s boiling point varies as it depends upon its mixture composition amount of propane and butane. It ranges from -42 °C to 0 °C. LPG is fuel and like normal fuel, it produces carbon dioxide and water when it is combusted with a sufficient amount of air. Less amount of air than required results in incomplete combustion which gives toxic gas that is carbon mono oxide. LPG is kept as a fluid under pressure. It is colorless and its weight is around a half portion of that of an equivalent volume of water. The pressure of LPG inside a closed container is equivalent to the vapor pressure of the fluid and gaseous LPG and relates to its temperature. Butane is twofold heavy as air and propane are one and half times heavy as air. Subsequently, the vapor may stream along the ground and into channels, reducing to the least degree of the environment and be exploded at a considerable distance from the source of spillage. The temperature required to ignite LPG in the air will be around 500°C. The calorific estimation of LPG is about 2.5 times higher than that of the primary gas, so more heat is delivered from a similar volume of gas. LPG is an odorless, colorless and non-toxic gas. It is provided industrially with an additional odorant to help location by smell LPG is a magnificent dissolvable of oil and elastic item and is for the most part non-acidic to steel and copper composites. The flashpoint of LPG is -104°C. LPG is propane (C_3H_8), butane (C_4H_{10}), or a blend of propane/butane [5].

Cooking is the most universal energy-consuming activities. LPG is a versatile fuel and provides many benefits associated with cooking. This fuel provides an easily controllable flame, which is blue so that the right level of flame can be maintained. As this is the cleaner fuel and doesn’t produce soot or smell, which increases cooker or burner life plus doesn’t damage or burn cooking appliances. It provides moist heat, which helps cook more delicious food. LPG is considered to be a blessing in rural areas as before LPG people have to go and collect wood and charcoal and when it burns, it emits hazardous gases which not only discomfort women doing the cooking but also disturb the people around it. LPG is available in cylinders and has not only made cooking easy and enjoyable but also made the life of people comfortable and healthy [5,6]. As one of the cleanest conventional fuels accessible, LPG supplements sustainable power sources and advances which rely upon certain climate conditions or light. LPG additionally empowers exceptionally proficient decentralized generation through little self-containing generators and micro-combined power and heat. For these sorts of confined force generation, LPG's carbon impression is under that of diesel and essentially lower than gasoline. LPG can be utilized in numerous applications in the modern part, to be specific in space and procedure heating, controlling mechanical stoves, creation of nourishment, ovens, heaters, manufacturing of packing material just as in fueling forklift trucks in distribution centers [5,6].

The benefits of LPG are clean-burning, no sediment, burners have a more extended life, so maintenance is low, no spillage as it disintegrates at air temperature and pressure. In a flash, controllable fire temperature abstains from scaling and decarburizing of parts, naturally benevolent fuel, with negligible sulfur substance and sulfur-free emissions. Exceptionally high proficiency with direct firing framework Instant heat for quicker warm-up and chill off can be utilized for an assortment of utilizations. Force, payload, acceleration and voyage speed are similar to those of a proportionate vehicle fueled on gas. Propane has a high octane rating of 104, in the middle of Compressed Natural Gas (CNG) (130) and ordinary unleaded fuel (87). The high octane rating empowers the propane to blend better with air and to consume more completely than gasoline, producing less carbon. With less carbon development, flash fittings regularly last more and oil changes are required less frequently. Since it consumes in the motor in the gaseous stage, propane brings about less corrosion and motor wear than does gasoline [7].

LPG has two causes: 60% is recuperated during the extraction of flammable gas and oil from the earth, and the staying 40% is delivered during the refining of unrefined petroleum. Unrefined petroleum is a liquid found usually in rock, comprising mostly complex hydrocarbons, with some extra natural material. It is the major fuel utilized on the earth and is utilized in the creation of numerous manufactured materials like plastics. It is profoundly flammable dark, the thick liquid that comprises of hydrocarbon molecules. It has been found in normal underground reservoirs. It produces oil-based commodities and records for about 40% of the world's essential vitality utilization. At the point when handled, it yields gaseous petrol and chemical residue, which are additionally energized. It is classified on basis of viscosity and the degree of polluting influences (like sulfur) present in it. The basic arrangement wt.% ranges for practically all unrefined oils carbon 83.9-86.8%, hydrogen 11.0-14.0%, sulfur 0.06-8.00%, oxygen 0.08-1.82%, nitrogen 0.02-1.70% and metals 0.00-0.14% [7,8].

The process of refining oil includes numerous stages. LPG is created from oil at a few of these stages, including atmospheric refining, cracking, reforming and others. It is created because the gases of which it is created (butane and propane) are caught inside the unrefined petroleum. To balance out the raw petroleum before pipeline or tanker circulation, these 'related' or characteristic gases are additionally handled into LPG. In unrefined petroleum refining, the gases that makeup LPG are the main items delivered while in transit to making heavier fuels, for example, diesel, stream fuel, fuel oil and gas. Generally, three percent of a typical barrel of unrefined petroleum is refined into LPG, while forty percent of a barrel could be changed into LPG.

At the point when gas is drawn from the earth, it is a blend of a few gases and fluids. Methane is sold by gas utilities like petroleum gas, establishes around 90 % of this blend. Of the staying 10 % is propane and 5 % is different gases, for example, ethane and butane. Before natural gas can be distributed or utilized, the gases (which are marginally heavier than methane, the significant constituent of natural gas) are separated. Contingent upon the wetness of a creating gas field, gas fluids usually contain 1% to 3% of the unprocessed gas stream [9].

1.1 Various Processes for Production of LPG

In a common vapor separation framework, the feed gas move in the membrane and the LPG segments especially permeate, making an LPG advanced permeate stream. The permeate is compressed and LPG is recuperated as a fluid in the condenser. The buildup stream from the membrane exhausted in LPG and enhanced in hydrogen and lighter hydrocarbon gases (ethane, methane), remains at pressure and can be sent straightforwardly to the fuel headers or for additional hydrogen purification. Now and again, the hydrogen purity is sufficiently high to permit direct recycle to other refinery methods is appeared in Figure 1 [10]. Vapour separation technology includes gas reception, gas sweetening, drying and filtration, followed by LPG recovery using a combination of turbo-expander technology and hydrocarbon washing to achieve high recovery of LPG. The plant also includes fractionation of LPG into its pure constituents, propane and butane. The distillation process is driven by a hot oil system and air cooling. The sales gas is then compressed in gas turbine driven centrifugal compressors.

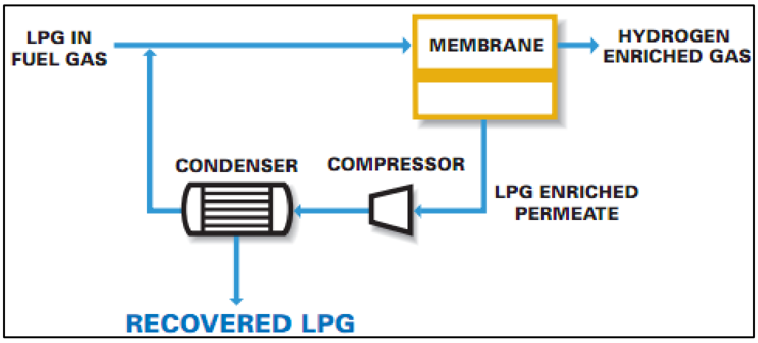


Fig. 1. Vapour separation technology

Figure 2 illustrates PRO-MAX technology. The rich low-pressure gas is chilled and partially condensed by cross heat exchange along with the refrigerant. The remaining vapor then enters an absorber. The re-circulating lean oil employed is a stream with high ethane content and low propane content. This is the ideal reflux composition to achieve high overall propane recovery. The de-ethanizer is a conventional distillation system employing propane refrigerant for the overhead condenser and some type of heat input (typically steam or hot oil) for tower re-boil. A slipstream of the tower reflux stream is withdrawn, subcooled by cross-exchange and recycled to the absorber. The cross-exchange warms the cold overhead vapors from the absorber and de-ethanizer. This combined residue gas stream (comprising the ethane and lighter components) can then be routed to the plant fuel system. Removal of the LPG components from the plant fuel gas system may also improve the operation of fired equipment throughout the facility [3,10].

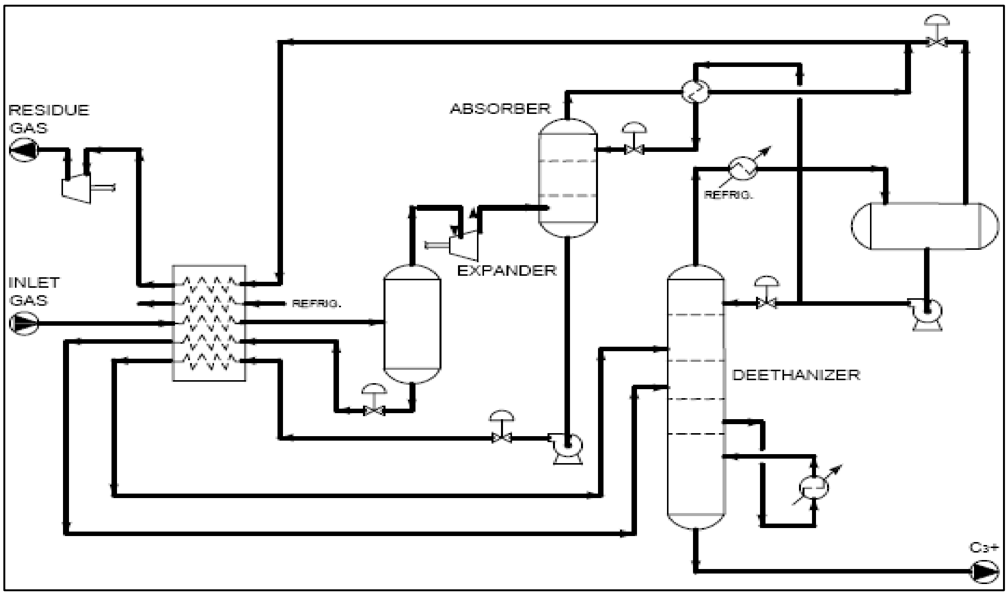


Fig. 2. Pro-Max LPG technology

Depending on the feed pressure, some limited amount of feed compression may still be required with PRO-MAX. Depending on the required residue gas delivery pressure, some limited amount of residue compression may also be required. It is most often advantageous to employ a turbo-expander to help balance overall plant chilling requirements. Propane recovery levels approaching 100% are typical with PRO-MAX. The only practical limitation of the technology is the composition of the de-ethanizer overhead being constrained by the use of propane (or similar) refrigerant. For leaner gas and with increasing feed pressures, the relative amounts of light components (specifical methane) that are condensed and fed to the de-ethanizer also increase. To maintain a low propane level in the de-ethanizer overhead then requires lower and lower deethanizer condenser temperatures. For propane refrigeration, -40 deg F represents the lowest practical limit to avoid vacuum operation. The deethanizer operating pressure can be raised to help mitigate this overhead temperature, but a practical pressure limit is about 500 psi due to critical pressure considerations [10,11].

One way to recover LPG from off-gases is to use the process of oil absorption since LPG is readily absorbed in kerosene under low temperature conditions. The off-gases from the platformer unit of a refinery are mainly composed of LPG and lighters, which account for C1-C5 components of the crude. Out of the off-gases, LPG absorbs in kerosene undercooled and moderate pressure conditions, whereas the lights that are composed of C1 and C2 of the crude components remain unabsorbed.

The off-gases from the platformer unit of the refinery are introduced into the gas absorption column, the liquid and gas flow in a counter-current direction to each other. Lean kerosene, which is cooled to around 40°C, is introduced from the top of the absorption column while off-gases from the base of the column. The mass transfer takes place and the heavier components of the off-gases that are LPG are absorbed in lean kerosene, whereas the lighters leave the column from its top. Kerosene, now rich with LPG, is taken out from the bottom and introduced into a stripper where LPG and kerosene are separated. LPG is taken from the top of the stripper and kerosene from its bottom [12,13].

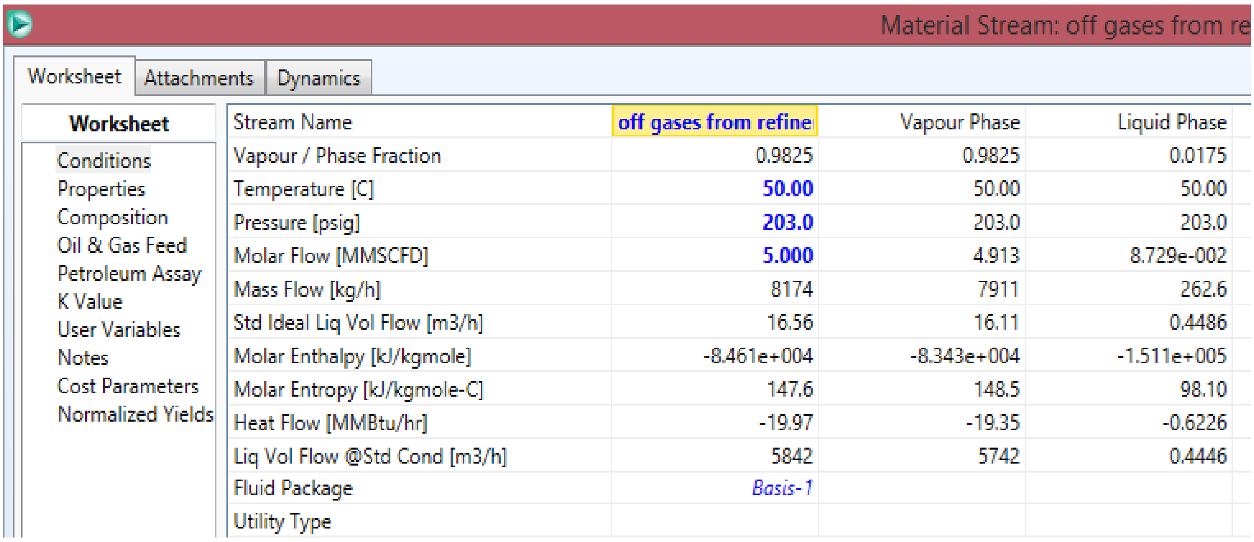
LPG is a cleaner fuel and is playing its role in the development of the agriculture sector all over the world. It is widely in use for many agricultural processes like thermal desiccation, fueling of farm vehicles, crop-drying, and insect repellent. LPG is the fuel that is extensively used by the automotive sector. On comparison of LPG with other fossil fuels, it has been found out that it has lesser toxic gas emissions, which result in a cleaner environment and protection of human health. Moreover, it mitigates the threat of climate change, which can cause a severe problem in the future. The other positive point of this fuel is its high octane number, which protects the vehicle and increases its performance. The most feasible recovery process is through absorption in kerosene due to the following advantages it has over other techniques. This process utilizes all the available raw materials within a refinery that are kerosene obtained from the crude oil is used for absorption purposes, so the cost for purchasing oil for absorption is cut down. The process is relatively simple as it involves the addition of only an absorption column and a stripper for the recovery process to the current refinery unit. The process is easily understandable and simple in operation as compared to other techniques that may involve designing of turboexpanders, catalytic reactors or de-methanizer, de-propanizer, debutanizer. The raw material kerosene can be recovered back by distillation 90% of the LPG can be recovered from off-gases through this process [14,15].

The objective of this research includes the simulation that can be used as a tool to acquire comprehensive information required for the design of a real plant, for experiment, control and optimization purposes. The benefits of the simulation include precise design information to ensure the process feasibility along with the process flow diagrams and multiple design cases or options that save valuable cost. The best retrofit option for the chemical plant, optimization to get the process highest performance point and sensitivity analysis, evaluating the process key control variables and degree of operating constancy. The simulation of the recovery of LPG recovery from off-gases by using cryogenic and absorption techniques.

2. Methodology

2.1 Simulation Approach

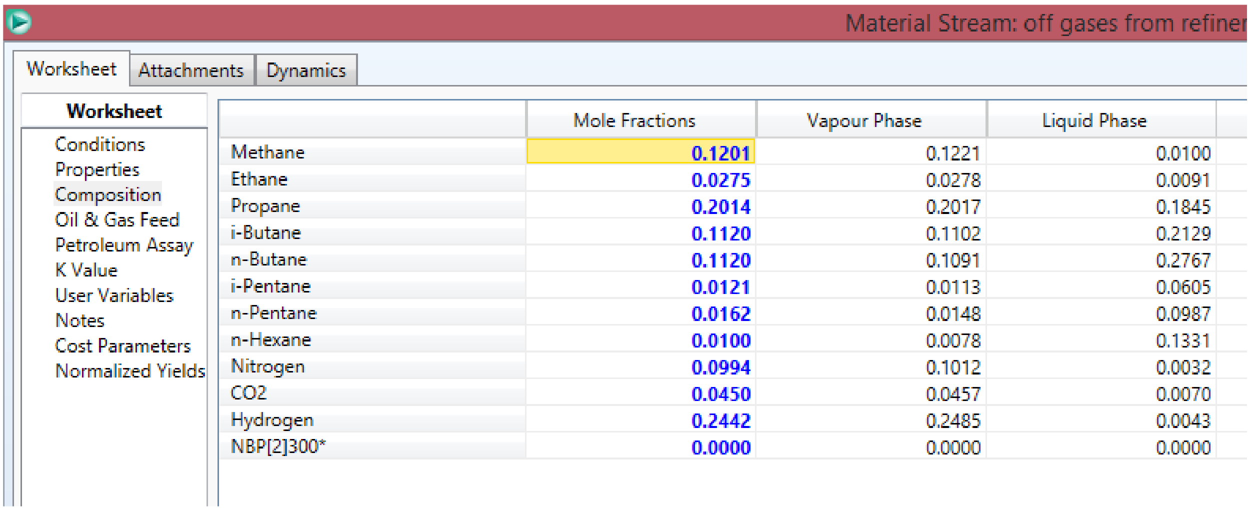
In this research, simulation of the LPG recovery system is carried out using Aspen Hysys version 8.8. The major components in a refinery are typically hydrocarbons for which the appropriate fluid package is Peng-Robinson. The main aspect of process simulation is the choice of an appropriate physical property method that will exactly analyze different physical properties. The main purpose of this simulation was to recover the maximum amount of LPG from the off-gases coming out from different units of the refinery is shown in Figure 3. Recovery of LPG has a trade-off with the purity of LPG, so extracting an optimum figure among the two parameters is important to make the system best efficient and economical. All the parameters of off-gases, solvent, and different units are based on real data, which was taken from the refinery [13,16].



Stream Name	off gases from refine	Vapour Phase	Liquid Phase
Vapour / Phase Fraction	0.9825	0.9825	0.0175
Temperature [C]	50.00	50.00	50.00
Pressure [psig]	203.0	203.0	203.0
Molar Flow [MMSCFD]	5.000	4.913	8.729e-002
Mass Flow [kg/h]	8174	7911	262.6
Std Ideal Liq Vol Flow [m3/h]	16.56	16.11	0.4486
Molar Enthalpy [kJ/kgmole]	-8.461e+004	-8.343e+004	-1.511e+005
Molar Entropy [kJ/kgmole-C]	147.6	148.5	98.10
Heat Flow [MMBtu/hr]	-19.97	-19.35	-0.6226
Liq Vol Flow @Std Cond [m3/h]	5842	5742	0.4446
Fluid Package	Basis-1		
Utility Type			

Fig. 3. Off gases data

The refinery off-gases come from different units, including alkylator, plate former, distillation column and hydrocracker. These off-gases are mostly at high temperatures, so their sensible heat is removed and then they combine into a header. The off-gases composition mentioned in Figure 4 is the composition of the gases present in this header.



	Mole Fractions	Vapour Phase	Liquid Phase
Methane	0.1201	0.1221	0.0100
Ethane	0.0275	0.0278	0.0091
Propane	0.2014	0.2017	0.1845
i-Butane	0.1120	0.1102	0.2129
n-Butane	0.1120	0.1091	0.2767
i-Pentane	0.0121	0.0113	0.0605
n-Pentane	0.0162	0.0148	0.0987
n-Hexane	0.0100	0.0078	0.1331
Nitrogen	0.0994	0.1012	0.0032
CO2	0.0450	0.0457	0.0070
Hydrogen	0.2442	0.2485	0.0043
NBP[2]300*	0.0000	0.0000	0.0000

Fig. 4. Off gases composition

2.2 Process Flow Diagram of Cryogenic Technique

Different equipment like LNG heat exchanger, separator, distillation column, compressors and expander are used in this technique. Figure 5 shows the recovery of LPG through the cryogenic technique.

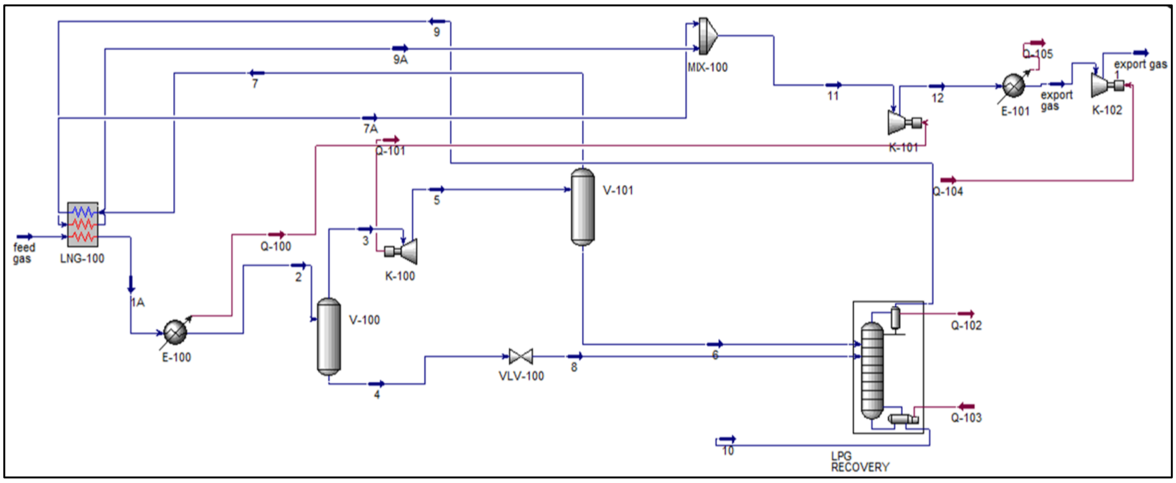
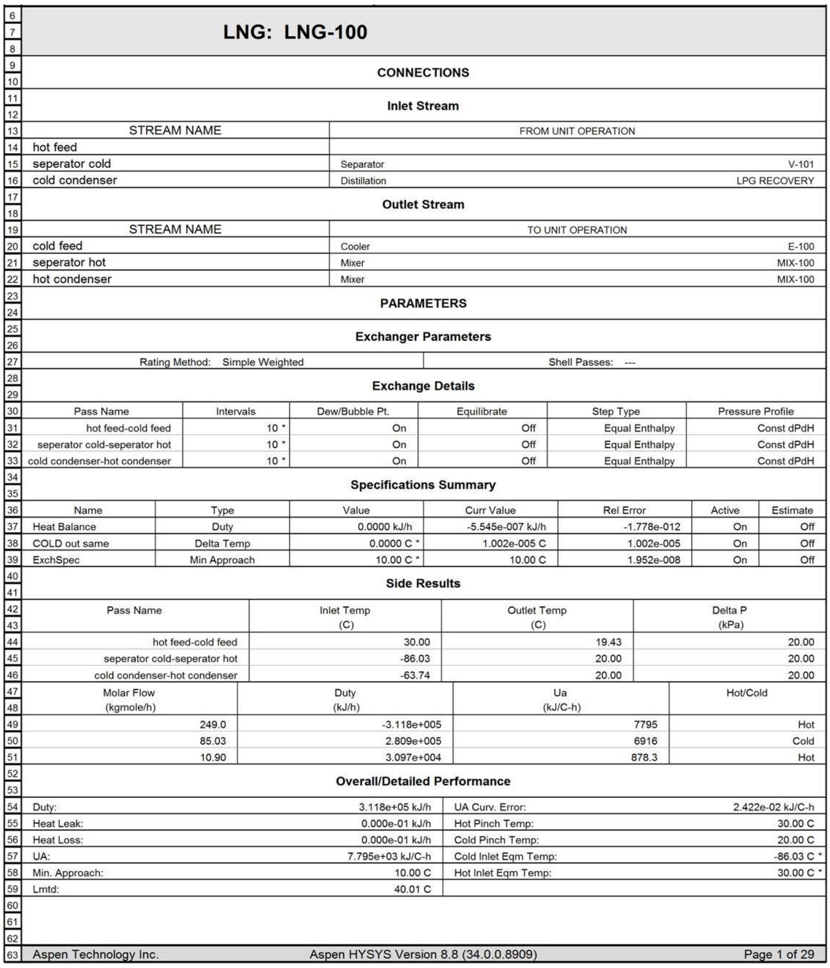


Fig. 5. Recovery of LPG through Cryogenic technique

Figure 6 shows the LNG heat exchanger datasheet.



LNG: LNG-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION	
hot feed		
seperator cold	Separator	V-101
cold condenser	Distillation	LPG RECOVERY

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
cold feed	Cooler	E-100
seperator hot	Mixer	MIX-100
hot condenser	Mixer	MIX-100

PARAMETERS

Exchanger Parameters

Rating Method: Simple Weighted	Shell Passes: ---

Exchange Details

Pass Name	Intervals	Dew/Bubble Pt.	Equilibrate	Step Type	Pressure Profile
hot feed-cold feed	10 *	On	Off	Equal Enthalpy	Const dPdH
seperator cold-seperator hot	10 *	On	Off	Equal Enthalpy	Const dPdH
cold condenser-hot condenser	10 *	On	Off	Equal Enthalpy	Const dPdH

Specifications Summary

Name	Type	Value	Curr Value	Rel Error	Active	Estimate
Heat Balance	Duty	0.0000 kJ/h	-5.545e-007 kJ/h	-1.778e-012	On	Off
COLD out same	Delta Temp	0.0000 C *	1.002e-005 C	1.002e-005	On	Off
ExchSpec	Min Approach	10.00 C *	10.00 C	1.952e-008	On	Off

Side Results

Pass Name	Inlet Temp (C)	Outlet Temp (C)	Delta P (kPa)
hot feed-cold feed	30.00	19.43	20.00
seperator cold-seperator hot	-86.03	20.00	20.00
cold condenser-hot condenser	-63.74	20.00	20.00

Molar Flow (kgmole/h)	Duty (kJ/h)	Ua (kJ/C-h)	Hot/Cold
249.0	-3.118e+005	7795	Hot
85.03	2.809e+005	6916	Cold
10.90	3.097e+004	878.3	Hot

Overall/Detailed Performance

Duty:	3.118e+05 kJ/h	UA Curv. Error:	2.422e-02 kJ/C-h
Heat Leak:	0.000e-01 kJ/h	Hot Pinch Temp:	30.00 C
Heat Loss:	0.000e-01 kJ/h	Cold Pinch Temp:	20.00 C
UA:	7.795e+03 kJ/C-h	Cold Inlet Eqm Temp:	-86.03 C *
Min. Approach:	10.00 C	Hot Inlet Eqm Temp:	30.00 C *
Lmtd:	40.01 C		

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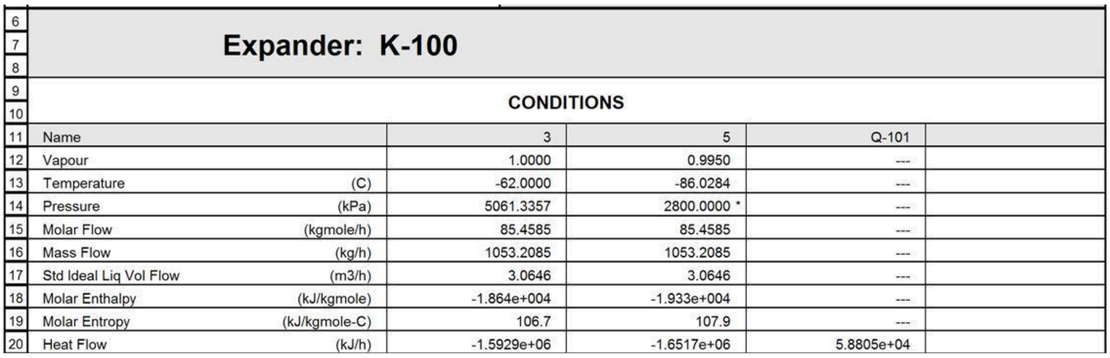
Fig. 6. LNG heat exchanger

Figure 7 shows the expander compressor K-100 datasheet.



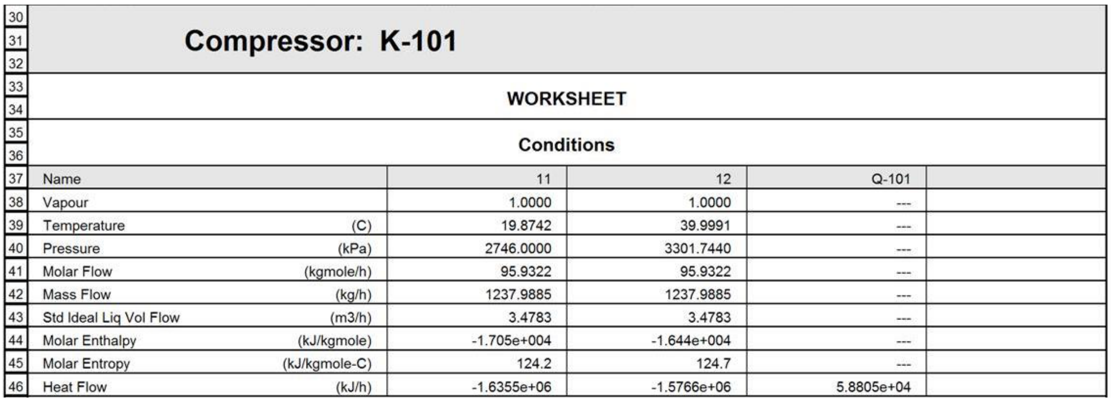
Expander: K-100

CONDITIONS

Name		3	5	Q-101
Vapour		1.0000	0.9950	---
Temperature	(C)	-62.0000	-86.0284	---
Pressure	(kPa)	5061.3357	2800.0000 *	---
Molar Flow	(kgmole/h)	85.4585	85.4585	---
Mass Flow	(kg/h)	1053.2085	1053.2085	---
Std Ideal Liq Vol Flow	(m3/h)	3.0646	3.0646	---
Molar Enthalpy	(kJ/kgmole)	-1.864e+004	-1.933e+004	---
Molar Entropy	(kJ/kgmole-C)	106.7	107.9	---
Heat Flow	(kJ/h)	-1.5929e+06	-1.6517e+06	5.8805e+04

Fig. 7. Expander K-100

Figure 8 and Figure 9 show the expanders of compressor K-101 and K-102 datasheets.



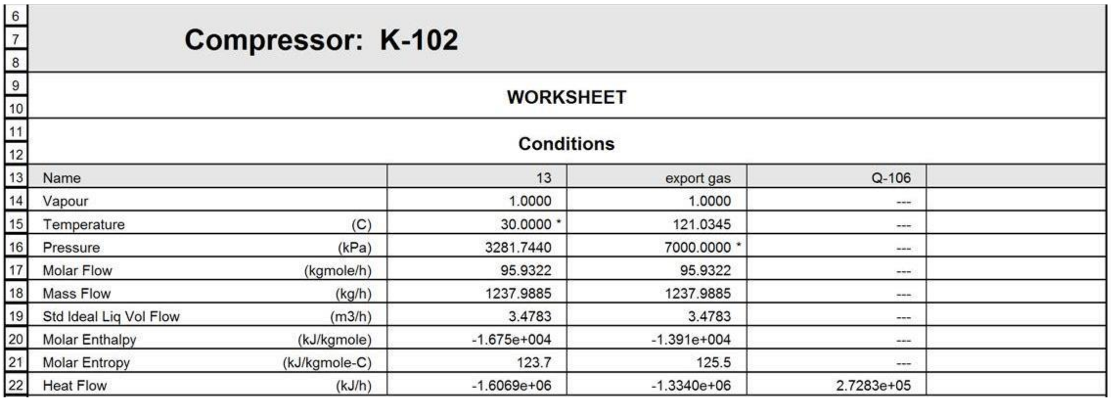
Compressor: K-101

WORKSHEET

Conditions

Name		11	12	Q-101
Vapour		1.0000	1.0000	---
Temperature	(C)	19.8742	39.9991	---
Pressure	(kPa)	2746.0000	3301.7440	---
Molar Flow	(kgmole/h)	95.9322	95.9322	---
Mass Flow	(kg/h)	1237.9885	1237.9885	---
Std Ideal Liq Vol Flow	(m3/h)	3.4783	3.4783	---
Molar Enthalpy	(kJ/kgmole)	-1.705e+004	-1.644e+004	---
Molar Entropy	(kJ/kgmole-C)	124.2	124.7	---
Heat Flow	(kJ/h)	-1.6355e+06	-1.5766e+06	5.8805e+04

Fig. 8. Compressor K-101



Compressor: K-102

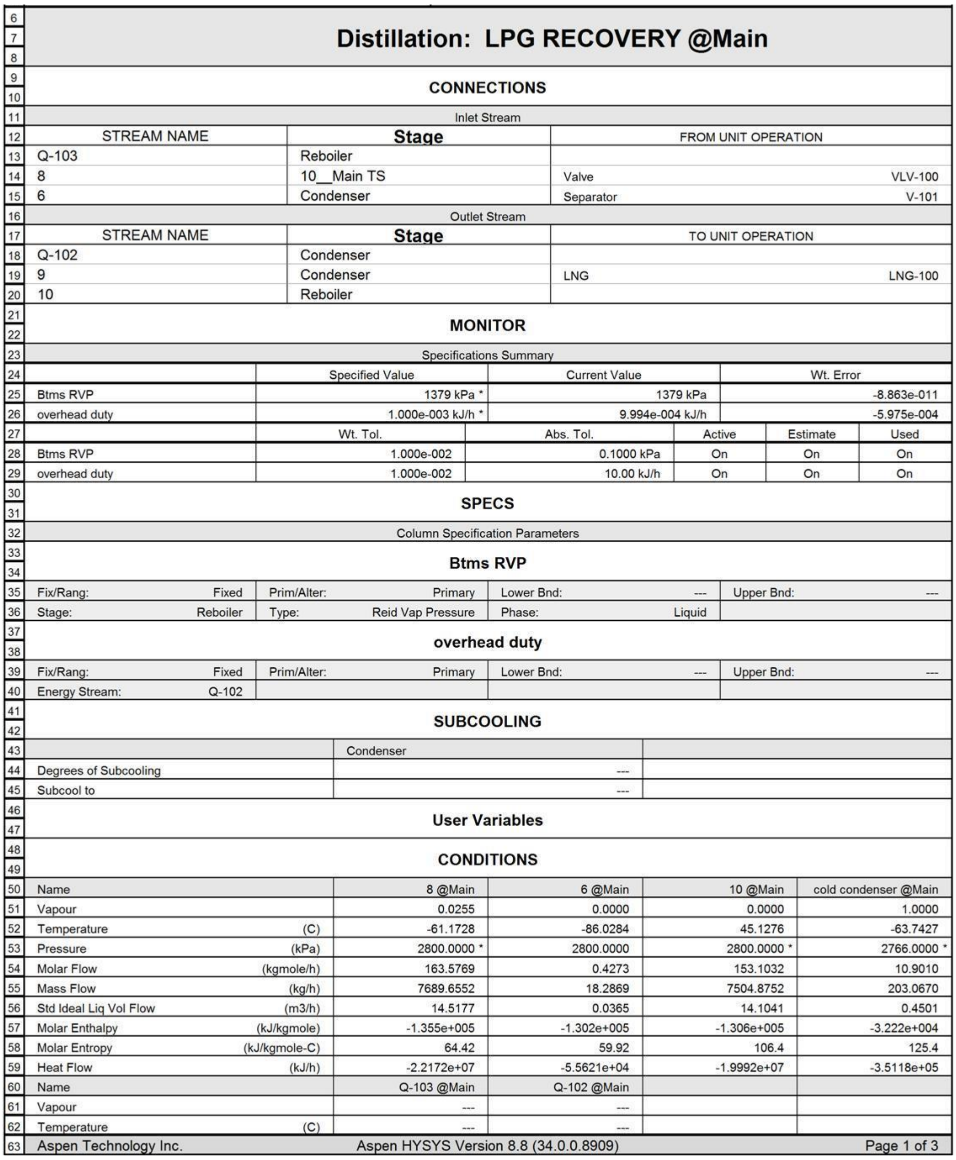
WORKSHEET

Conditions

Name		13	export gas	Q-106
Vapour		1.0000	1.0000	---
Temperature	(C)	30.0000 *	121.0345	---
Pressure	(kPa)	3281.7440	7000.0000 *	---
Molar Flow	(kgmole/h)	95.9322	95.9322	---
Mass Flow	(kg/h)	1237.9885	1237.9885	---
Std Ideal Liq Vol Flow	(m3/h)	3.4783	3.4783	---
Molar Enthalpy	(kJ/kgmole)	-1.675e+004	-1.391e+004	---
Molar Entropy	(kJ/kgmole-C)	123.7	125.5	---
Heat Flow	(kJ/h)	-1.6069e+06	-1.3340e+06	2.7283e+05

Fig. 9. Compressor K-102

Figure 10 shows the distillation column parameter.



Distillation: LPG RECOVERY @Main

CONNECTIONS

Inlet Stream

STREAM NAME	Stage	FROM UNIT OPERATION	
Q-103	Reboiler		
8	10__Main TS	Valve	VLV-100
6	Condenser	Separator	V-101

Outlet Stream

STREAM NAME	Stage	TO UNIT OPERATION	
Q-102	Condenser		
9	Condenser	LNG	LNG-100
10	Reboiler		

MONITOR

Specifications Summary

	Specified Value	Current Value	Wt. Error
Btms RVP	1379 kPa *	1379 kPa	-8.863e-011
overhead duty	1.000e-003 kJ/h *	9.994e-004 kJ/h	-5.975e-004

	Wt. Tol.	Abs. Tol.	Active	Estimate	Used
Btms RVP	1.000e-002	0.1000 kPa	On	On	On
overhead duty	1.000e-002	10.00 kJ/h	On	On	On

SPECS

Column Specification Parameters

Btms RVP

Fix/Rang:	Fixed	Prim/Alter:	Primary	Lower Bnd:	---	Upper Bnd:	---
Stage:	Reboiler	Type:	Reid Vap Pressure	Phase:	Liquid		

overhead duty

Fix/Rang:	Fixed	Prim/Alter:	Primary	Lower Bnd:	---	Upper Bnd:	---
Energy Stream:	Q-102						

SUBCOOLING

	Condenser	
Degrees of Subcooling	---	
Subcool to	---	

User Variables

CONDITIONS

Name		8 @Main	6 @Main	10 @Main	cold condenser @Main
Vapour		0.0255	0.0000	0.0000	1.0000
Temperature	(C)	-61.1728	-86.0284	45.1276	-63.7427
Pressure	(kPa)	2800.0000 *	2800.0000	2800.0000 *	2766.0000 *
Molar Flow	(kgmole/h)	163.5769	0.4273	153.1032	10.9010
Mass Flow	(kg/h)	7689.6552	18.2869	7504.8752	203.0670
Std Ideal Liq Vol Flow	(m3/h)	14.5177	0.0365	14.1041	0.4501
Molar Enthalpy	(kJ/kgmole)	-1.355e+005	-1.302e+005	-1.306e+005	-3.222e+004
Molar Entropy	(kJ/kgmole-C)	64.42	59.92	106.4	125.4
Heat Flow	(kJ/h)	-2.2172e+07	-5.5621e+04	-1.9992e+07	-3.5118e+05
Name		Q-103 @Main	Q-102 @Main		
Vapour		---	---		
Temperature	(C)	---	---		

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Fig. 10. Distillation column parameter

2.3 Process Flow Diagram of Absorption Technique

Figure 11 shows the recovery of LPG through the absorption technique.

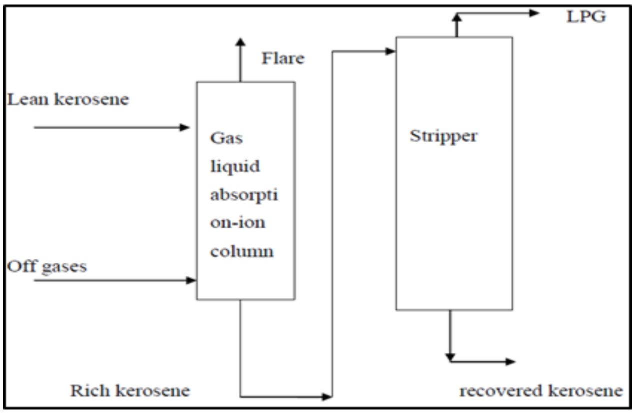
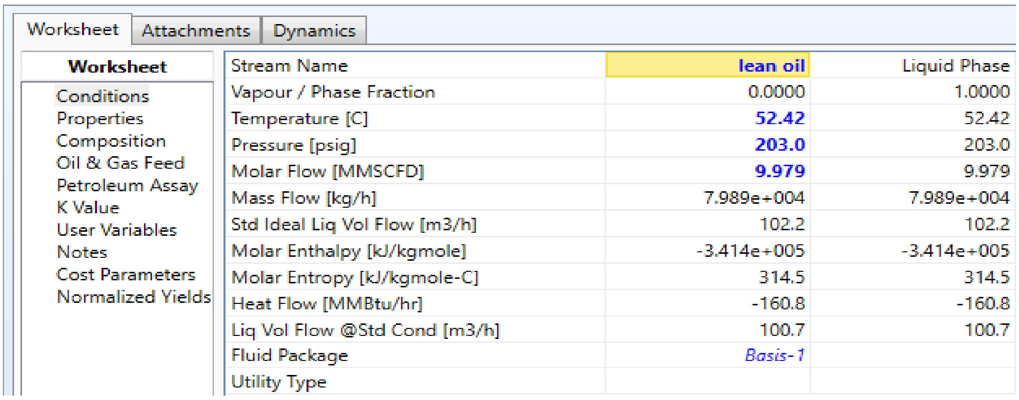


Fig. 11. Process flow diagram for the absorption of LPG in oil

Figure 12 shows the conditions of the kerosene (solvent), which is entered at the top of the absorption column. The major factor is the optimum flow rate of the solvent, which can recover most of the LPG from the off-gases stream [16,17].



Stream Name	lean oil	Liquid Phase
Vapour / Phase Fraction	0.0000	1.0000
Temperature [C]	52.42	52.42
Pressure [psig]	203.0	203.0
Molar Flow [MMSCFD]	9.979	9.979
Mass Flow [kg/h]	7.989e+004	7.989e+004
Std Ideal Liq Vol Flow [m3/h]	102.2	102.2
Molar Enthalpy [kJ/kgmole]	-3.414e+005	-3.414e+005
Molar Entropy [kJ/kgmole-C]	314.5	314.5
Heat Flow [MMBtu/hr]	-160.8	-160.8
Liq Vol Flow @Std Cond [m3/h]	100.7	100.7
Fluid Package	Basis-1	
Utility Type		

Fig. 12. Lean oil (solvent) parameters

To find out the optimum flow rate of the solvent, the case study is important. As it is clear from Figure 13 that almost 95% of LPG is recovered while having a flow rate of approximately 10 MMSCFD.

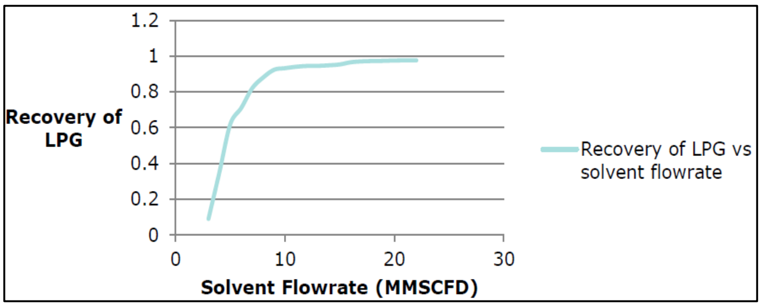
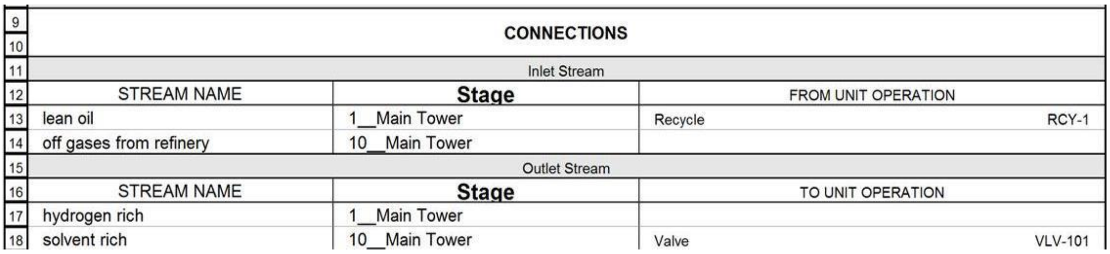


Fig. 13. A case study for solvent optimum flow rate

Figure 14 shows the connections of lean oil absorber.



CONNECTIONS

Inlet Stream

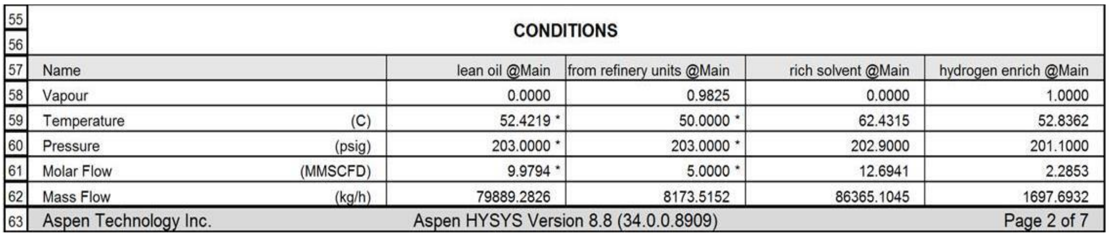
STREAM NAME	Stage	FROM UNIT OPERATION	
lean oil	1__Main Tower	Recycle	RCY-1
off gases from refinery	10__Main Tower		

Outlet Stream

STREAM NAME	Stage	TO UNIT OPERATION	
hydrogen rich	1__Main Tower		
solvent rich	10__Main Tower	Valve	VLV-101

Fig. 14. Connections of lean oil absorber

Figure 15 shows the conditions and parameters of the lean oil absorber.



CONDITIONS

Name		lean oil @Main	from refinery units @Main	rich solvent @Main	hydrogen enrich @Main
Vapour		0.0000	0.9825	0.0000	1.0000
Temperature	(C)	52.4219 *	50.0000 *	62.4315	52.8362
Pressure	(psig)	203.0000 *	203.0000 *	202.9000	201.1000
Molar Flow	(MMSCFD)	9.9794 *	5.0000 *	12.6941	2.2853
Mass Flow	(kg/h)	79889.2826	8173.5152	86365.1045	1697.6932

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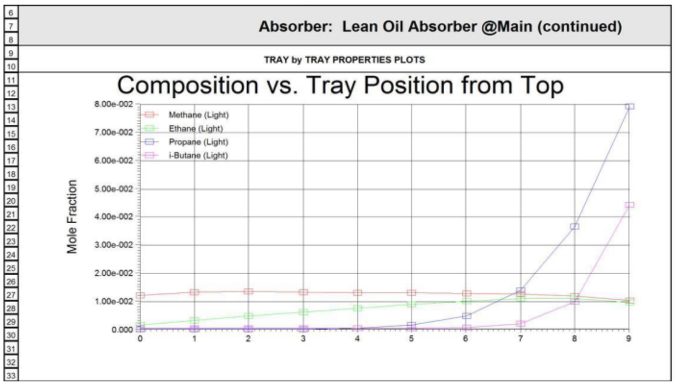
Fig. 15. Conditions and parameters of lean oil absorber

Figure 16 shows the optimum number of plates for the absorber column. If place 10 plates in the absorber column can get negligible LPG losses, which will certainly improve the percent recovery [18,19].


Absorber: Lean Oil Absorber @Main (continued)

TRAY by TRAY PROPERTIES PLOTS

Fig. 16. Composition versus tray position from the top

Figure 17 case study concludes that if no of the trays in the absorber unit is lea than 10 plates, then adequate losses of LPG will occur in the column. To save LPG from losses and to erect an absorption column with minimum cost, 10 plates are optimum for this column.

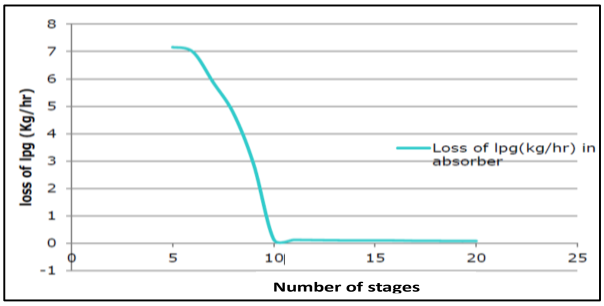
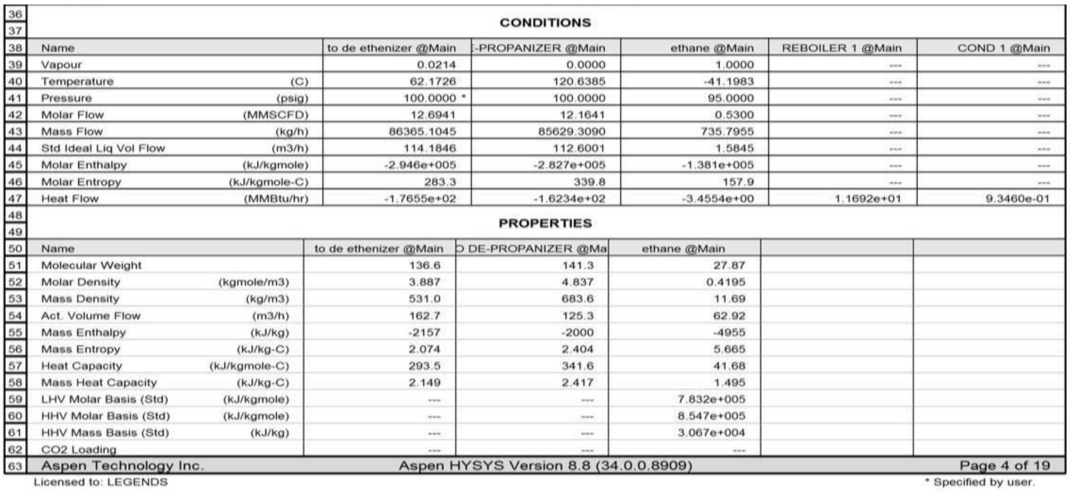


Fig. 17. A case study for optimization of LPG loss

2.4 De-Ethanizer Column

Figure 18 shows the condition and properties of the de-ethanizer column and Figure 19 shows the specifications and parameters of the de-ethanizer column.


CONDITIONS

Name		to de ethenizer @Main	-PROPANIZER @Main	ethane @Main	REBOILER 1 @Main	COND 1 @Main
Vapour		0.0214	0.0000	1.0000	---	---
Temperature	(C)	62.1726	120.6385	-41.1983	---	---
Pressure	(psig)	100.0000 *	100.0000	95.0000	---	---
Molar Flow	(MMSCFD)	12.6941	12.1641	0.5300	---	---
Mass Flow	(kg/h)	86365.1045	85629.3090	735.7955	---	---
Std Ideal Liq Vol Flow	(m3/h)	114.1846	112.6001	1.5845	---	---
Molar Enthalpy	(kJ/kgmole)	-2.946e+005	-2.827e+005	-1.381e+005	---	---
Molar Entropy	(kJ/kgmole-C)	283.3	339.8	157.9	---	---
Heat Flow	(MMBtu/hr)	-1.7655e+02	-1.6234e+02	-3.4554e+00	1.1692e+01	9.3460e-01

PROPERTIES

Name		to de ethenizer @Main	D DE-PROPANIZER @Ma	ethane @Main		
Molecular Weight		136.6	141.3	27.87		
Molar Density	(kgmole/m3)	3.887	4.837	0.4195		
Mass Density	(kg/m3)	531.0	683.6	11.69		
Act. Volume Flow	(m3/h)	162.7	125.3	62.92		
Mass Enthalpy	(kJ/kg)	-2157	-2000	-4955		
Mass Entropy	(kJ/kg-C)	2.074	2.404	5.665		
Heat Capacity	(kJ/kgmole-C)	293.5	341.6	41.68		
Mass Heat Capacity	(kJ/kg-C)	2.149	2.417	1.495		
LHV Molar Basis (Std)	(kJ/kgmole)	---	---	7.832e+005		
HHV Molar Basis (Std)	(kJ/kgmole)	---	---	8.547e+005		
HHV Mass Basis (Std)	(kJ/kg)	---	---	3.067e+004		
CO2 Loading		---	---	---		

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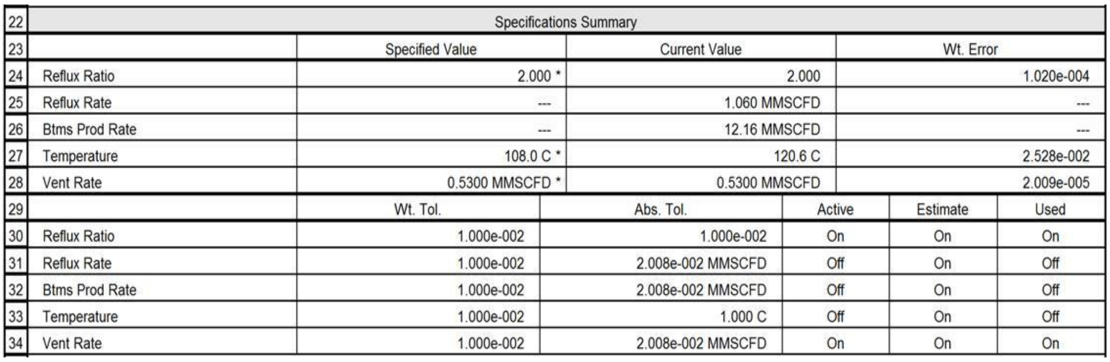
* Specified by user.

Fig. 18. Condition and properties of the de-ethanizer column



22	Specifications Summary			
23		Specified Value	Current Value	Wt. Error
24	Reflux Ratio	2.000 *	2.000	1.020e-004
25	Reflux Rate	---	1.060 MMSCFD	---
26	Btms Prod Rate	---	12.16 MMSCFD	---
27	Temperature	108.0 C *	120.6 C	2.528e-002
28	Vent Rate	0.5300 MMSCFD *	0.5300 MMSCFD	2.009e-005

29		Wt. Tol.	Abs. Tol.	Active	Estimate	Used
30	Reflux Ratio	1.000e-002	1.000e-002	On	On	On
31	Reflux Rate	1.000e-002	2.008e-002 MMSCFD	Off	On	Off
32	Btms Prod Rate	1.000e-002	2.008e-002 MMSCFD	Off	On	Off
33	Temperature	1.000e-002	1.000 C	Off	On	Off
34	Vent Rate	1.000e-002	2.008e-002 MMSCFD	On	On	On

Fig. 19. Specifications and Parameters of the de-ethanizer column

Figure 20 case study provides us information about the maximum phase separation spot in the stripper column. At 10th plate can have optimum results, which will help us in generating healthy recovery of LPG [20].

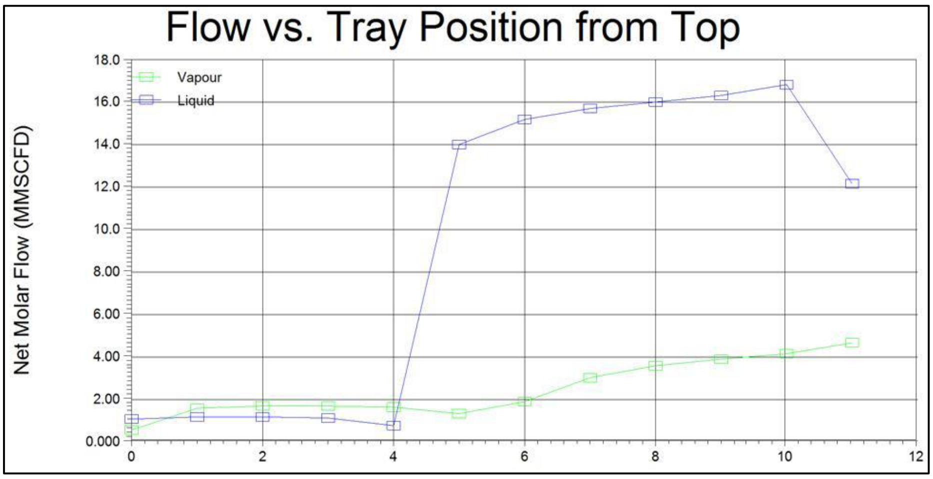


Fig. 20. A case study of flow versus tray position from the top of the de-ethanizer column

Vent rate is an important specification on the de-ethanizer column, as it can be a cause for LPG loss along with ethane at the top of the column. Figure 21 observed the case study. The optimum vent rate is 0.53 MMSCFD. Almost 98% of ethane is recovered at this vent rate, which means only 2 % of LPG losses occur, which is a negligible loss [11,21].

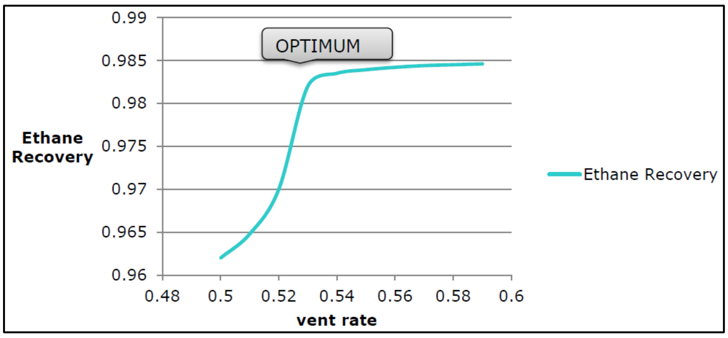
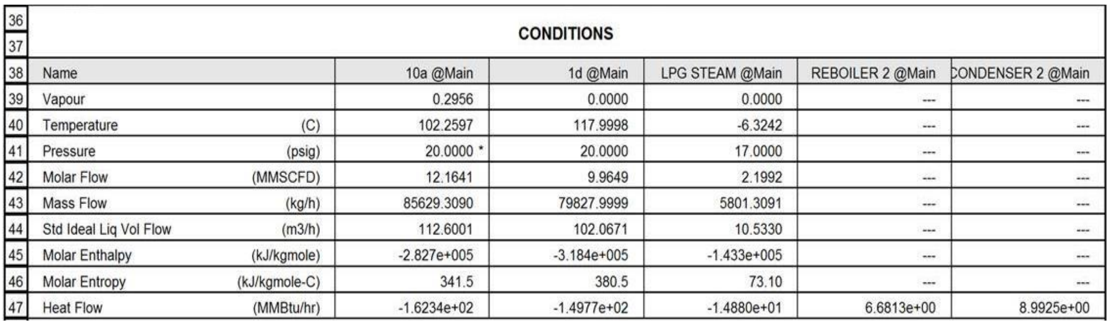


Fig. 21. A case study for maximum ethane recovery from de-ethanizer

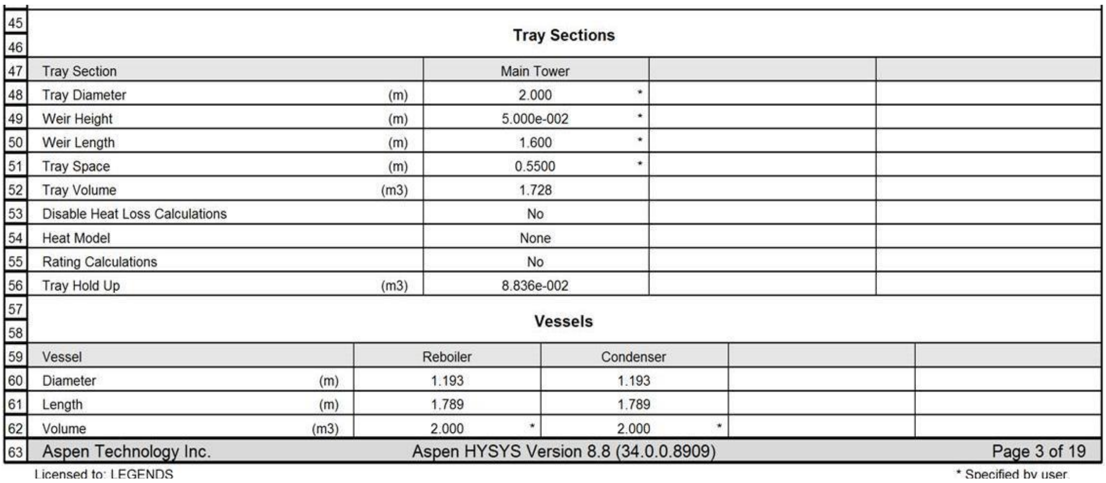
2.5 De-Propanizer Column

Figure 22 and Figure 23 show the conditions and design parameters of the de-propanizer column.



36						
37	**CONDITIONS**					
38	Name	10a @Main	1d @Main	LPG STEAM @Main	REBOILER 2 @Main	CONDENSER 2 @Main
39	Vapour	0.2956	0.0000	0.0000	---	---
40	Temperature (C)	102.2597	117.9998	-6.3242	---	---
41	Pressure (psig)	20.0000 *	20.0000	17.0000	---	---
42	Molar Flow (MMSCFD)	12.1641	9.9649	2.1992	---	---
43	Mass Flow (kg/h)	85629.3090	79827.9999	5801.3091	---	---
44	Std Ideal Liq Vol Flow (m3/h)	112.6001	102.0671	10.5330	---	---
45	Molar Enthalpy (kJ/kgmole)	-2.827e+005	-3.184e+005	-1.433e+005	---	---
46	Molar Entropy (kJ/kgmole-C)	341.5	380.5	73.10	---	---
47	Heat Flow (MMBtu/hr)	-1.6234e+02	-1.4977e+02	-1.4880e+01	6.6813e+00	8.9925e+00

Fig. 22. Conditions of de-propanizer column



45				
46	**Tray Sections**			
47	Tray Section	Main Tower		
48	Tray Diameter (m)	2.000 *		
49	Weir Height (m)	5.000e-002 *		
50	Weir Length (m)	1.600 *		
51	Tray Space (m)	0.5500 *		
52	Tray Volume (m3)	1.728		
53	Disable Heat Loss Calculations	No		
54	Heat Model	None		
55	Rating Calculations	No		
56	Tray Hold Up (m3)	8.836e-002		

57					
58	**Vessels**				
59	Vessel	Reboiler	Condenser		
60	Diameter (m)	1.193	1.193		
61	Length (m)	1.789	1.789		
62	Volume (m3)	2.000 *	2.000 *		

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Fig. 23. Design parameters of the de-propanizer column

The bottom product of the de-propanizer solvent is to be recycled, so it mustn't contain light fractions in it. Figure 24 shows an optimum column height by calculating the best no of plates, which give maximum phase separation. The recycled solvent carries kerosene along with C5 and C6 components.

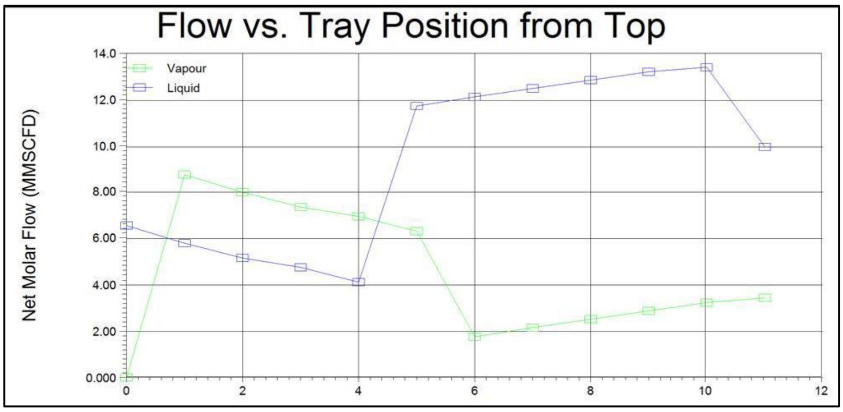


Fig. 24. A case study of flow versus tray position from the top of de-propanizer

3. Results

This LPG is a valuable fuel, is gaining a key reputation in the global market due to its widespread use. The crisis can be addressed to a certain extent by making purposeful use of fuel resources available currently, which includes solar energy, ethanol and biogas diesel. LPG is being recovered by different processes like cryogenic process, double-wall column process, membrane process, and absorption process through different solvents. This research aims to do a comparative analysis between two techniques, cryogenic technique and absorption technique using kerosene as a solvent. This study recovered more than 90% LPG by both techniques and with a reasonable purity level. Absorption technology and cryogenic technique are simulated using ASPEN HYSYS V8.8 and calculations are further rechecked linking values from ASPEN HYSYS to Microsoft EXCEL and by applying different formulae. The operating cost found for the cryogenic technique is higher than the absorption process. The results showed that the absorption technology is better than cryogenic technique while issues like compressors compressibility factor, high cost and life-cycle of equipment would be resolved.

3.1 Comparative Analysis of Cryogenic and Absorption Techniques for the Recovery of LPG from Off Gases

Liquefied petroleum gas abbreviated as LPG is an efficient nontoxic, odorless, environment-friendly hydrocarbon fuel which comprises propane and butane primarily with some fractions of ethane and pentane. As the fuel represents the family of lighter hydrocarbons from C1-C5, it is also termed as gas liquids. The concentration of propane and butane in LPG varies by the season. That is, the fuel sold includes more propane in winter while butane is a prime component in summer. A powerful odorant ethanethiol is added in an odorless fuel for leakage detection. The international standard of LPG is EN 589. The LPG was developed at the beginning of the 20th century, which is indeed very late in the oil and gas business. It was developed when the scientist was working on the problem of quick gasoline evaporation and in 1911, an American scientist found that there are two gases propane and butane in gasoline, which causes its quick evaporation so they should be removed. He found methods to remove these gases from gasoline and these removed gases are LPG. LPG is fuel and like normal fuel, it produces carbon dioxide and water when it is combusted with a sufficient amount of air. Less amount of air than required results in incomplete combustion, which gives toxic gas that is carbon mono oxide [11,14].

3.2 Economic Evaluation

The economic investigation of the cryogenic and absorption process is carried out utilizing ASPEN Economic Analyzer V8.8. It is a cost assessing programming that gives CAPEX evaluations and OPEX estimates for relating and screening various procedure plans. It depends on model-based estimation to produce capital cost and operating cost estimates. Key highlights incorporate interactive equipment to decide working expenses and venture investment analysis and programmed generation of block and procedure stream diagrams. It is coordinated with process simulators systems Aspen HYSYS and Aspen Plus, sparing time and eliminating mistakes brought about by physically moving information between process structure and estimation departments. With Activated Economics, process simulation clients can create CAPEX and OPEX assessments utilizing a similar expense evaluating programming as estimators [22].

The simulated cryogenic and absorption methods are analyzed through the ASPEN Economic analyzer. The equipment used in the absorption process includes pumps, reboiler absorbers and absorption column. And the equipment utilized in cryogenic is Heat Exchanger, coolers, expanders, separators, compressors, mixer and distillation column. The economic analysis for the equipment capital cost is carried for an off-gases flow rate of 10 MMSCFD. For the off-gases stream of 10 MMSCFD, the equipment cost of the Expander procedure is incredibly higher than that of the absorption procedure. For the expander procedure, the equipment cost is 10.07 million USD and for the equipment procedure, it is 7.8 million USD, as appeared in Figure 25 [3,5].

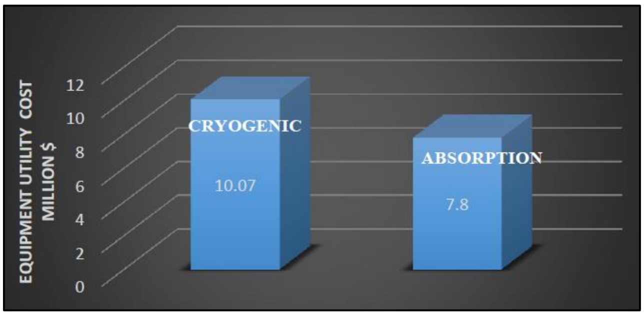
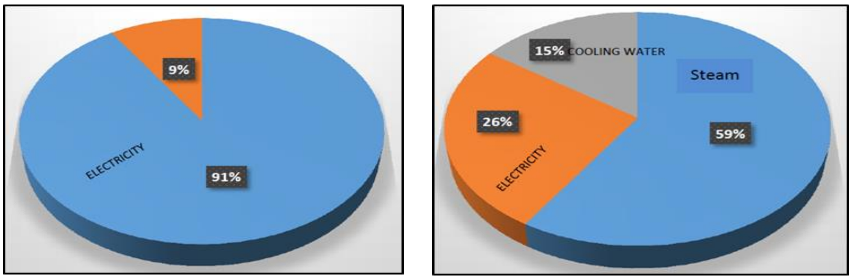


Fig. 25. Cryogenic versus Absorption equipment's

Operating cost is looked at dependent on utility utilization by each procedure. The significant utility in the absorption procedure is steam that is us in reboiler for the recovery of the lean oil solvent. Different utilities are cooling water and power. In the expander procedure, the significant utility utilization is power and cooling water is additionally utilized. Operating examination is made for flue gas stream rate running somewhere in the range of 1 and 200 MMSCFD. The working expense is higher for the expander procedure when contrasted with the assimilation procedure. For 10 MMSCFD stream of off-gases, the working or utility expense of the cryogenic procedure is 356.77 USD/hr and for the retention procedure, it is 239.07 USD/hr. This gap in working cost increments as the flow rate of off-gases increments. Figure 26 shows the comparison.

Fig. 26. Cryogenic versus Absorption utility cost

As discussed above that the major utility for the absorption process is steam, whereas, for the expander process, the major utility is electricity. In the expander process, 91% of the total operating cost came from electricity consumption and 9% from cooling water consumption. And for the absorption process, steam constitutes 59% of total operating cost, cooling water 26% and electricity 15%. The pie charts are shown in Figure 27.



(a) (b)

Fig. 27. Utility distribution cost (a) Cryogenic (b) Absorption

Figure 28 shows the absorption and cryogenic product purity. The limitation is the maximum allowable heavier hydrocarbons (C5+) in LPG is 7%.

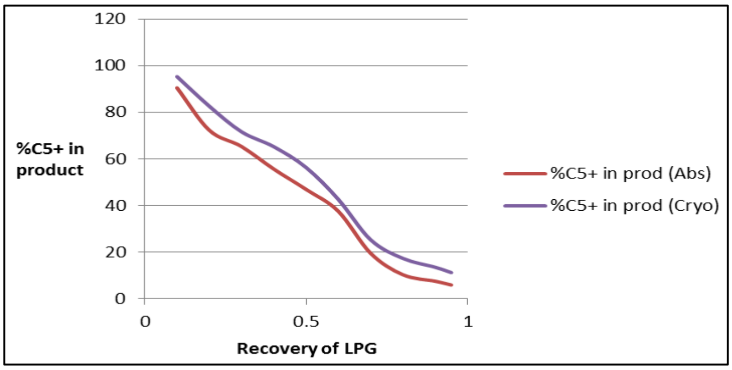


Fig. 28. Absorption and cryogenic products purity

Figure 29 shows the utility cost of absorption and cryogenic techniques.

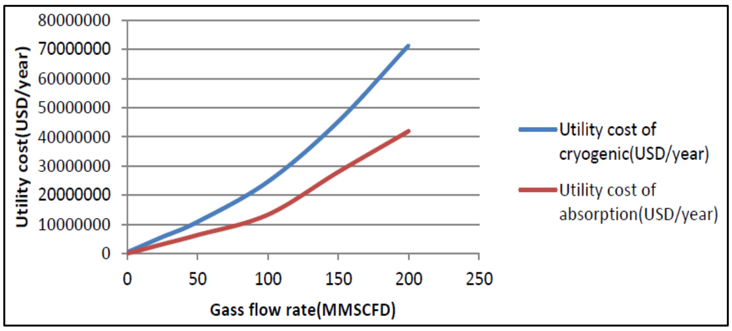
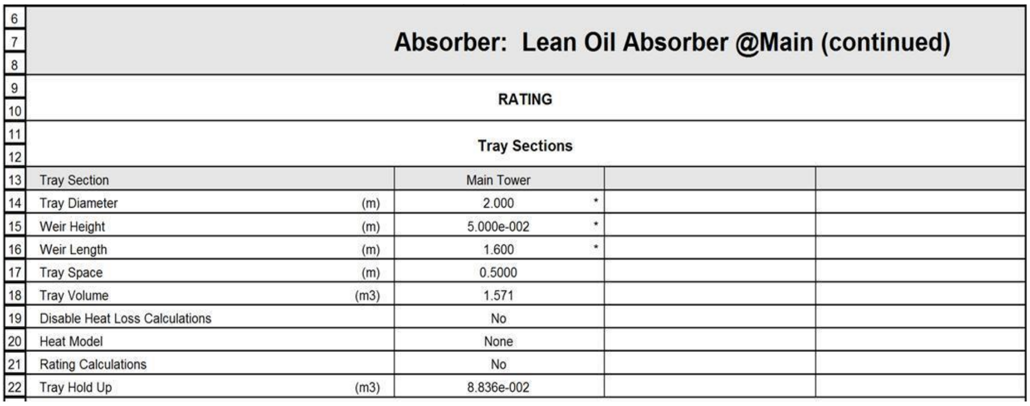


Fig. 29. Absorption versus Cryogenic utilities

The most feasible recovery process is through absorption in kerosene due to the advantages it has over other techniques. This process utilizes all the available raw materials within a refinery that are kerosene obtained from the crude oil is used for absorption purposes, so the cost for purchasing oil for absorption is cut down. According to this research work, the expander partition has a higher working expense than the absorption strategy, which is financially advantageous. Another factor of decision is utilities accessible since membrane separation, for the most part, required electricity and little amount of water. Thusly membrane separation is an earlier choice in the remote zones where utilities like cooling water and steam are not effectively accessible. Convincingly, expander separation is efficient for little to the medium progression of off-gases and higher stream rates; absorption is the favored procedure [21].

3.3 Equipment Designing of Absorption Column

Absorption is utilized to separate gas mixtures; expel contaminations, contaminants, toxins, or catalyst harms from a gas; and recoup significant chemicals. Figure 30 shows the lean oil absorber structure parameters. In the absorber segment, plate sections can deal with a wider range of liquid and gas stream proportions than packed columns. Packed columns are not reasonable for extremely low fluid rates. The productivity of a plate can be projected with more conviction than the equal term for packing (HTU or HETP). Plate columns can be planned with more assertion than packed columns. There is some uncertainty in every case that great fluid distribution can be retained up all through a packed column under every single working condition, particularly in large segments. It is simpler to make cooling in a plate segment; coils can be presented on the plates. It is simpler to have a withdrawal of side-streams from plate segments [4].



Absorber: Lean Oil Absorber @Main (continued)

RATING

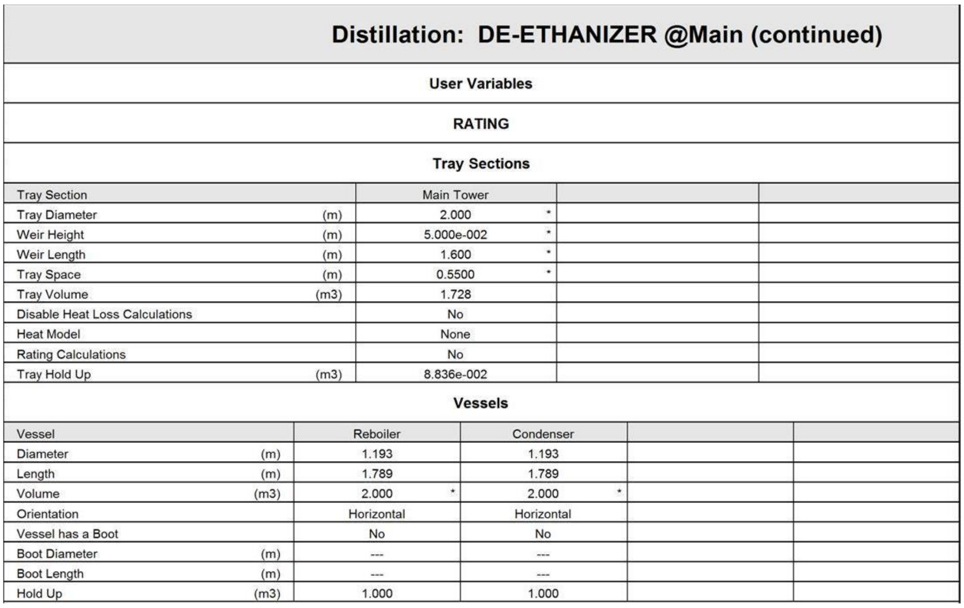
Tray Sections

Tray Section		Main Tower		
Tray Diameter	(m)	2.000 *		
Weir Height	(m)	5.000e-002 *		
Weir Length	(m)	1.600 *		
Tray Space	(m)	0.5000		
Tray Volume	(m3)	1.571		
Disable Heat Loss Calculations		No		
Heat Model		None		
Rating Calculations		No		
Tray Hold Up	(m3)	8.836e-002		

Fig. 30. Lean oil absorber design parameters

3.4 Equipment Designing of Distillation Column

Distillation is a procedure that isolates at least two segments into an overhead distillate and bottoms. The bottoms item is only fluid, whereas the distillate might be fluid or fume or both. The separation method involves three things. Initial, a subsequent stage must be shaped so both fluid and fume stages are available and can reach each other on each phase inside a separation column. Besides, the segments have various volatilities with the goal that they will separate among the two stages to an alternate degree. In conclusion, the two stages can be separated by gravity and mechanical methods. Distillation contrasts from absorption and stripping in that the subsequent stage is made by thermal methods. Figure 31 shows the de-ethanizer segment plan parameters. Table 1 shows the ideal temperature distinction.



Distillation: DE-ETHANIZER @Main (continued)

User Variables

RATING

Tray Sections

Tray Section		Main Tower		
Tray Diameter	(m)	2.000 *		
Weir Height	(m)	5.000e-002 *		
Weir Length	(m)	1.600 *		
Tray Space	(m)	0.5500 *		
Tray Volume	(m3)	1.728		
Disable Heat Loss Calculations		No		
Heat Model		None		
Rating Calculations		No		
Tray Hold Up	(m3)	8.836e-002		

Vessels

Vessel		Reboiler	Condenser		
Diameter	(m)	1.193	1.193		
Length	(m)	1.789	1.789		
Volume	(m3)	2.000 *	2.000 *		
Orientation		Horizontal	Horizontal		
Vessel has a Boot		No	No		
Boot Diameter	(m)	---	---		
Boot Length	(m)	---	---		
Hold Up	(m3)	1.000	1.000		

Fig. 31. De-ethanizer column design parameters

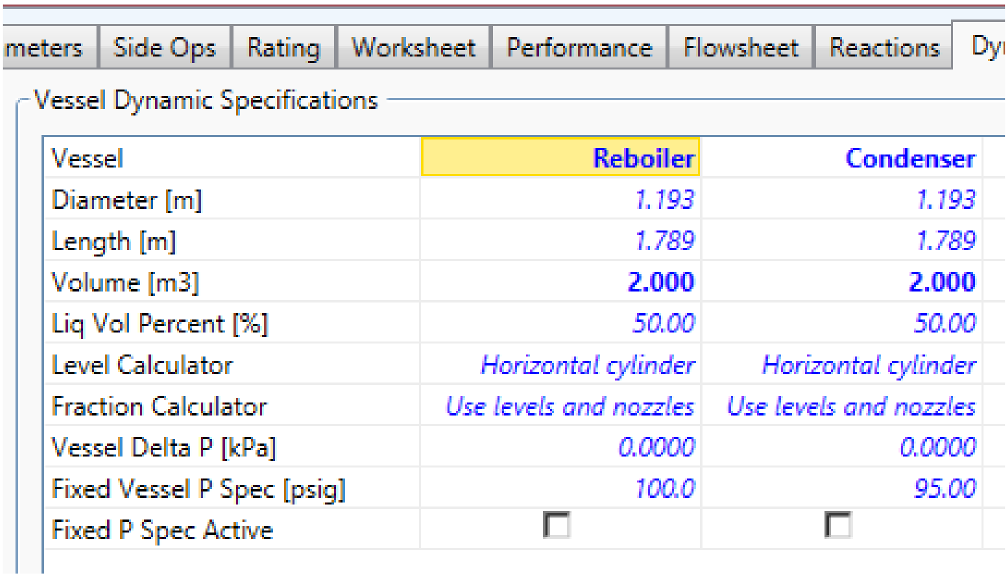
Distillation is the most affordable method for separating mixtures of fluids. If comparative volatilities of segments, distillation turns out to be extravagant (Douglas, 1988) and extraction or receptive refining ought to be thought of. Sieve trays are metal plates with openings in them. Vapour goes upward through the fluid on the plate. The direction of fume and fluid stream through a plate and a column. Each plate has two conductors on both sides, called down comers. Fluid falls through the down comers by gravity from one plate to another below it [4,12].

Table 1
Optimum temperature difference

Parameters	Temperature 'K'
Condenser	
Refrigeration	3-10
Cooling water	6-20
Pressurized fluid	10-20
Boiling water	20-40
Air	20-50
Reboiler	
Process fluid	10-20
Steam	10-60
Hot oil	20-60

A weir on the plate assurances that there is some fluid (holdup) on the plate and is structured such that the holdup is at a suitable height, to such an extent that the bubble caps are protected by fluid. Being lighter, fume streams up the section and is forced to go through the fluid, by the openings on each plate. The section of fumes on every plate is termed as the active tray zone.

Figure 32 shows the de-ethanizer section plan parameters of dynamic vessel particulars. Steam boiler is an equipment used to change over the fluid into high-pressure fume. As a rule, the fluid is bubbled in a shell with the assistance of hot channels (tubes). On the outside surface of the cylinders, fluid changes its stage by watching heat (dormant warmth + reasonable warmth). Thusly, the necessary high temperature of the hot cylinders is kept up by circling low weight or high-pressure steam inside the cylinders. Because of the temperature affectability of the material and pace of fume development, bubbling is done inside or outside of the cylinders [18].



Vessel Dynamic Specifications

Vessel	Reboiler	Condenser
Diameter [m]	1.193	1.193
Length [m]	1.789	1.789
Volume [m3]	2.000	2.000
Liq Vol Percent [%]	50.00	50.00
Level Calculator	Horizontal cylinder	Horizontal cylinder
Fraction Calculator	Use levels and nozzles	Use levels and nozzles
Vessel Delta P [kPa]	0.0000	0.0000
Fixed Vessel P Spec [psig]	100.0	95.00
Fixed P Spec Active	☐	☐

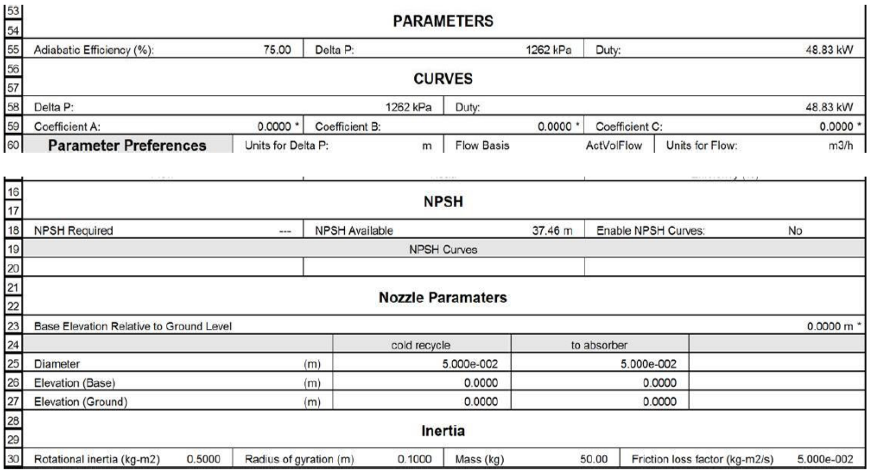
Fig. 32. De-ethanizer column design parameters of dynamic vessel specification

The tube bundle is inundated in a pool of fluid at the base of the column in a larger than usual shell. Kettle reboiler is additionally called a "submerged bundle reboiler." The height of the tube bundle is generally 40 to 60% of the shell ID. The submergence of the tube bundle is guaranteed by a flood weir at the height of regularly 5-15 cm from the upper surface of topmost cylinders—the favorable position reasonable for vacuum activity and high vaporization rate up to about 80% of the feed. Low heat transfer rate than different kinds as there is no fluid course (low speed); not proper for fouling liquids; kettle reboiler isn't appropriate for heat-delicate materials as it has higher habitation time.

The change from the fluid stage to the fume stage is known as vaporization and the opposite stage move is condensation. The change from a fluid to fume or fume to fluid happens at one temperature (named as saturation or equilibrium temperature) for the pure liquid compound at a given pressure. The mechanical act of vaporization and condensation happens at practically constant pressure; hence, the stage change happens isothermally. Condensation happens by two diverse physical components that are film condensation and drop-wise condensation [23]. The idea of the condensation relies on whether the condensate (fluid shaped from fume) wets or doesn't wet the strong surface. If the condensate wets the surface and streams on a superficial level as a film, it is called film condensation. At the point when the condensate doesn't wet the strong surface and the condensate is collected as droplets, it is drop-wise buildup. The heat transfer coefficient is around 4 to multiple times higher for dropwise condensation. The condensate frames a fluid film on the uncovered surface if there should be an occurrence of film condensation. The heat transfer coefficient is lower for film condensation because of the obstruction of this fluid film. Dropwise condensation generally happens on new, spotless and cleaned surfaces. The heat exchanger utilized for condensation is known as a condenser. In modern condensers, film condensation ordinarily happens [5,18].

3.5 Equipment Designing of Centrifugal Pump

These are a sub-class of dynamic axisymmetric work-engrossing turbomachinery, utilized to move liquids by the change of rotational active vitality to the hydrodynamic vitality of the liquid stream. Figure 33 shows the centrifugal siphon P-100 structuring.



53 54	PARAMETERS						
55	Adiabatic Efficiency (%):	75.00	Delta P:	1262 kPa	Duty:	48.83 kW	
56 57	CURVES						
58	Delta P:	1262 kPa	Duty:	48.83 kW			
59	Coefficient A:	0.0000 *	Coefficient B:	0.0000 *	Coefficient C:	0.0000 *	
60	**Parameter Preferences**	Units for Delta P:	m	Flow Basis	ActVolFlow	Units for Flow:	m3/h

16 17	NPSH							
18	NPSH Required	---	NPSH Available	37.46 m	Enable NPSH Curves:	No		
19	NPSH Curves							
20								
21 22	Nozzle Paramaters							
23	Base Elevation Relative to Ground Level	0.0000 m *						
24			cold recycle	to absorber				
25	Diameter	(m)	5.000e-002	5.000e-002				
26	Elevation (Base)	(m)	0.0000	0.0000				
27	Elevation (Ground)	(m)	0.0000	0.0000				
28 29	Inertia							
30	Rotational inertia (kg-m2)	0.5000	Radius of gyration (m)	0.1000	Mass (kg)	50.00	Friction loss factor (kg-m2/s)	5.000e-002

Fig. 33. Centrifugal pump P-100 Design

The accessible Net Positive Suction Head (NPSH or NPSHA) a proportion of how close the liquid at a given point is too blazing thus to cavitation. The required NPSH (NPSHR) the head an incentive at a particular point (the inlet of a siphon) required to shield the liquid from enrapturing the siphon thus. Bubbling starts when the pressure in the fluid is diminished to the fume pressure of the liquid at the actual temperature. To portray the potential for bubbling and cavitation, the distinction between the all-out head on the suction side of the siphon - near the impeller, and the fluid fume pressure at the actual temperature can be utilized [23]. The fluids fume head at the real temperature can be stated as;

$$h_v = p_v / \gamma_{vapor} \tag{1}$$

where; h_v = vapor head in m or inch, p_v = vapor pressure in m or inch, γ_{vapor} = specific weight of the vapor in N/m^3 or lb/ft^3.

The vapor pressure in a liquid relies upon the temperature. Water, the most normal liquid, begins bubbling at 20 ^{o}C if the absolute pressure is 2.3 kN/m^2. For a 47.5 kN/m^2 absolute pressure of, the water begins bubbling at 80 ^{o}C and 101.3 kN/m^2 (typical climate), the bubbling beginnings at 100 ^{o}C [3,6,7,19].

4. Conclusions

This research focuses on bridging up with the uprising demand of LPG in the country since it aims at the recovery of LPG from waste gases in a fuel oil refinery. The research has been proved to be beneficial for the industry as it generates profit out of waste gases as well as for the market since it would cater to the shortage of LPG in the country. The economic analysis and cost estimation have yielded the project feasible as well as highly profitable. This research encloses the detailed description of the process, designing of equipment followed by basic knowledge regarding LPG, its use, applications, storage considerations and environmental aspects. The scope of this study can be elaborated and it can be applied to the recovery of LPG from refinery off-gases. The waste gases currently being flared at these plant sites can be used to recover LPG from them and cope up with the shortage in the country.

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