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Optimized Process Scheme Selection for Nitrogen Removal from Natural Gas and Present Accurate Equation of State Model

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ABSTRACT

This study presents applications of various Equation of State (EOS) models (including specifically, Peng-Robinson, Soave Redlich-Kwong, and Peng–Robinson–Stryjek–Vera), in the simulation of the process for removing nitrogen (N_2) from the natural gas (pre-treated) on Aspen HYSYS v11 using the cryogenic distillation method. Different equations of state models were applied to analyze the efficiency of the process and to make a comparison between the models, in removing the incoming nitrogen content from feed gas, also to identify and troubleshoot the problems occurring during the simulation phase of the work by applying different models keeping the process scheme and feed stream conditions and the composition same for each model utilized. The basic theme selected for the process was the cryogenic distillation, since it is the most widely adopted and efficient method comparable to all other methods being used for the same purpose of work. The pre-treated feed gas stream passes through various processing equipment's employing physical means of operations (energy transfer, separation etc.). It was observed that the percentage error between the plant data results and simulated results for nitrogen removal was 3.14% by using Peng-Robinson EoS model which is the most accurate comparatively to the other EoS models used, methane recovery was observed 99% and total nitrogen removal was 91.2% which is highest percentage removal observed. The objective of the project was to select optimized process scheme and select the best Equation of state model and by the all the critical analysis it was observed Peng-Robinson EoS model is best among all the EoS models used.

Keywords:

Natural gas
Cryogenic distillation
Nitrogen Removal
Aspen HYSYS

List of Abbreviations

AP	Aspen Plus
BTU	British Thermal Unit
EOS	Equation of State
GPM	Gallons Per Minute
HP	High Pressure
HP	High pressure
LNG	Liquefied Natural Gas
NGL	Natural Gas Liquids
NO_x	Nitrogen Oxides
NPSH	Net Positive Suction Head
NRTL	Non-Random Two-Liquid
NRU	Nitrogen Rejection Unit
OGRA	Oil and Gas Regulatory Authority
PPM	Parts Per Million
PR	Peng-Robinson
PRSV	Peng-Robinson-Stryjek-Vera
PSA	Pressure Swing Adsorption
RK	Redlich Kwong
SRK	Soave-Redlich-Kwong
TEG	Tri-Ethylene Glycol
UA	Overall Heat Transfer Coefficient
UNIFAC	Universal Quasi Chemical Functional Group Activity Coefficients
UNIQUAC	Universal Quasi Chemical

1. Introduction

Natural gas is a complex mixture of hydrocarbon and non-hydrocarbon elements and exists as a gas under atmospheric situations. It is a mineral strength source deep underground. Natural gas is the most energy efficient fuel with extensive energy-saving benefits, used in the area of oil or coal. Besides similarity to gasoline, it is also a hydrocarbon supply of petrochemical feedstock and a first-rate supply of elemental sulfur [1]. For the accurate measurements of hydrocarbons, their representative sampling and overall pipeline operations, determination of their fluid properties and hydrocarbon mixtures phase conditions are crucial [2]. Compressibility factors are required for the standard treatment of phase behavior and for quick estimation of initial gas in place as well as when it comes on dealing with gas metering. Measurement of gas properties, Pressure–Volume–Temperature (PVT), in laboratory using reservoir samples Standing is industry standard. [3]

PVT assessment has two approaches: 1) Simulation approach based on equation of state (EOS), 2) Correlation approach which is based on the statistical analysis of research results. [4]. Typical composition of natural gas is given in Table 01.

Table 01: Typical Composition of Natural Gas

Components	**Volume (%)**
Methane	>85
Ethane	3-8
Propane	1-2
Butane	<1
Pentane	<1
Carbon dioxide	1-2
Hydrogen Sulfide	<1
Helium	1-5

Table 02 describes the typical pipeline quality natural gas composition in Pakistan [5].

Nitrogen is an inevitable part of natural gas, and its value by mixing varies with different sources of natural gas pools. Because of its inert nature, it is difficult to remove nitrogen.

However, it is important to remove nitrogen gas from natural gas for the following reasons [1].

Table 02: Typical Pipeline Natural Gas composition in Pakistan

Components	**Mole (%)**
Methane	85
Ethane	5
Propane	2
Butane	1
Higher Hydrocarbons	1.5
Carbon dioxide	2
Nitrogen	3.5

Nitrogen lowers the amount of BTU gas and makes it unusable in most pipelines. Frequent, high nitrogen content leads to reduced gas regeneration. Low nitrogen gas recovery directly affects the processing costs and, therefore, the process economy. The cost of removing nitrogen from low-grade gas increases costs and operating costs for gas processing to the point where the economy is worse. In order to store or transport natural gas in liquid form, the nitrogen content must be less than 1%. Nitrogen pollutants found everywhere in natural gas at low temperatures and pose a safety concern to the transport and storage of liquefied natural gas (LNG). Liquid natural gas (LNG) should not contain more than 1% nitrogen to avoid storage problems. To make money with nitrogen-rich gas fields, the available gas can be combined with another low-nitrogen gas stream or NRU can be installed.

There are various methods for the removal of nitrogen from natural gas which includes cryogenic distillation, membrane technique, pressure swing adsorption, molecular gate adsorption and absorption etc. In membrane technique, a typical membrane system includes a filter treatment unit and a heater for the operation adjustment of the separation system. But design complexity and compression requirements are the major drawbacks of this technique. The pressure swing adsorption procedure involves adsorption at high pressure, desorption at low pressure. As a result, the adsorbent bed is renewed. The adsorbent can be regenerated, leaving a highly pure nitrogen stream. But it is suitable for smaller scale gas processing facilities and includes non-durability of the materials used in novel gas processing technologies and a moderate methane recovery.

The Molecular gate adsorption technique is based totally on using titanium silicate molecular filters, wherein pore sizes are installed at some point of the manufacturing process. Product compression is required where the product is routed to a high-pressure transmission pipeline, pipeline gas sales can be complex and includes moderate recovery of methane.

Absorption uses a liquid solution to separate the gas mixture from the absorption tower. But refusal of nitrogen using liquid-based technology is not widely used in natural gas plants mainly due to the difficulty of finding the right liquid solution that can absorb methane or nitrogen effectively [6].

Cryogenic distillation is the best among the available methods. Cryogenic distillation is the most common and proves to be the most economical and provides the higher recovery of nitrogen from the natural gas at high gas throughputs [7]. Negligible amount of traces of methane or some other hydrocarbons rejects in nitrogen stream, high hydrocarbons recovery, minimum loss of hydrocarbons by the use of the process, minimal emissions of methane to the atmosphere and maximum amount of methane is provided or supplied in the sales gas for the commercial use. In cryogenic distillation, the variation between nitrogen (normal boiling point = -320.44° F) and methane (normal boiling point = -258.7 ° F) are large enough to drive the separation process successfully. For feeds of less than 30% N_2, a single column structure may be used, and for high concentrations, a two-column tower should be used. Cryogenic distillation has the potential to achieve significant gas purification up to 98% methane recovery and less than 1% methane in the nitrogen vent. Cryogenic processing is used where flow rates are high (usually above 6130.79 ft^3/s) at normal pressure and it requires pre-gas treatment of feed gas to remove moisture and CO_2 also high cost of cryogenic equipment and additional operating costs to extract nitrogen from the natural gas is also encountered. The process simulation using cryogenic distillation was done on Aspen HYSYS v11.

Aspen HYSYS is dynamic simulation software, based on the thermodynamic properties of the streams and calculations for simulating and optimizing the real data process for its dynamic performance over changing parameters and environment so as to check out the feasibility and to achieve maximum efficiency.

The help of thermodynamic models represents pure and mixed compound system's energy levels and phase equilibrium behaviors. They are one of versatile tools in predicting the properties of compounds and species of different kinds including the hydrocarbons over a wide of operating conditions and varying parameters of the system under consideration. 1) For verifying sound speed measurements for an ultrasound meter, and, 2) For inspecting if the conditions through a sample line could result in condensation of a liquid out of a gas phase [8]. Slightly different fluid properties are expected to be obtained from each EOS correlation for identical input conditions [9]. Since the introduction of Van der Wall's equation of state back in 1873, a number of equation of states have been proposed and developed to represent and study the phase behavior of pure substances which were later extended to mixture of fluids using the mixing rules [10].

In this work, a process design is proposed for Nitrogen Removal Unit (NRU). Process intensification is simulated ASP software. Real plant data is set as an input parameters. This study presents applications of various Equation of State (EOS) models (including specifically, Peng-Robinson, Soave Redlich-Kwong, and Peng–Robinson–Stryjek–Vera), in the simulation of the process for removing nitrogen (N_2) from the natural gas (pre-treated) on Aspen HYSYS v11 using the cryogenic distillation method. Different equations of state models were applied to analyze the efficiency of the process and to make a comparison between the models, in removing the incoming nitrogen content from feed gas, also to identify and troubleshoot the problems occurring during the simulation phase of the work by applying different models keeping the process scheme and feed stream conditions and the composition same for each model utilized. The basic theme selected for the process was the cryogenic distillation, since it is the most widely adopted and efficient method comparable to all other methods being used for the same purpose of work. The pre-treated feed gas stream passes through various processing equipment's employing physical means of operations (energy transfer, separation etc.).

2. Mathematical model

Peng-Robinson EOS is mostly used by users during simulation on HYSYS [11]. Peng-Robinson model is extensively used for the systems of non-polar nature, whereas gases being of slightly polar nature can also be dealt accordingly to this model. Hydrocarbons and light gases, such as carbon dioxide, hydrogen sulfide, and hydrogen are a few systems which are worked according to this equation model. API method of the pseudo-components for liquid molar volume are utilized [11]. Peng-Robinson is employed in the simulation of Tri-Ethylene Glycol (TEG) dehydration, with the aromatics, cryogenic Processing of gas, air separation, atmospheric crude towers, vacuum towers, high hydrogen gas (H_2) systems, reservoir systems, inhibition of hydrates and crude systems etc. For the components in the liquid phase (especially, which are nonpolar in nature), it is found to be suitable in predicting there densities before the application of equations.[12] Due to the simplicity and practical applicability of Peng-Robinson in chemical engineering, it claims to be a popular equation for the natural gas systems. [13] The PR equation claims the superiority over SRK equation in predicting the liquid densities. It performs well for the gas and the condensate systems comparatively to the SRK. [14] The model is presented as follows:

$$P=\frac{RT}{V_m-b}-\frac{\alpha}{V_m^2+2abV_m-b^2} \tag{1}$$

$$\alpha=\frac{0.45724R^2T_c^{2.5}}{P_c} \tag{2}$$

$$b=\frac{0.07780RT_c}{P_c} \tag{3}$$

$$\alpha=\{1+(0.37464+1.5422\omega-0.26692\omega^2)(1-T_r^{0.5})\}^2 \tag{4}$$

The Soave-Redlich-Kwong (SRK) model is aimed at improving liquid molar volume using volume correction. Based on cubic state equations, this model is comparable to other equations. Some applications of this model are in gas processing, refinery, and petrochemical units, ethylene plants etc. This model is generally used for the non-polar systems. Whereas systems of slightly polar nature are also satisfied to be evaluated using this property model. For hydrocarbon processing, or supercritical extraction and for high temperature and pressure conditions, this model is particularly suitable. This model proves to provide smooth results within critical region. The conclusions are less valid in the critical point region of the mixture. Whereas, appropriate results are definite at all pressure and the temperature ranges. SR-POLAR, WILSON, NRTL, VANLAAR, or UNIQUAC property models are applied for the systems which are polar in nature [11]. The SRK model equation is typically applied during the simulation of Tri-Ethylene Glycol (TEG) Dehydration, Sour Water, Cryogenic Processing of Gas, Separation of Air, Atmospheric Crude Towers, Vacuum Towers, High Hydrogen (H_2)

Systems, Reservoir Systems, Inhibition of Hydrate, Chemical systems, Alkylation of Hydrogen Fluoride (HF) and Dehydration of Tri-Ethylene Glycol (TEG) with Aromatics. Soave replaced the term of $\propto/\sqrt{T}$ back in 1972, of the Redlich-Kwong equation by the expression α (T, ω), which is in basic a function of temperature, and acentric factor. The function conceived to be suitably fit with the data of vapor pressure for hydrocarbons; thus, the behavior of those substances is described accurately. It could be employed suitably to represent both liquid and vapor phases. Equation of SRK model is given below [12].

$$P = \frac{RT}{V_m - b} - \frac{\alpha}{V_m + b} \tag{5}$$

$$\alpha = \frac{0.45724 R^2 T_c^{2.5}}{P_c} \tag{6}$$

$$b = \frac{0.0866 R T_c}{P_c} \tag{7}$$

$$\alpha = \{1 + (0.48508 + 1.55171\omega - 0.15613\omega^2)(1 - T_r^{0.5})\}^2 \tag{8}$$

Peng–Robinson–Stryjek–Vera (PRSV) equation model is an improved form of the original Peng-Robinson equation of state (EOS). It extends its applicability for to be applied more realistically on the non-polar systems. PRSV model equation of state is broadened to proof successful in being applied and providing accurate results for working with non- ideal systems. This equation has resulted to be more successful in showing better match of the vapor pressures of pure components and the mixtures, comparative to Peng-Robinson model state equation, especially at low vapor pressures. For the systems consisting particularly of dissimilar components, this equation has the capability of forecasting the phase behavior of the hydrocarbon systems suitably. This equation is broadened to include its application for the handling of the non-ideal systems with the accuracies ranging further more. For aqueous systems composed of H_2O, CH_3OH, glycols, as well as systems consisting of other hydrocarbons or non-hydrocarbons in the second liquid phase, PRSV equation of state model also facilitates the user for performing the rigorous three- phase flash calculations [11]. PRSV model equation of state is applied particularly in the simulation Cryogenic Processing of Gas, Air Separation, Chemical systems and Alkylation of Hydrogen Fluoride (HF). An improvement to the attraction term of Peng–Robinson state equation published by Stryjek and Vera back in 1986 (PRSV) improved greatly model's validity by instituting an adaptable parameter for the pure component and by modifying the polynomial fit of acentric factor [7].

PRSV EOS is found to give slightly better predictions of liquid densities than the SRK EOS. For rigorous treatment of hydrocarbon systems, enhanced EOS as PR and the PRSV models are used [15]. The modification thus is,

$$Ꝁ = Ꝁ_0 + Ꝁ_1 \, (1 + T_r^{1/2}) \, (0.7 - T_r) \tag{9}$$

$$Ꝁ = 0.378893 + 1.4897153\omega - 0.17131848\omega^2 + 0.0196554\omega^3 \tag{10}$$

Where, $Ꝁ_1$ is an adjustable parameter of the pure component. Stryjek and Vera publish parameters for pure components in their original journal article for many compounds of industrial importance.

2.1. Defining the system model, NRU

The natural gas feed stream entering at 62.6 °F with a pressure of 763 psig with a mass flow of 2.643×10^5lb/h had the compositions as mentioned in Table 02. The feed contained 76.06 % methane and 21.56 % nitrogen. The goal was to remove nitrogen from the natural gas stream such that it did not exceed a total of 7 % nitrogen content. With the help of the data and the process flow diagram given by Pakistan Petroleum Limited**,** the process simulation was carried out and the work moved further. The data and the process flow diagram given were of Zamzama NRU plant and our system was in accordance with it.

The boiling point and critical values of methane and nitrogen are presented in Table 03.

The process simulation of our project was done on Aspen HYSYS v11. Equipment used in the simulation and selected from Aspen HYSYS palette are LNG Exchanger, Vertical Separators, Stripper Reflux Separator, Absorber (Absorption column), TEE Mixer/ Absorber, Control valves, Pump and Recycle tank.

Table 03: Boiling point and Critical Values of Methane and Nitrogen

Component	Boiling Point °F	Critical Temperature °F	Critical Pressure Psig
Methane	-258.88	-116.68	668.624
Nitrogen	-320.44	-232.51	493.128

The feed gas entering in the LNG Exchanger 1 (Stripper warm exchanger) was pre-treated before to meet the specifications of NRU. It consisted 76.07 % Methane and 21.56% nitrogen. Table 04 shows the composition of natural gas feed stream in mole fractions.

Table 04: Feed composition of Nitrogen Rejection Unit

S.no	Components	Mole fractions
1	CO_2	0.0003
2	Nitrogen	0.2156
3	Methane	0.7606
4	Ethane	0.0146
5	Propane	0.0035
6	i-Butane	0.0011
7	n-Butane	0.0010
8	i-Pentane	0.0007
9	n-Pentane	0.0005
10	n-Hexane	0.0008
11	Benzene	0.0004
12	n-Heptane	0.0005
13	Mcyclohexane	0.0001
14	n-Octane	0.0002
15	n-Decane	0.0001

Table 05 shows the inlet feed stream conditions which include the temperature, pressure and the mass flow rate of the natural gas feed stream.

Table 05: Inlet Conditions of the Feed Gas

Parameters	
Temperature	62.6 ^{o}F
Pressure	763 psig
Mass Flow	2.643×10^{5} lb/h

3. Result and discussion

3.1. Simulation Validation

Based on the feed data which is retrieved from information given for Zamzama NRU in manner for simulation validation, some of the trends from retrieved plant data validate our simulated results based on comparison of various trends.

Comparison of Industrial Plant Data and Simulated Results

The composition of methane in mole fraction in sales gas stream of Industrial plant was compared with that of this project's simulated result and the validations are stated in table 06 below.

Table 06: Comparison of industrial plant data and simulated model data using different EOS models

Equation of state model	Results from Industrial Plant Data (mole fractions)	Simulated Results (mole fractions)	Percentage Error (%)
PR	0.985306	0.9544	3.14
SRK	0.985306	0.923	6.38
PRSV	0.985306	0.912	7.49

Nitrogen Removal in Sales Gas

The percentage of nitrogen removal was analyzed by comparing the feed gas nitrogen content and sales gas nitrogen content and the results are stated in Table 07,

Table 07: Nitrogen removal in sales gas using different EOS models

Equation of state model	Feed Gas Composition (mole fraction)	Sales Gas Composition (mole fraction)	Percentage of Nitrogen Removal (%)
PR	0.2156	0.0199	91.2
SRK	0.2156	0.026	87.94
PRSV	0.2156	0.023	89.33

3.2. Optimization and Process Intensification

Different Equation of State models were studied for the given objective and the results were compared and based on performance and results, it was decided to carry on our simulation on Peng-Robinson fluid package (Equation of State Model). The Simulation contains the following steps:

After pre-treatment, the feed gas was introduced into the LNG 1 heat exchanger (stripper warm exchanger) at 62.6^{o}F and 73.41 lb/s where the feed gas was cooled to -45.04^{o}F and the feed gas mixture entered the high-pressure separator (HP separator). The top vapor phase stream went to the second LNG 2 heat exchanger (stripper cold exchanger) and then vapor phase stream went to second separator (stripper reflux separator) column at -129.46^{o}F and at 72.28 lb/s. Vapor phase (top stream) from the separator 2 (stripper reflux separator) entered to the LNG-2 heat exchanger and entered as a feed in the absorber 1 (stripper) at -202^{o}F and 18.99 lb/s while the liquid phase (bottom stream) from the separator 2 went direct to the absorber 1 at -157^{o}F and 20.17 lb/s. Two heat transfer passes from the absorber 1 to the LNG heat exchanger 2 were used. The bottom stream of the absorber 1 at -142.06^{o}F and the rate of 39.72 lb/s passed through the valve with differential pressure of 14 psig and mixed with a stream coming from the bottom of the absorber 2 (N_2 column). The mixed bottom stream first went to the LNG 2 and then to the LNG heat exchanger 1 and exited at 57.02^{o}F and 0.12 lb/s. The top stream of the absorber 1 at -184.36^{o}F and 32.56 lb/s entered in the LNG 3 (NRU exchanger) and left at -216.94^{o}F with flow rate of 32.56 lb/s entered to the valve with differential pressure of 181.29 psig and then entered separator 3 as a feed at -393.484^{o}F and flow rate of 32.56 lb/s. The top stream of the Separator 3 (LP Separator) went to LNG 3 and entered to the separator 3 at -282.1^{o}F and flow rate of 6.8 lb/s. The top stream of the separator 3 first went to the LNG 4 (NRU reflux condenser) and then to the absorber 2 (nitrogen Rejection Column) as a top feed stream at -302.62 ^{o}F and 1.11 lb/s. While on the other hand the bottom stream of the separator 3 (LP Separator) and separator 4 (NRU Reflux Separator) entered as the Absorber 2 as bottom and middle feed at -284.8 ^{o}F, 25.76 lb/s and 363.38 ^{o}F, 5.32 lb/s respectively. In the absorber 2 (Nitrogen Rejection Column) 99.2% N_2 was removed and collected from the top stream and stored in the N_2 storage tank and about 99% recovered from the bottom of the NRU column at temperature of -233.68 ^{o}F and pressure of 40.61 psig and went to the pump where flow pressure increases to 413.36 psig and then the stream splits into two flow streams at the same temperature and pressure. While on the other hand, at the bottom of the absorber 1, 94% of CH_4 has obtained at temperature of -144.58 ^{o}F. Both the bottom streams of the absorber-1 and 2 respectively were mixed in the CH_4 recovery mixer at temperature of -148 ^{o}F and pressure of 28.1 bar and the mixed stream had went to the LNG-Exchanger 2 at temperature of -100^{o}C and pressure of 407.56 psig the output stream of the LNG-Exchanger 2 entered to the LNG-Exchanger 1 at temperature of 176 ^{o}F and pressure of 400.3 psig. The product stream from the LNG-Exchanger 1 was mixed with the split bottom stream (b) of NRU column to attain the sales gas composition by the recovery of 95.44% of CH_4. N_2 gas was removed from the vent at the composition 95.42%. Since N_2 gas have many uses in different industries so the removed N_2 gas from the natural gas mixer was supplied to the different industries to produce fertilizers, nylon, nitric acid, dyes, medicines, and explosives. On the other hand, the CH_4 recovered and obtain at the sales gas stream contain 1.9% of N_2 which is under the limits of CH_4 sells gas standards (allowable 7% in the natural gas stream) was obtained. In this process, the highest efficiency for the nitrogen rejection unit is achieved.

Table 08 shows the information about the equipment used in the design of NRU and Fig. 01 shows the process flow diagram of the unit that was designed as per the specifications and the data.

Table 08: Equipment used in the NRU

S.no	**Components**
Separator-1	HP- Separator
Separator-2	Stripper Reflux Separator
Separator-3	LP- Separator
Separator-4	NRU- Reflux Separator
Heat Exchanger-1	LNG-Exchanger- 01
Heat Exchanger-2	LNG- Exchanger- 02
Heat Exchanger-3	NRU-Exchanger
Heat Exchanger-4	NRU- Reflux Condenser
Absorber-1	Stripper
Absorber-2	N_2 Rejection Column
Pump	LNG Pump

3.3. Piping and Instrumentation Diagram

Table 09 shows the control strategy and instruments used in the designing and Fig. 02 shows the piping and instrumentation diagram (P&ID) of this project design.

The P&ID is of the Nitrogen Rejection Unit. The Temperature Control Loop (TC), Pressure Control Loop (PC), Flow Control Loop (FC), Level Control Loop (LC) respectively was used and all the control loops were working under the concept of Closed Control Loop System. The advantage of using the Control Loops during the process is that it reduces the chances of errors caused by the different parameters such as Temperature, pressure. Flow, level during the process in the system and gives more stability to the system.

In the current process different instruments and control strategies were chosen to get the best results. As it can be seen, the pre-treated stream of Natural gas was entering in the high-pressure separator (HP- Separator), where the pre-treated stream was separated into the top and bottom streams of vapor and liquid respectively. In both the streams pressure control valve system has been installed. One of the most important reasons to install the pressure control system on both the streams was to regulate and maintain a constant stream pressure of the system and gives better comfort, increases efficiency, and reduces expensive call back.

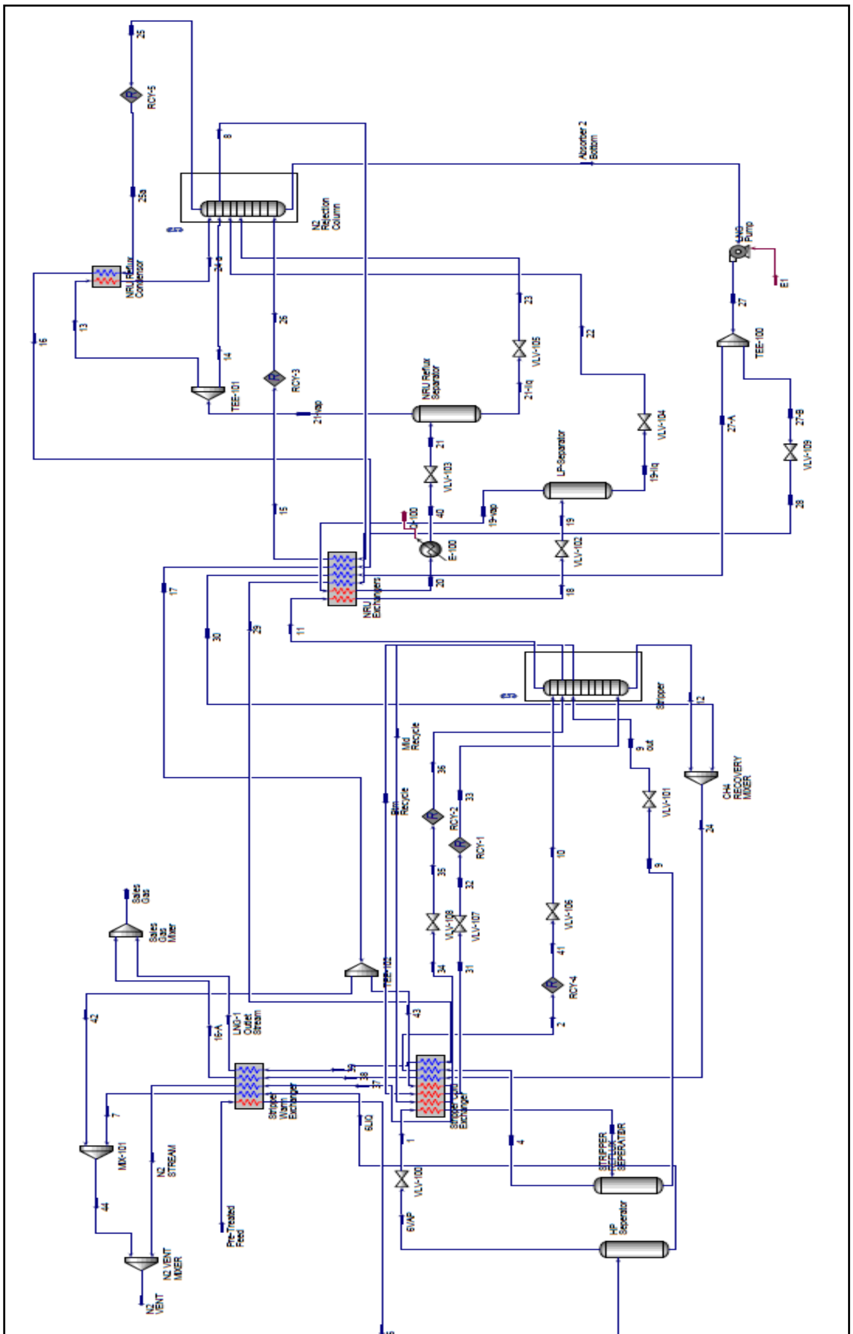

Fig. 01: Process optimization of NRU

Further the streams went to the LNG Exchanger- 1 and at the entering stream; the temperature control system has been installed. One of the most important reasons to install the temperature control system was to ensure the temperature of the entering stream to the exchanger to avoid the temperature cross error and make the results more accurate and reliable.

The out streams from the LNG-Exchanger 1 went to the Absorber-1 (Stripper). Here, flow control system at the inlet and outlet of the column were used. The main reason of installing the flow control system was to avoid the excess flow on the inlet and outlet side of the column that can cause the flooding of the liquid natural gas mixture from the different plates of the Stripper Column.

Now the streams had passed through the LP-Separator and the product of LP-separator went to the NRU- Reflux Separator. Then level control system is used. The main reason of installing the level control system in this project was to maintain the level of the columns and avoid inefficient separation in the separation column. Then the product streams of the NRU-Reflux Separator went to the Nitrogen Rejection Column where Pressure Control system, Temperature Control system and Flow Control system were used for the most accurate results.

In this complete project, four types of control systems were used i.e.1) Pressure Control Loop (PC), 2) Temperature Control Loop (TC), 3) Flow Control Loop (FC), 4) Level Control Loop (LC). All these four control loops were used to make the process system more convenient, reliable, and accurate.

Table 09: Instruments Used in P&ID

Legends	**Equipment**
EQ:100	HP-Separator
EQ:102	Stripper Reflux Separator
EQ:103	LNG- Exchanger- 02
EQ:104	LNG-Exchanger- 01
EQ:105	Stripper
EQ:106	LP- Separator
EQ:107	NRU- Reflux Separator
EQ:108	NRU-Exchanger
EQ:109	NRU- Reflux Condenser
EQ:110	N_2 Rejection Column
EQ:111	LNG Pump
P-C	Pressure Control Loop
T-C	Temperature Control Loop
L-C	Level Control Loop
F-C	Flow Control Loop

3.4. Efficiency Analysis

The basic purpose of efficiency analysis is to understand how inputs are translated into value results. Conversely, efficiency requires evaluating the output level of output in terms of the size that can be produced, given the inputs used, system issues and available technology. Efficiency will always be calculated considering factors (such as scale) that hinder improved production.

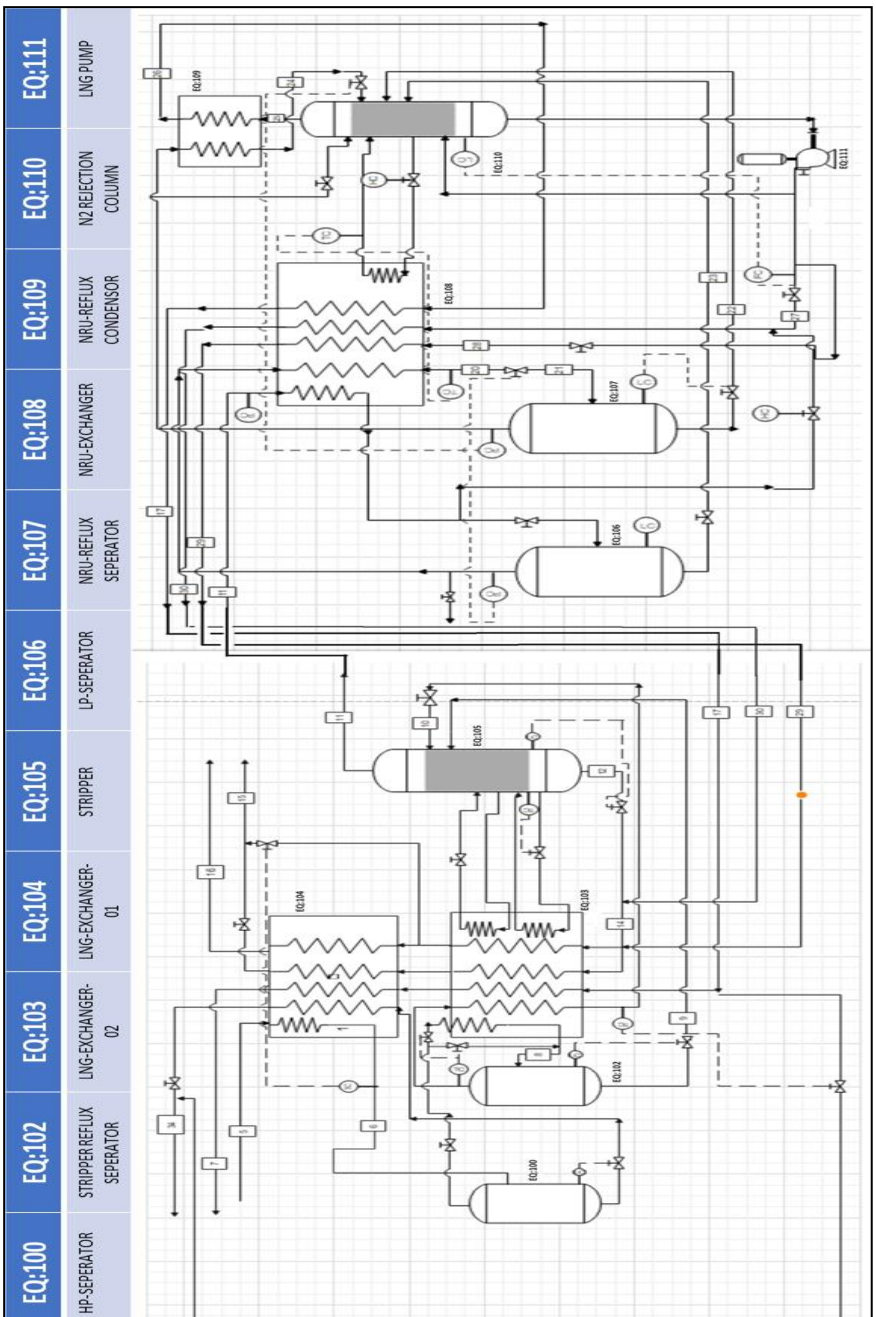

Fig. 02: P&ID of the NRU

Ideally, efficiency will reflect the results produced in terms of its value to consumers or the public. Therefore, there is a sense in which efficiency is a more complete and common tool than productivity. Now we will discuss the Nitrogen Rejection Unit efficiency based on N_2 removal and CH_4 recovery by considering the different parameters.

Number of Plates against CH_4 Content

Fig. 03 shows the content of CH_4 in mole fractions at different plates in the stripper present in the Nitrogen Rejection Unit. It can be seen with the trend that CH_4 had almost 99% recovered at 16^{th} plate of the NRU. Still 4 extra trays were added in the NRU for the better efficiency and less percentage error on the working plant.

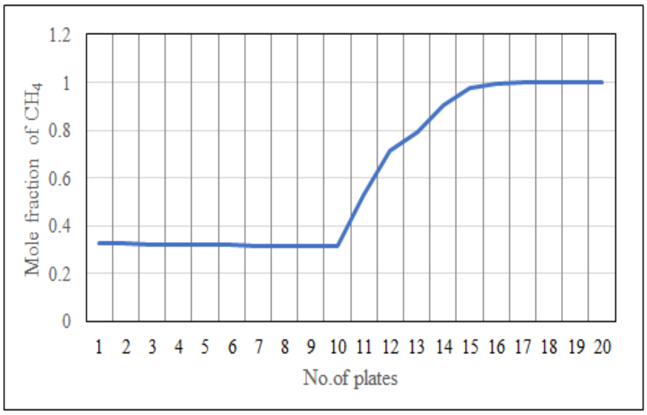

Fig. 03: Number of Plates against CH_4 Content

Number of Plates against N_2 Content

Fig. 04 shows the removal of N_2 at different plates in Nitrogen Rejection Unit. The above graphical trend states that N_2 was completely removed at the 16^{th} plate of the NRU column. However, for more accuracy and appropriate result, 4 extra plates were used to minimize all possible N_2 removal errors while installing the current plant on industrial scale.

Temperature at the plates against CH_4 content

Fig. 05 shows the content of CH_4 in mole fractions at different temperature on the different plates, respectively. The liquefaction point of N_2 is -320°F so, as the temperature increases by increasing the plates in the downward direction recovery of CH_4 increases.

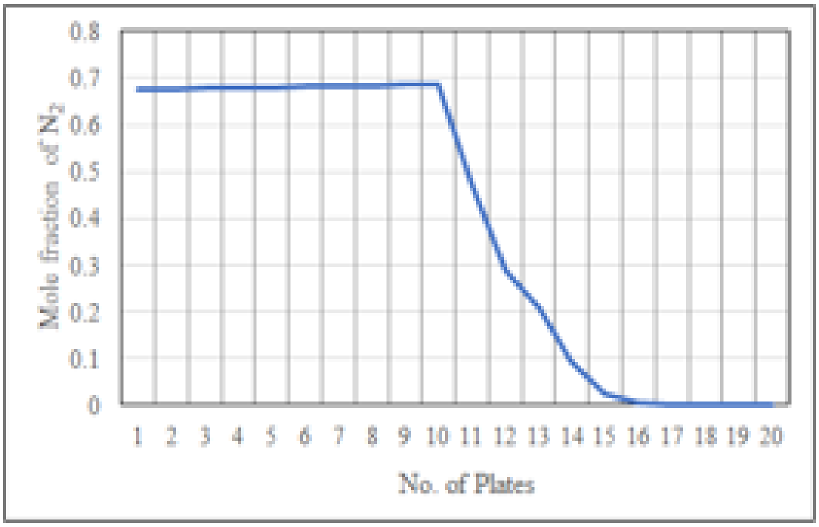

Fig. 04: Number of Plates against Nitrogen Removal

As the temperature reaches to -297.94°F at respective plate 16, 99% of CH_4 has been recovered from the NRU column. To minimize the error while installing the simulated plant on industrial scale, 4 extra plates were added in the design.

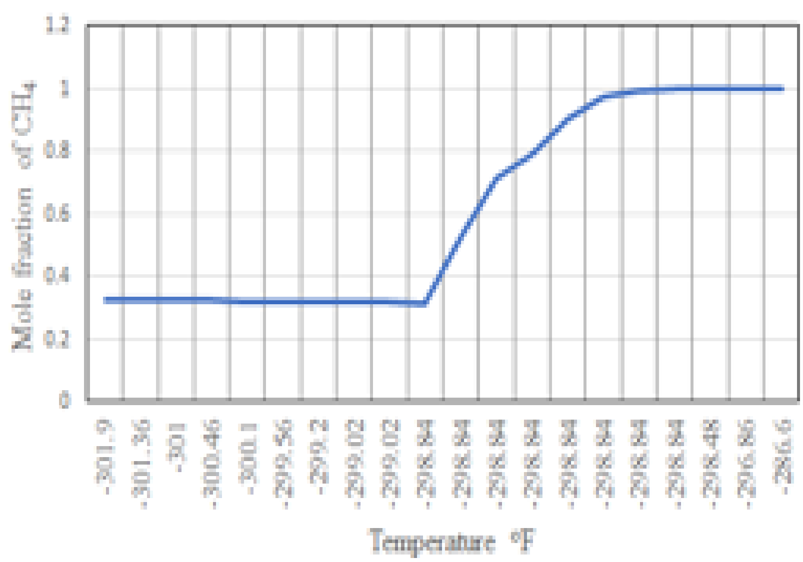

Fig. 05: Temperature against CH_4 Content

Pressure at the Plates against CH_4 Content

Fig. 06 shows the graphical trend between the content of CH_4 in mole fractions and the pressure on the different plates of the Nitrogen Rejection Column from top to bottom. According to the graph, the pressure gradually increases from top to bottom in the NRU column and at the pressure of 39.45 psig at the 16^{th} plate, about 99% CH_4 was recovered. As to minimize the operational error while installing the simulated plant on the industrial scale, 4 extra plates were considered but they can be removed as per the economic analysis.

Nitrogen removal from various eos models

Fig. 07 shows the percentage of nitrogen removed using the various EOS model and it can be clearly seen that the nitrogen removal was greatest in Peng-Robinson model. 91.2 % of nitrogen was removed when using the PR model.

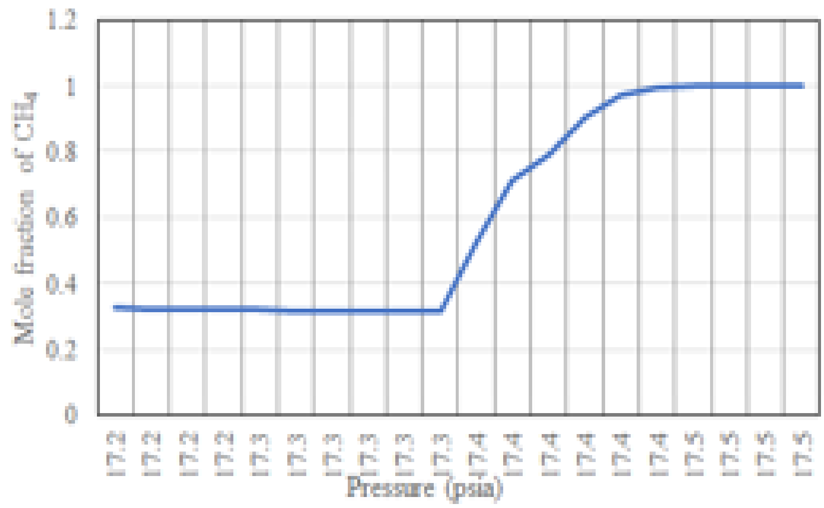

Fig. 06: Pressure against CH_4 Content

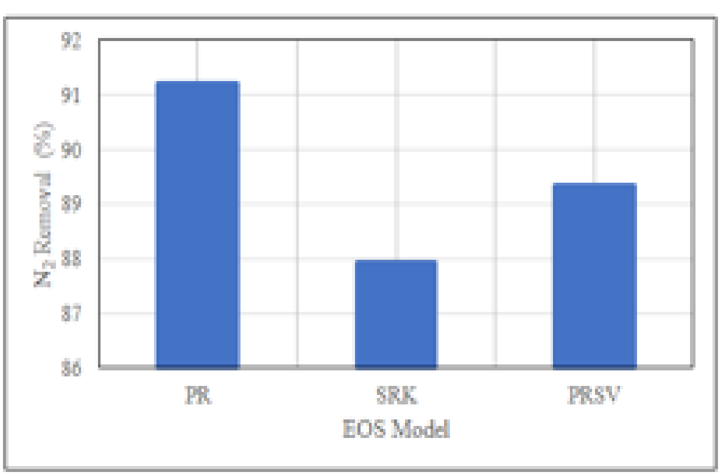

Fig. 07**:** Nitrogen Removal from Different Thermodynamic Models

Table 10: Process Simulation results for Peng-Robinson EOS model

Equation of state model	Deviation of simulation results for methane Percentage Error (%)	Percentage of nitrogen removed as per the simulation (%)
PR	3.14	91.2

4. Conclusion

Peng-Robinson, Soave-Redlich-Kwong and Peng-Robinson-Stryjek-Vera EOS models were studied for the given objective and the results were compared and based on performance and results, it is decided to move forward with our simulation on Peng-Robinson fluid package (Equation of State Model). It was observed that the percentage error between the plant data results and simulated results for nitrogen removal was the least using Peng-Robinson EOS model and methane recovery and total nitrogen removal was also the highest and the objective of the project was to select optimized process scheme and select the best Equation of State model. Hence, Peng-Robinson suits the best as per the requirements of the project. Table 10 refers to the results obtained from PR EOS model. From Aspen HYSYS V11, Peng-Robinson, Soave-Redlich-Kwang and PRSV EOS models for the simulation of NRU were used. The results of the three models were analyzed. When using Peng-Robinson method, 91.2 % nitrogen was removed in the sales gas stream. When using SRK method, 87.94 % nitrogen was removed. When using PRSV method, 89.33 % nitrogen was removed. The percentage error between the plant data results and simulated results for nitrogen removal was the least using Peng-Robinson EOS model, total nitrogen removal was also the highest, and the objective of the project was to select optimized process scheme. Hence, Peng-Robinson suits the best as per the requirements of the project and based on nitrogen removal and methane recovery.

It is important to remove nitrogen gas from natural gas due to multiple reasons. Hence, rejection of nitrogen from natural gas is necessary to meet sales gas specification. On the basis of efficiency to remove nitrogen and methane recovery, Cryogenic distillation is the most suitable and is highly feasible or energy-efficient process as it does not require amazing external resources, all equipment and streams are integrated in such a way that there is minimal demand and energy costs. It is one common method and it can result in up to 98-99% methane recovery. Nitrogen depleted in the supply gas can be used for further treatment such as EOR, Helium recovery etc. The nitrogen stream still contains traces of hydrocarbon gas. Therefore, the stream is rejected in space after passing through the flare system. As a result, flammable gases are removed from the stream and nitrogen should be released at the top of the plant process with the upper air. In refined oil regeneration (EOR), compressors are used to increase the pressure of the nitrogen gas stream to extract substrate oil. Inert nitrogen gas is ideal for this purpose.

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