NATURAL GAS SWEETENING: SIMULATION FOR CARBON DIOXIDE CAPTURE USING TEA AMINE-BASED ABSORPTION

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ABSTRACT

This paper attempts to summarize the simulation results of a steady-state for a natural gas sweetening based on absorption process using tetra ethylamine (TEA). Carbon dioxide (CO_2) capture simulation with the use of UNISIM software package was conducted using tetra ethylamine (TEA) to obtain sweet natural gas product that meets standard market specification. The amine weight predicted at 28% loading capacity of the process begins with an appropriate level of hydration for optimum absorption. The aim is to eliminate the CO_2 gas to at least 97% level of purity and achieve possible recovery of the amine solvent at the end of the process cycle. The results show that the CO2 gas stream increases with increasing feed temperature and flow rate. The end of the simulation result yields an optimization of 0.036 mole fraction for the CO2 gas and a total recovery of the TEA amine solvent. Equipment duty such as the cooler and lean pump were also determined to evaluate the success rate of the process. However, the amount of the CO2 in the final sweet gas can be affected by the TEA solvent, but it proves better performance than other solvents. In other to ascertain this, the percentage of the methane loss to the solvent was achieved at 0.00104 moles.

Key words: CO_2 capture, TEA amine, Simulation, Absorption.

Introduction

Natural gas from the petroleum industry plays an important role in the supply of energy to the world for various industrial and domestic purposes. The growth in this potential demand has led to increased level of the natural gas production with Russia having the highest in the production index. On the other hand, the activities and processes involved in the petroleum production always leave a global warming and climate change concerns of the increased carbon dioxide (CO_2) release to the atmosphere. Because of this, petroleum producing countries were always making global efforts to reduce the concentration of the carbon dioxide in the atmospheric foot print (Leung *et al*, 2014). Carbon dioxide is a major Greenhouse gas which is mainly blamed for the global warming usually constitute the highest volume of the total emissions (Moazzem *et al*, 2012). Figure 1 shows the global foot print for the CO2 gas from the year 1985 to the year 2025.

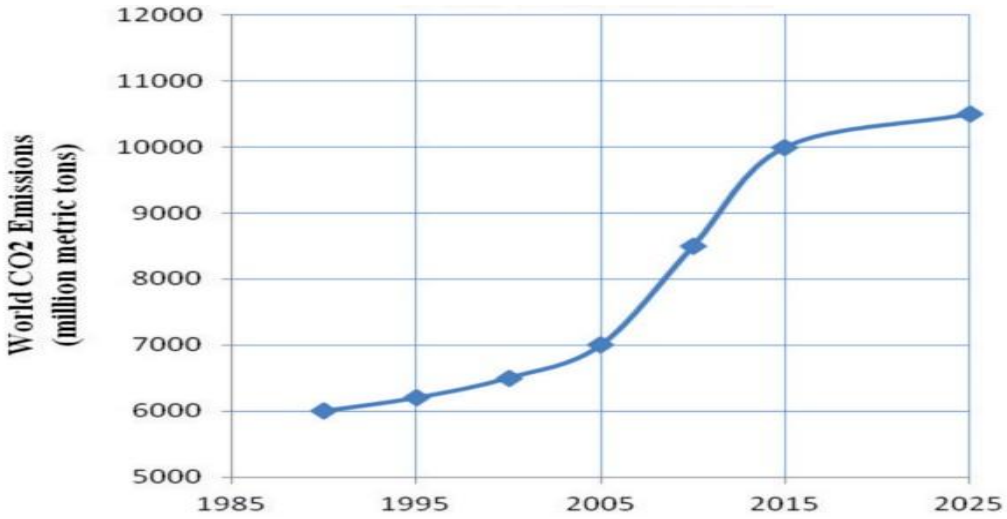

Figure 1. The global foot print for the CO2 gas from 1985 to 2025.

Nowadays, there are more emerging applications and various techniques to design and optimize Carbon dioxide (CO_2) gas capture from natural gas using chemical absorption. Natural gas as a combustible gas vary in compositions containing a mixture of different gases. For high economic value, it has to be pure and free from

contaminants such as CO_2 and H_2S. It is commonly refereed as a sour gas when it contains other gaseous contaminants such as the CO_2 and H_2S (Abotaleb *et al*, 2018). Furthermore, natural gas containing contaminants with high level of CO2 is considered potentially harmful when burned as it releases more CO_2 to the atmosphere.

Meanwhile, on the other side it can be mentioned that CO2 has other economic applications including; production of dry ice, Urea and industrial application like waste water treatment, increased crude oil extraction, commonly known as Enhanced Crude Oil Recovery (EOR) and among others (Massarweh, and Abushaikha, 2021). For this reason, nowadays about 80% of the CO_2 separation usually aimed for this purpose. However, the environmental protection need for clean atmosphere is a global requirement behind the control of Carbon dioxide. For its greenhouse effect, CO_2 has been estimated to enhance about 60% of our global warming (Yadav *et al.* 2020)

Historical review on CO2 Capture:

The technology behind the process of CO_2 capture as a way or means of gas sweetening can be traced back to the period of around 1970'S (Mac Dowell *et al.* 2017). This idea was brought about because of the global warming impact level of the gas. To mention this, the first commercial CO_2 capture process facility was started in Norway in September 1996 by the Statoil oil and gas company (Plaza *et al*, 2020)

Materials and method

The Simulation was conducted using the HYSYS process simulator v8.4design application SUITE package using TEA amine solvent. This application software enables engineers create steady-state and dynamic models for plant design as well as performance monitoring. Meanwhile, Amine is generally one of the good candidate solvents used for CO2 capture from flue gas by ordinary conventional absorption process (Nuchitprasittichai and Cremaschi 2011). Meanwhile, the selection of this package is as a result of good performance indicator earlier established in the literature. According to (Borhani *et al*, 2016), the model is usually in good agreement with experimental data. It is important to note that the simulation process is a multi-stage process that requires careful input of the simulation data for the absorption cycle. A complete process flow diagram of the amine unit is shown in Figure 2.

Firstly, the sour gas was filtered and cleaned making it free from contaminants by an inlet filter separator Then, the gas separator was fed up to the bottom level of the TEA amine absorber. Furthermore, gas goes upward through the column to make in contact with the aqueous TEA amine solution which comes from the amine column absorber. The CO_2 will then have affinity or reaction with the amine forming a weakly bonded compound which later would be broken down. At this level, the gas will then be scrubbed, washed and vented to the atmosphere. The solution carrying the CO_2 will then be allowed to pass through a heat exchanger subsequently heated under a low-pressure stream in the reboiler. The earlier produced carbonate is then broken down with the action of heat reforming back the sorbent thereby giving a steam of concentrated CO_2. This stream is then returned to the heat exchanger for cooling and then sent back again to the exchanger. Through the length period of the process, there is a need of adding amine continually in other to supplement reduction in the system.

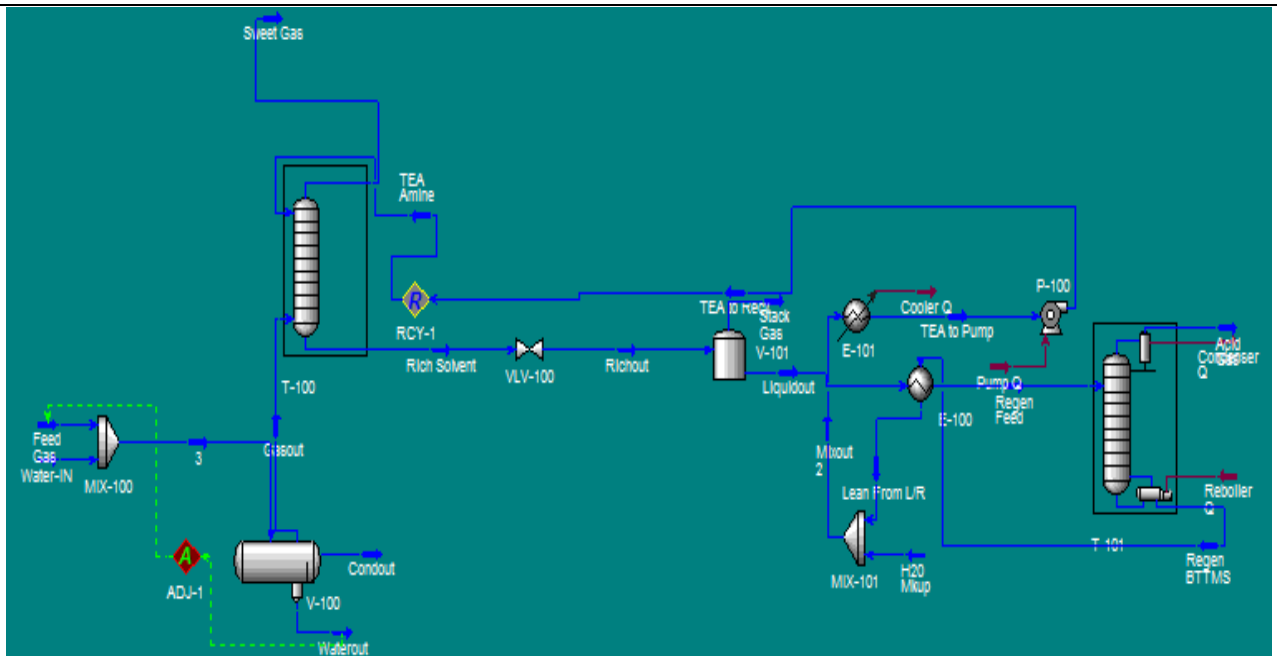

Figure 2: The Schematic gas sweetening process flow by HYSYS.

Validation of the Simulation results:

To ascertain validity and reliability of the simulation results, the results of the simulation were compared with results of simulation from an industrial database and the average standard error is than 10 percent. Hence, it can be concluded that the data shows a good agreement.

At Temperature of 35F and Pressure of 150Psi, 1000kgmole/hour that is 1% mole fraction of the vapour has been utilized for the Saturation of the TEA amine. At the predicted 28% amine weight the results of the simulation yields the following parameters (Figure 3).

The effects of Operating Conditions:

The flow rate and temperature of the feed gas and the concentration of the TEA amine were the operating conditions. The concentration of the CO2 rapidly increases with increasing feed gas flow rate. Furthermore, temperature and pressure of the fluids also plays an important in this section. Results show that temperature of the feed gas increases and in the sweet gas subsequently. This, increase in temperature would further increase the temperature of the CO2 contents. And acid gases such as the CO_2 gas increase in volatility with increasing temperature.

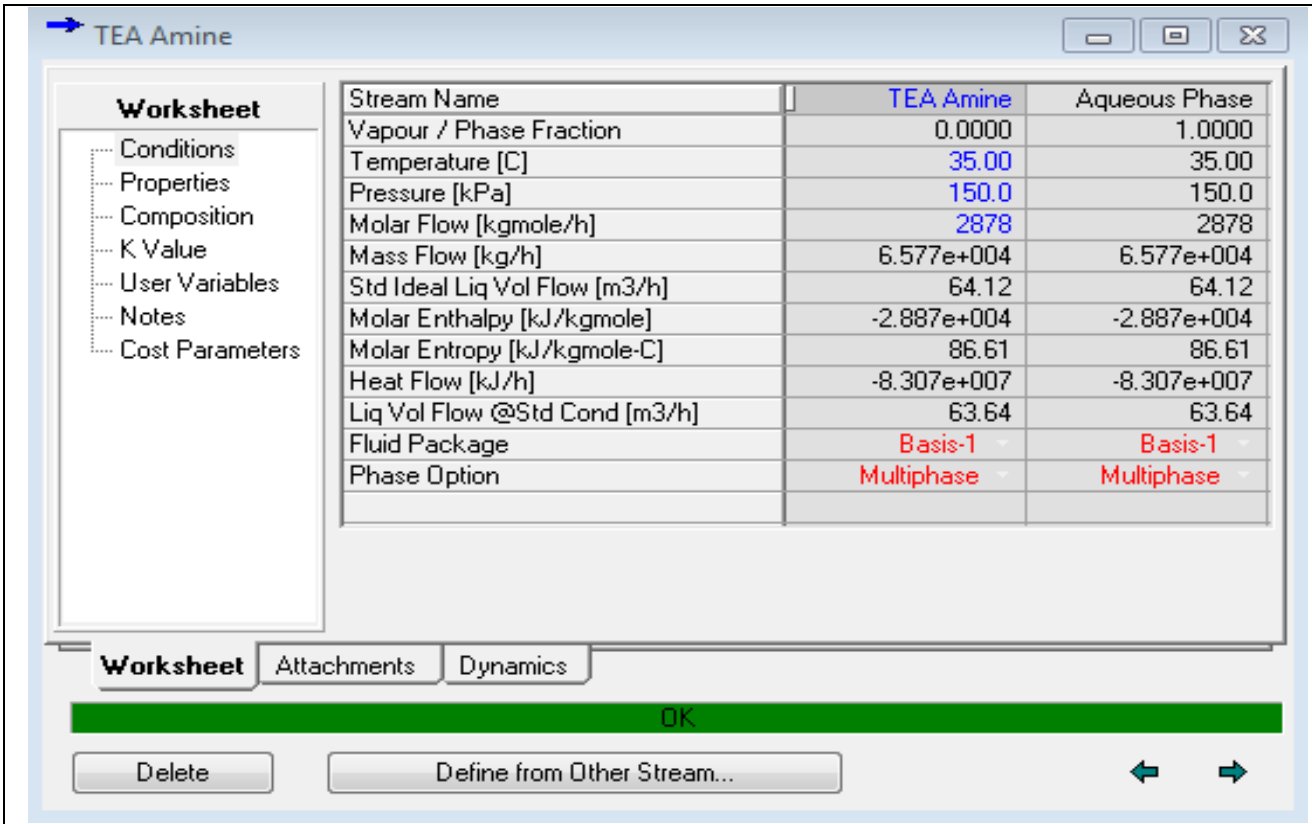

Figure 3: The Flow data of the TEA amine.

Table of Fluid Property

The Dew and bubble point properties of the fluid at 30℃ and a pressure of 6500Kpa were observed as can be seen in tables 1and 2 respectively. The fluid envelop curve was plotted based on the pressure and temperature relativities as presented in figure 4.

Table 1: Dew point property of fluid

Pressure (KPa)	Temperature (C)
202.7	-77.94
429.	-68.57
908.2	-58.61
1823	-49.53
3331	-43.36
4472	-42.14
5175	-42.64
6145	-45.55
6538	-49.05
6619	-51.98
6617	-52.48
6513	-55.85
6332	-58.70

Table 2: Bubble point property of fluid

Pressure (KPa)	Temperture (C)
201.4	-152.4
274.0	-147.6
370.9	-142.4
498.8	-136.9
665.2	-131.2
878.0	-125.2
1145	-119.0
1473	-112.0
1866	-106.2
2324	-99.73
2841	-93.36
3404	-87.18
3995	-81.27
4588	-75.70
5153	-70.58
5663	-65.87
5959	-62.95
6133	-61.09
6285	-59.30
6332	-58.70

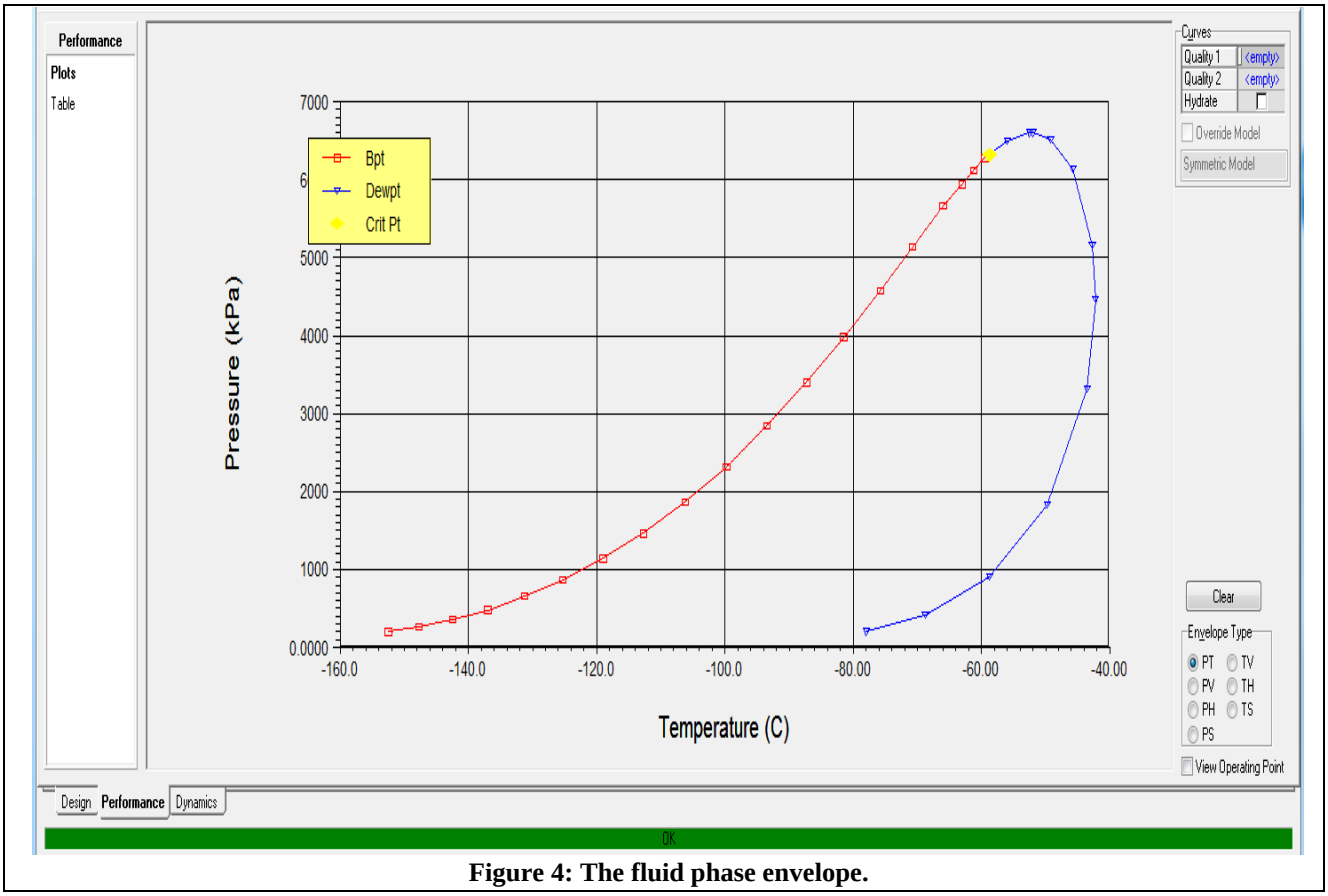

Figure 4: The fluid phase envelope.

1. ***The mole of CO_2 in the sweet gas:***

As earlier indicated, one of the most commonly used techniques for the removal of acid gases is the use of the amine based solvents. However, operating cost and other limiting factors has always lead process designers to select some sensitive parameters that can improve performance and meet market specification at a minimum energy requirement in sweetening plants (Sharif *et al*, 2015 and Zahid *et at*, 2017). In fact, this is the goal of any sweetening plants TEA.

The simulation result for the residual CO_2 gas in the sweet gas stream shows that the CO_2 contents of the sweet gas stream decreases by an increasing amine rate (Figure 5). Hence, at the end of the simulation process, the CO_2 gas content was found to be 0.036440 mole fraction Figure 5. This is approximately 3.6%.

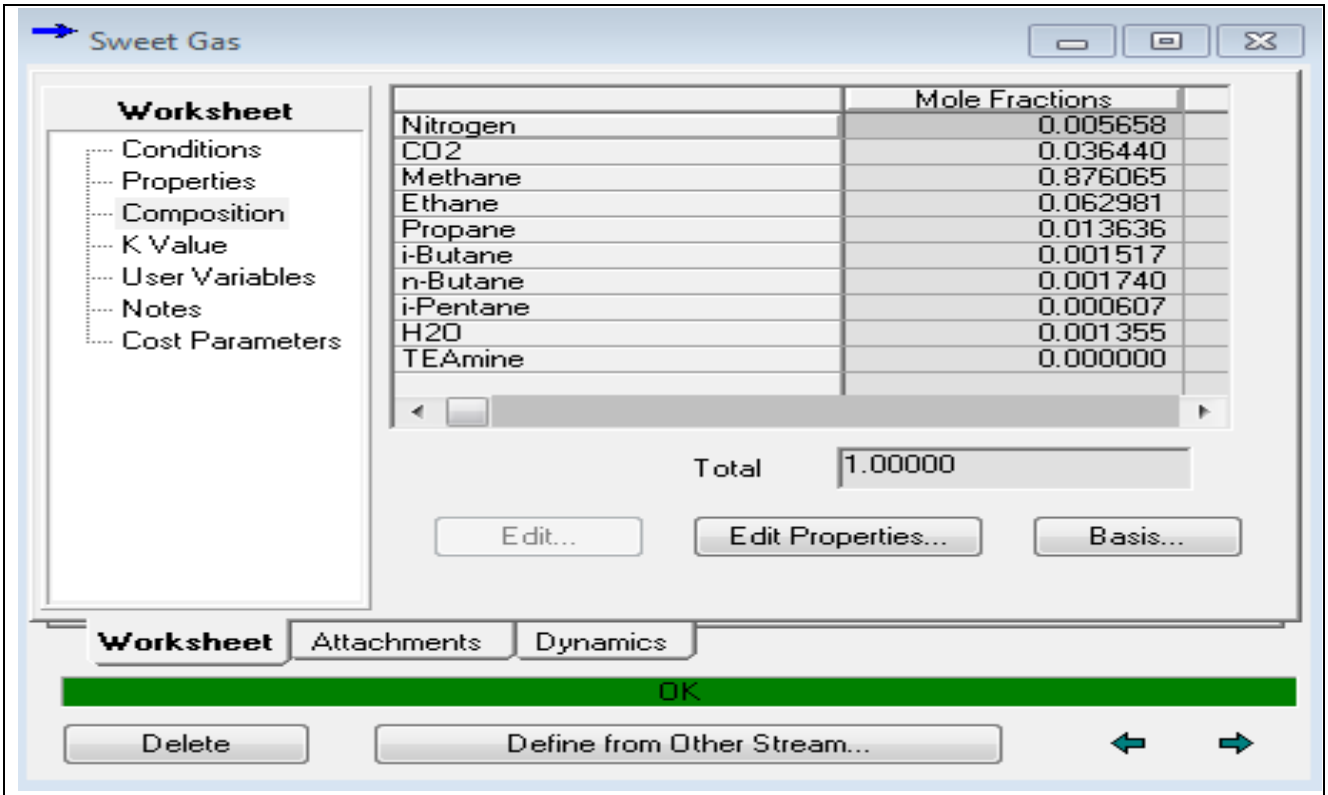

Figure 5: The CO_2 composition in the sweet gas.

2. ***The mole of Amine in the acid gas:***

The mole of the TEA Amine at the end of the in the acid gas was found to be 0.000 mole fractions. This is an indication of a total amine recovery (Figure 6).

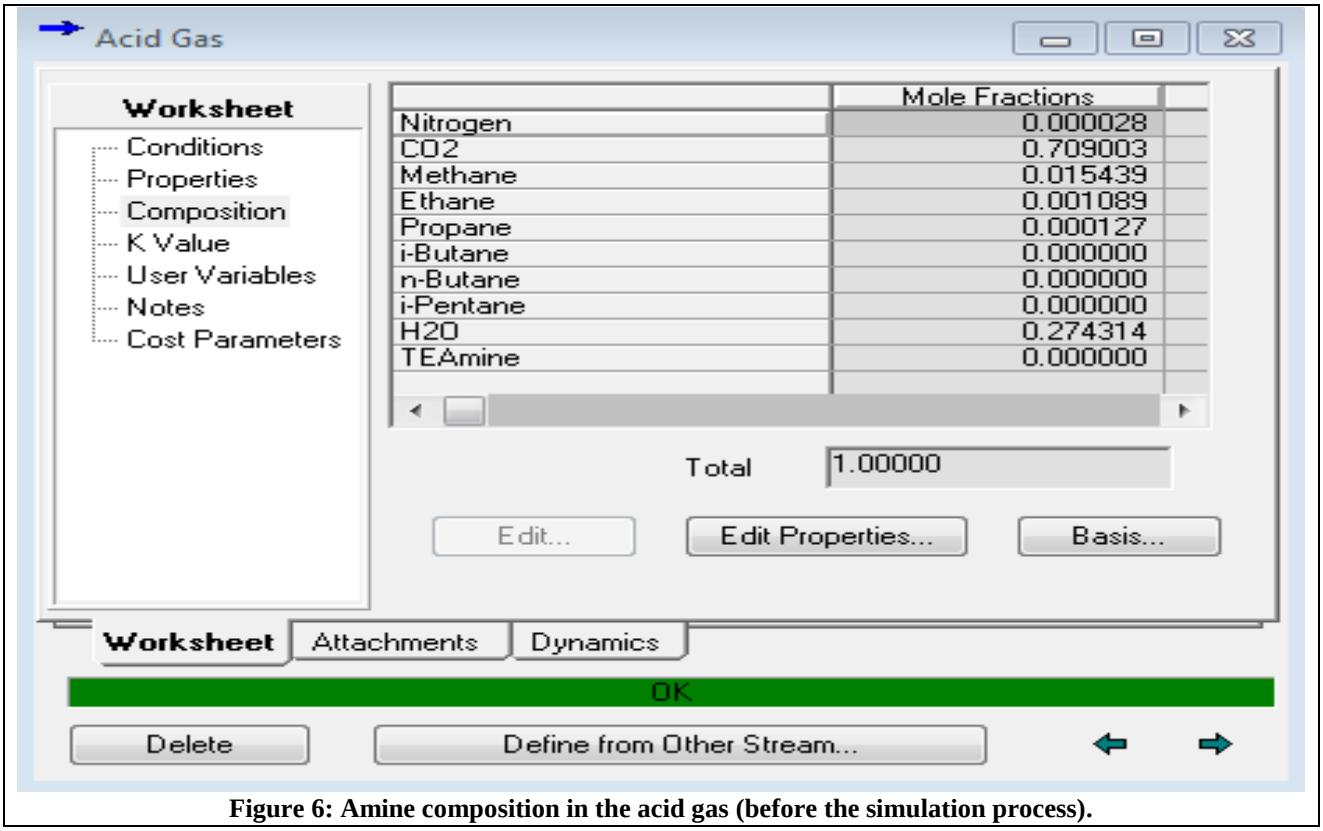

Figure 6: Amine composition in the acid gas (before the simulation process).

3. ***The Amine CO2 loading capacity:***
This is calculated by the relation as;

$$Moles\ of\ \frac{CO2}{Amine}$$

$$= \frac{\mathbf{21.54}}{\mathbf{2878}} = \mathbf{0.00748\%}$$

4. ***Methane loss to the Solvent:***
The moles of methane loss to the solvent at the end of the simulation is 0.001047moles. This is obtained in the solvent stream as indicated in the flow sheet table in figure 7.

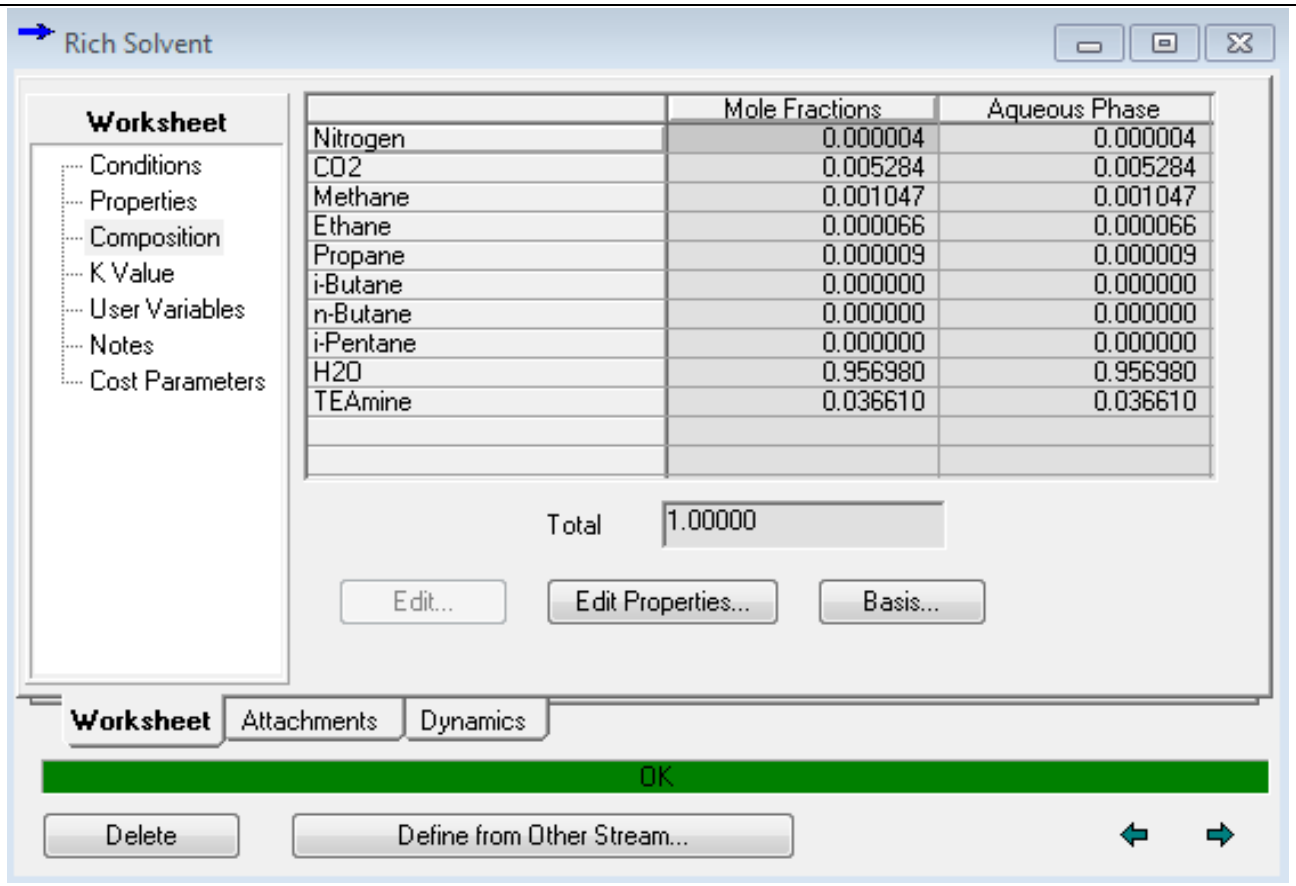

Figure 7: Methane loss to the Solvent.

It is generally known that the reaction of the acid gases with solutions of the amine in the absorption tower is a balanced exothermic reactions (basically a forward reaction) and that absorption capacity is more appreciated at the lower temperature. This is similarly reported by (Khanjar and Amiri, 2021) during their Simulation and parametric analysis of natural gas sweetening process.

The distillation column section of the simulation design provides multiple numbers of trays ranging from 18-20 stages. About 18 stages stripper were used in this design for the simulation at the distillation column of the amine gas mixture as indicated in the column for the fluid package in figure 8. This selection decision would demonstrate an enhanced gradient based optimization for the Amine scrubbing under the operating conditions (Bernal *et al*, 2018). (Calvin Tsay, 2019) also suggested that the selection of 18 stages stripper usually improves the process economics of the carbon capture.

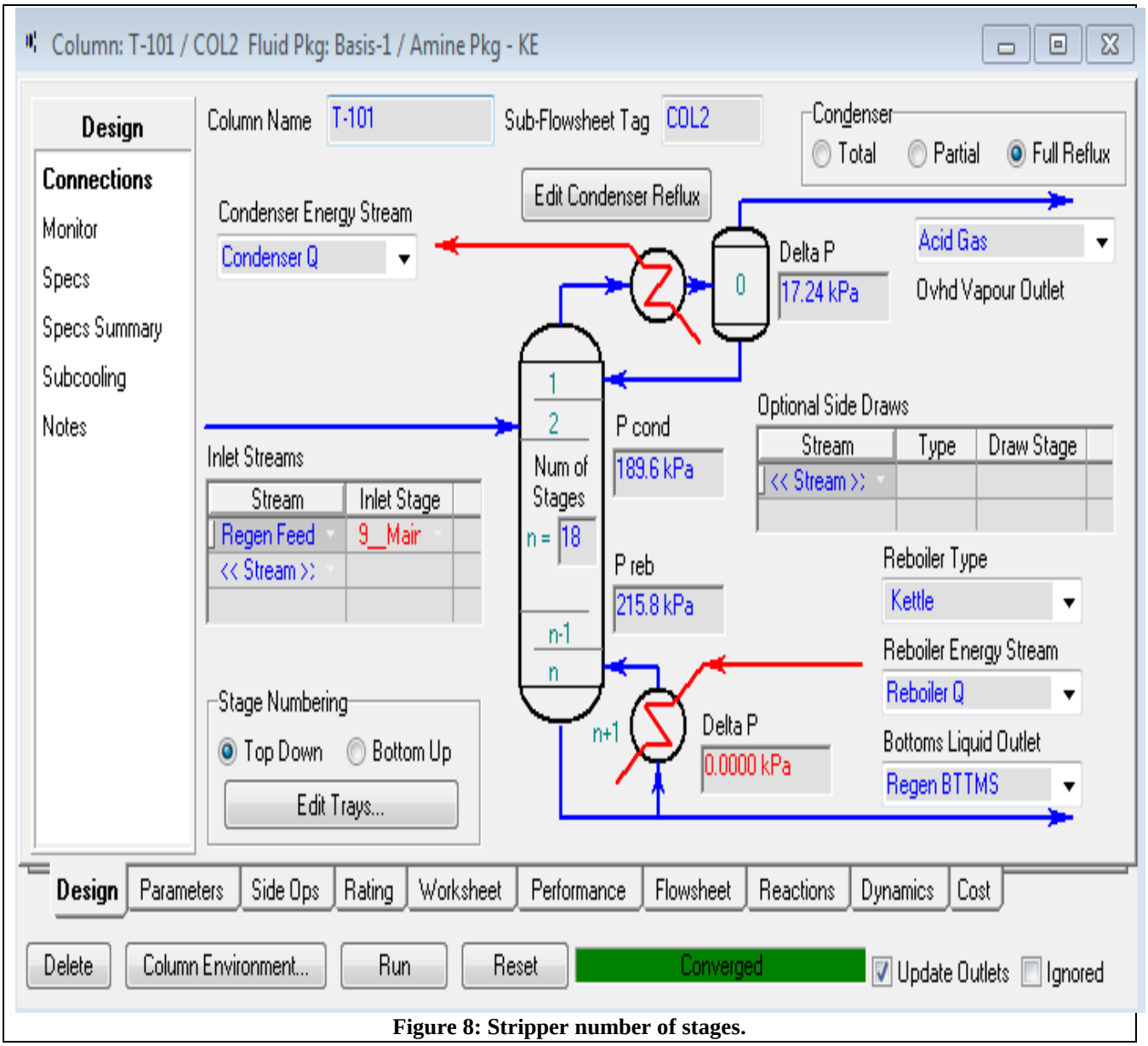

Figure 8: Stripper number of stages.

The Section equipment Duties

From the results of the simulation, the duty of the following section were obtained as follows in Table 3.

Table 3: Simulation equipment duties

Equipment	Rate duty
Lean Pump	0.862783 KW
Lean-rich Heat exchang	1.47 E + 7KJ/h
Reboiler	1.4 E + 7KJ/h
Condenser	Disregarded
Cooler	8.688 E + 6 KJ/h

It is Important to note that the condenser duty is not considered during the simulation because is a component attached to the distillation column. The lean pump duty is at a power of 0.862783KW as indicated in the simulation package in figure 9, while the cooler and the reboiler were at a very indices of KJ/h. The adiabatic efficiency of the lean pump is about 75% efficient.

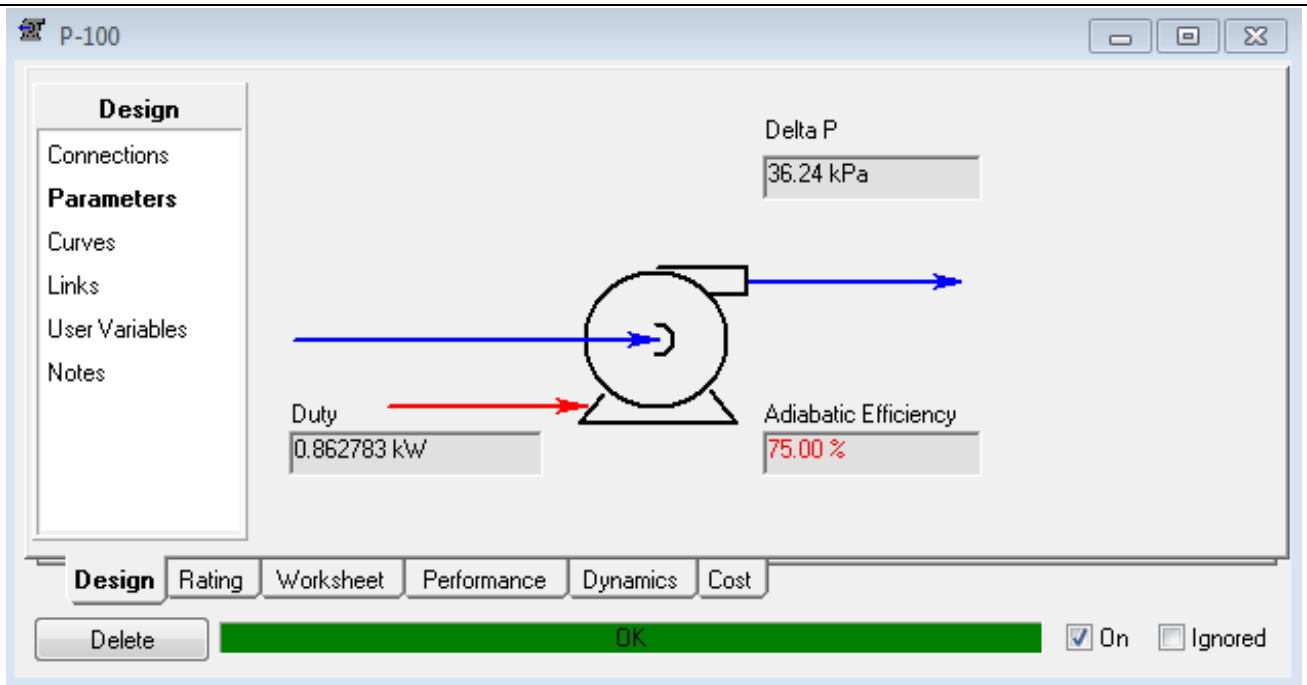

Figure 9: The Lean Pump duty and adiabatic efficiency.

CONCLUSION

The simulation process was carried out using the HYSYS process simulator v8.4 UNISM application software for the purpose of evaluating the absorption performance of natural gas sweetening using TEA amine solvent. The result of the simulation shows an optimization for the removal of the CO_2 using the TEA amine based absorption process. Indirect relativity has been observed as the decrease in the amine mole fraction which reflects an increased CO_2 composition in the acid gas. The market sales specification of the sweet gas was attained at 28% total molecular weight of the TEA amine. Hence Increase in the circulation rate signifies increased removal efficiency.

The results of the simulation shows that with an increasing feed flow rate and the temperature, the amount of the CO2 gas also increases. Furthermore, the simulation result for the residual CO_2 gas in the sweet gas stream shows that the CO_2 contents of the sweet gas stream decreases by an increasing amine rate. By the end of the simulation process the result yields an optimization of 0.036 mole fraction for the CO2 gas and a total recovery of the TEA amine solvent. However, the amount of the CO2 in the final sweet gas can be affected by the TEA solvent, but it proves better performance than other solvents. Limitations of the UNISIM simulation model includes temperature limitations at some specific levels in the simulation process. Furthermore, this simulation process was performed using TEA amine, subsequent combination of other amine solvents may also be utilised in some instances to evaluate steady-state and dynamic models as well as performance monitoring.

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