JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# Purification of Natural Gas by Using Amine Solution Technology (using Aspen HYSYS)

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## Abstract:

Purification of natural gas from impurities such as carbon dioxide ($CO_2$) and hydrogen sulfide ($H_2S$) is a vital step in the gas industry. Amines technology is widely used due to its effectiveness in removing these acidic gases. Amines are compounds that contain an amino group, and amines such as methyl diethanolamine (DEA) have proven to be highly efficient in $CO_2$ removal, making them the preferred choice in many industrial applications.

The process begins with passing natural gas through an absorption column filled with an amine solution, where a chemical reaction occurs between the amines and the gaseous impurities, resulting in the formation of soluble compounds in the solution. This stage is critical to ensure absorption efficiency, as it is affected by conditions such as temperature, pressure, and amine concentration.

After the absorption process is complete, the amine solution is regenerated using a stripping column, where the solution is heated to separate the impurities from the amines. The amines are restored to their original state for reuse, ensuring reduced operational costs.

It is important to note that the efficiency of the process depends on several factors, including column design and control operations, which impact the overall performance of the purification system. Amines technology is widely used in natural gas processing plants, oil refineries, and chemical production facilities such as ammonia.

Economic considerations include operating costs and materials, along with the benefits associated with improving gas quality. Amines technology is a reliable option for natural gas purification, as it meets quality requirements and environmental standards, contributing to enhanced efficiency in industrial processes and reducing environmental impact.

## Introduction:

Natural gas is one of the most important energy sources in the world and is considered a cornerstone of the global energy mix [1]. It is primarily made up of methane ($CH_4$), but it also contains small amounts of other hydrocarbons like ethane ($C_2H_6$), propane ($C_3H_8$), and butane ($C_4H_{10}$), as well as impurities such as carbon dioxide ($CO_2$) and hydrogen sulfide ($H_2S$) [2]. Natural gas is one of the cleanest types of fossil fuels, as it has low levels of harmful impurities, making it a preferred choice in many industrial and residential applications [3].

Natural gas has been discovered and used since ancient times, with the Chinese using it in the 5th century BC to transport water through bamboo pipes. In later centuries, the Romans and Greeks used natural gas for religious practices and ceremonies. However, commercial use of natural gas began in the 19th century, with the development of techniques to extract and distribute it, leading to the establishment of the first gas lighting systems in major cities [4].

Natural gas is extracted from underground reserves, which can be either conventional or unconventional. Conventional fields contain gas in natural traps, while unconventional gas is extracted from solid rocks like shale or from coal seams. Extracting gas requires advanced techniques such as horizontal drilling and hydraulic fracturing, which involve significant investments but have greatly increased production in recent years, especially in the United States. After extraction, natural gas must undergo careful processing to remove impurities. This involves removing water, carbon dioxide, and hydrogen sulfide to ensure that the resulting gas meets quality standards for use [5]. One of the main techniques used for processing gas is absorption with amines, where amines are used to efficiently remove acidic gases. Other methods include cooling, adsorption, and membrane separation [4].

Natural gas has various uses, including electricity generation, home heating, and in industries. It is also a key raw material in chemical manufacturing, including plastics and fertilizers. Recently, natural gas has become important in energy transition, as it is used to produce hydrogen, which is considered a clean and sustainable fuel [6].

## Methodology:

## Case Study:

Design a natural gas sweetening unit, that comes out from the previous unit (take all data from stream 10 in the example 1) by using DEA solution (di-ethylamine) if you know that the DEA solution must be about 30% weight percent, the mole flow ratio is about 1:1.5 (NG:DEA).

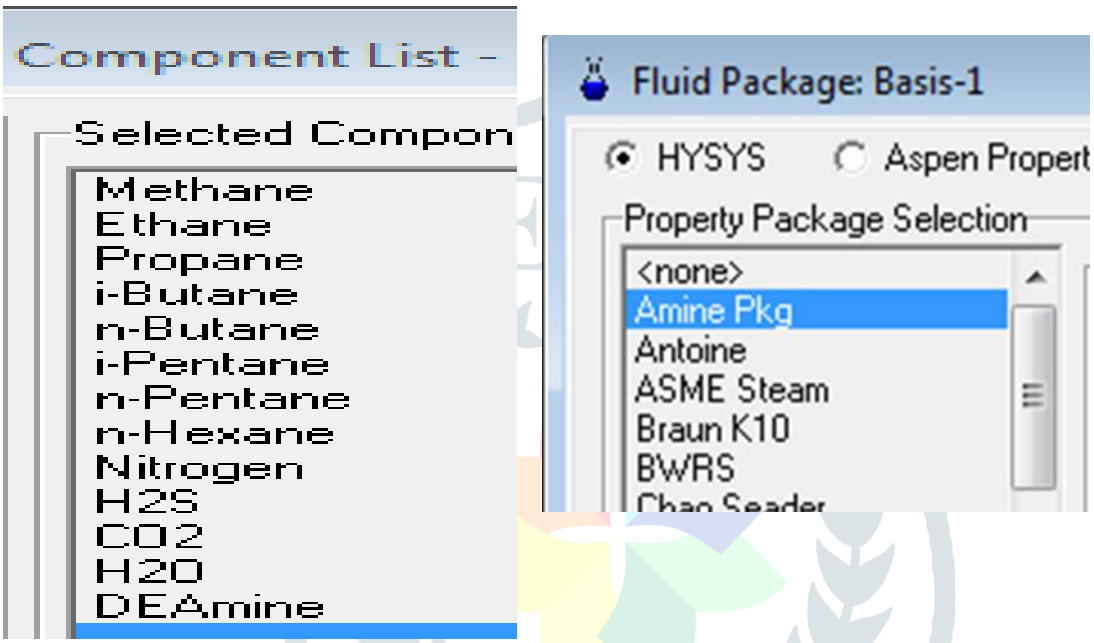
In the beginning we have to define the components, it's the same components but with addition of DEA.

Also the fluid package will be Amine solution because the main process fluid is amine solution treatment.

The feed gas composition:

C1=0.7008, C2=0.1244, C3=0.0647, i-C4=0.0235, n-C4=0.0144, i-C5=0.0158, n-C5=0.0093, C6=0.0025, $N_2$=0.0111, $H_2S$=0.0103, $CO_2$=0.0215, $H_20$=0.0017, DEA amine=0 Also the temperature will be 95°F, pressure=548 psi, the molar flow= 4913 Ib.mole/hr.

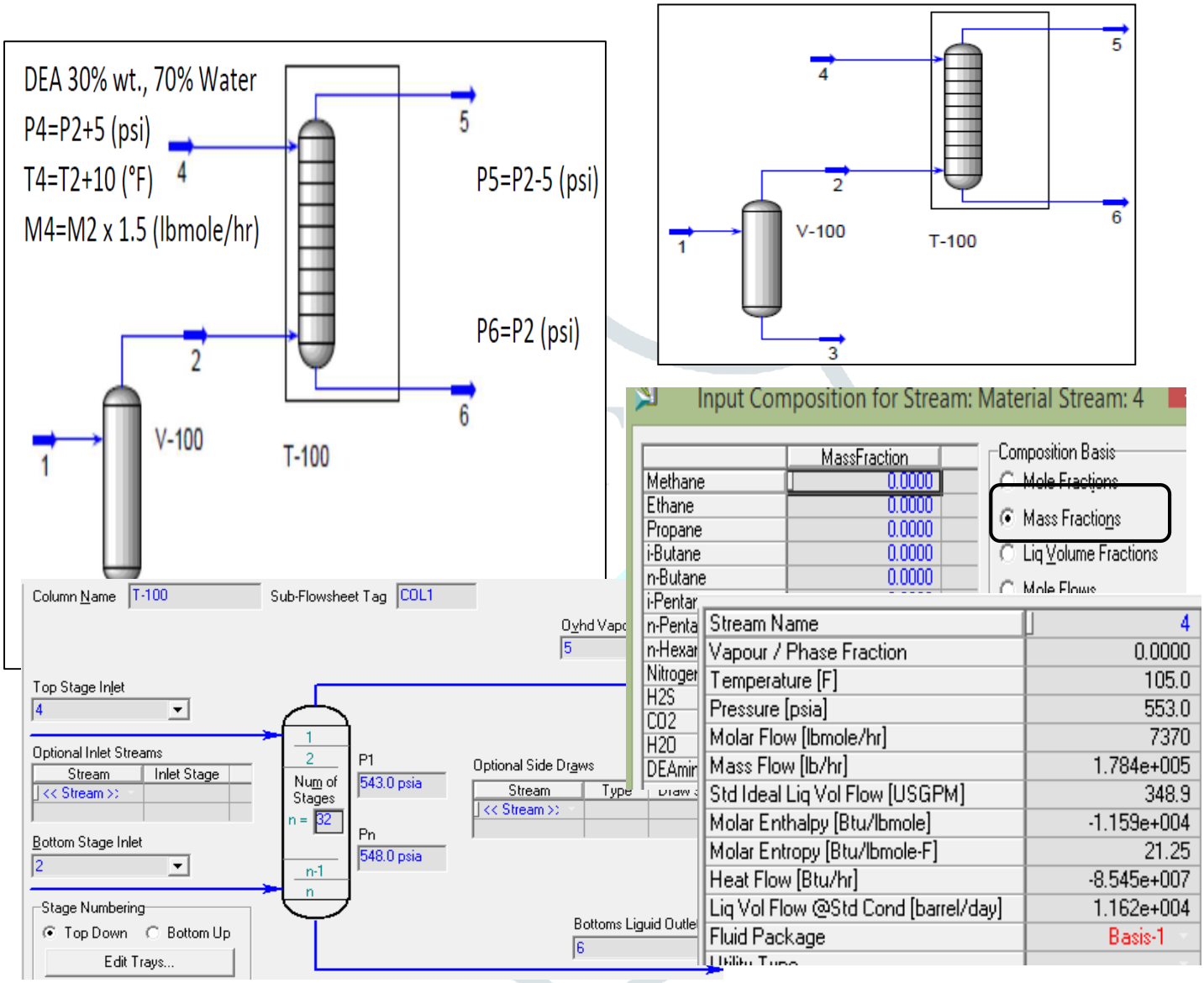
**Step 1** is to separate any traces of condensate by using separator and that will be very helpful if the feed gas containing heavy condensable gases that could make a foam or froth in the absorber, so we need to add a separator.




**Step 2** is to absorb $CO_2$ and $H_2S$ gases by amine solution inside the absorber, the flow is must be about **1.5 times** of the gas flow = 4913 * 1.5 = 7369.5 Ib.mole/hr, pressure of the amine solution must be more than the feed gas pressure of about **5 psi ; 548+5= 553 psi**, and that is important to prevent the gas from flow backward inside the amine solution line, amine concentration is **30% weight percent**, also it must be hotter enough to prevent gas from condensation, so let the temperature about **10°F** over the gas.

The absorber has **32 trays**, top pressure is less than feed gas about **5 psi**, and the pressure at the bottom is the same of feed gas.

Stream 1 is the feed gas, stream 2 is the gas phase of the separator, stream 3 is the liquid phase that separated, stream 4 is the DEA solution, stream 5 is the treated gas outlet, and stream 6 is the rich amine solution




**And for a composition comparison before and after absorber**

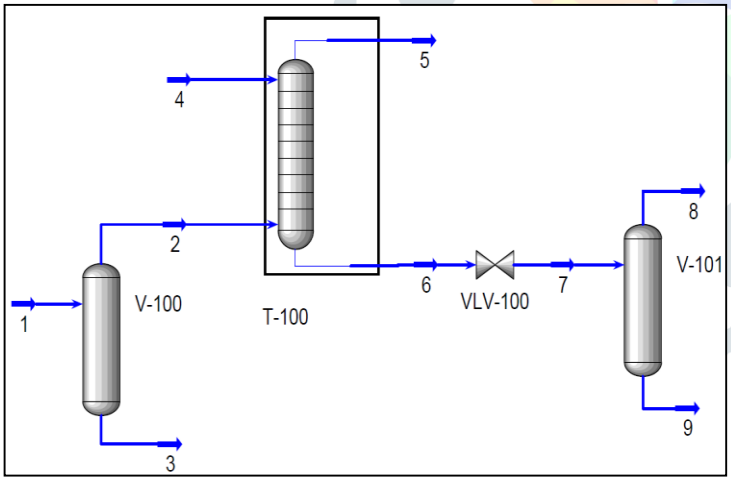
| Component | Before Absorber (Stream 2) | After Absorber (Stream 5) |
|---|---|---|
| **$CO_2$** | 105.6 lb.moles/hr | 0.0385 lb.moles /hr |
| **$H_2S$** | 50.6 lb.moles/hr | Nail lb.moles /hr |

**That is means the absorption percentage will be:**

| Component | |
|---|---|
| **$CO_2$** | (105.6-0.0385) x 100/105.6 = 99.95% removed |
| **$H_2S$** | (50.6) x 100 / 50.6 = 100 % removed |
| **$CO_2$** | (0.0385/4755) *10^6= 8 ppm remaining |
| **$H_2S$** | (0/4755) *10^6= 0 ppm remaining |

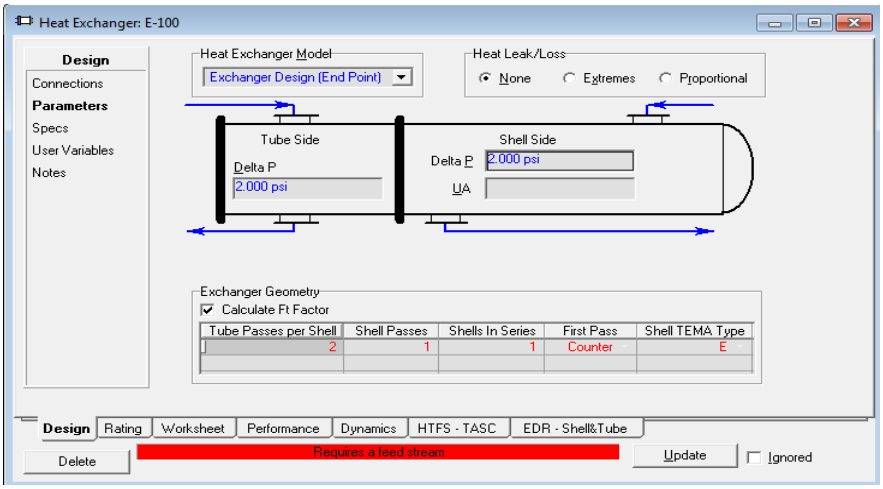
And that is excellent values that make the treated gas ready and safe to use.

**Step 3** the rich amine solution (stream 6) have a pressure of **548 psia**, in this step we will release the pressure to **100 psia** by using a valve and separator, to separate vapor line (stream 8) and liquid line (stream 9) and to do so just define the pressure out of the valve (stream 7) to be **100 psia**. And the bottom product will be a hot lean amine solution, must be cooled down to be reused, so instead of reheat the feed and cooling the bottom product this could be done by heat exchanger first before the distillation step, the rich solution (stream 9) will be heated to about **200 °F**, the pressure drop in general throw heat exchangers is **2 psi for each side**, so let us define the heat exchanger step by step.




**Step 4** this separated liquid stream must be regenerated by evaporation by using distillation column that have reboiler and condenser, the reboiler will heat up all the solution and the condenser will return back all amine solution back to the column but let the water vapor comes out from the condenser, this column will work to purify the amine solution from water, the top product is all vapor and gas traces like water, $H_2S$ and $CO_2$ comes out to flare to be burned. And the bottom product will be a hot lean amine solution, must be cooled down to be reused, so instead of reheat the feed and cooling the bottom product this could be done by heat exchanger first before the distillation step, the rich solution (stream 9) will be heated to about **200 °F**, the pressure drop in general throw heat exchangers is **2 psi for each side**, so let us define the heat exchanger step by step.

| Stream Name | 7 |
|---|---|
| Vapour / Phase Fraction | 0.0005 |
| Temperature [F] | 128.0 |
| Pressure [psia] | 100.0 |
| Molar Flow [lbmole/hr] | 7527 |
| Mass Flow [lb/hr] | 1.848e+005 |
| Std Ideal Liq Vol Flow [USGPM] | 364.9 |
| Molar Enthalpy [Btu/lbmole] | -1.134e+004 |
| Molar Entropy [Btu/lbmole-F] | 21.36 |
| Heat Flow [Btu/hr] | -8.532e+007 |
| Liq Vol Flow @Std Cond [barrel/day] | 1.165e+004 |
| Fluid Package | Basis-1 |
| Utility Type | |




Add two streams type of heat exchanger, connect the streams (9 and 10), define pressure drop for each side to about **2 psi**.

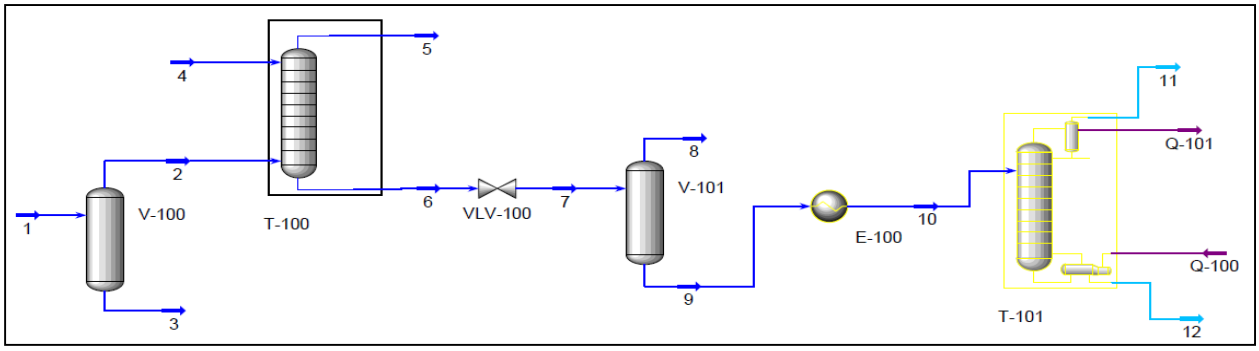
And then define the output temperature for (stream 10) to be **200 °F** we will notice that stream 10 will be done and accepted but the heat exchanger itself was not fully defined yet, while the distillation column has **18** trays, feed at tray number **4**, have full reflux condenser type, top pressure **27.5 psi**, bottom pressure **31.5 psi**. The condenser has a top vent stream that ventilate all water and undesired gases, while the amine solution will be concentrated inside the column and comes out from the reboiler bottom product, the distillation parameters are:

| Stream Name | 10 |
|---|---|
| Vapour / Phase Fraction | 0.0001 |
| Temperature [F] | 200.0 |
| Pressure [psia] | 98.00 |
| Molar Flow [lbmole/hr] | 7523 |
| Mass Flow [lb/hr] | 1.847e+005 |
| Std Ideal Liq Vol Flow [USGPM] | 364.5 |
| Molar Enthalpy [Btu/lbmole] | -9766 |
| Molar Entropy [Btu/lbmole-F] | 22.44 |
| Heat Flow [Btu/hr] | -7.347e+007 |
| Liq Vol Flow @Std Cond [barrel/day] | 1.165e+004 |
| Fluid Package | Basis-1 |
| Utility Type | |

1- Top temperature is **115 °F**.
2- Bottom component fraction for (DEA) is **0.3** mass fraction.

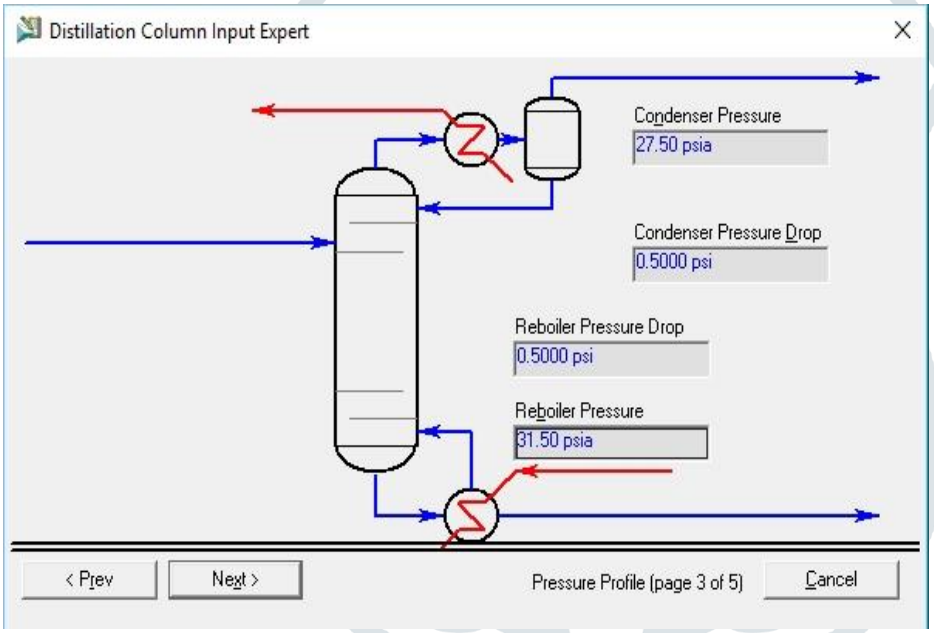
These parameters are inserted as Design Specs.

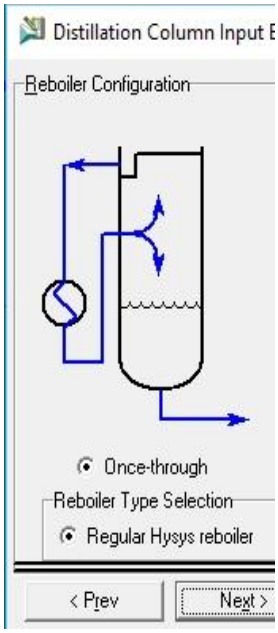
The distillation column must be connected like this way as showing in the figure.




And now we open the distillation column specification and define the number of stages to be 18 trays, feed stage at tray 4, the condenser must be full reflux condenser.

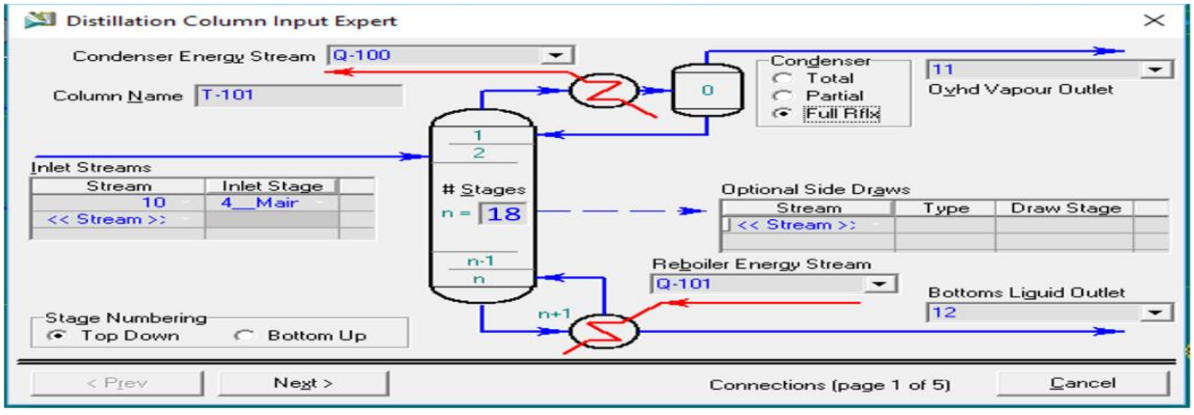
The reboiler type will be regular HYSYS reboiler with once though.




The top pressure will be **27.5 psia**, and bottom pressure **31.5 psia**, and the condenser and reboiler pressure drop is **0.5 psi**.

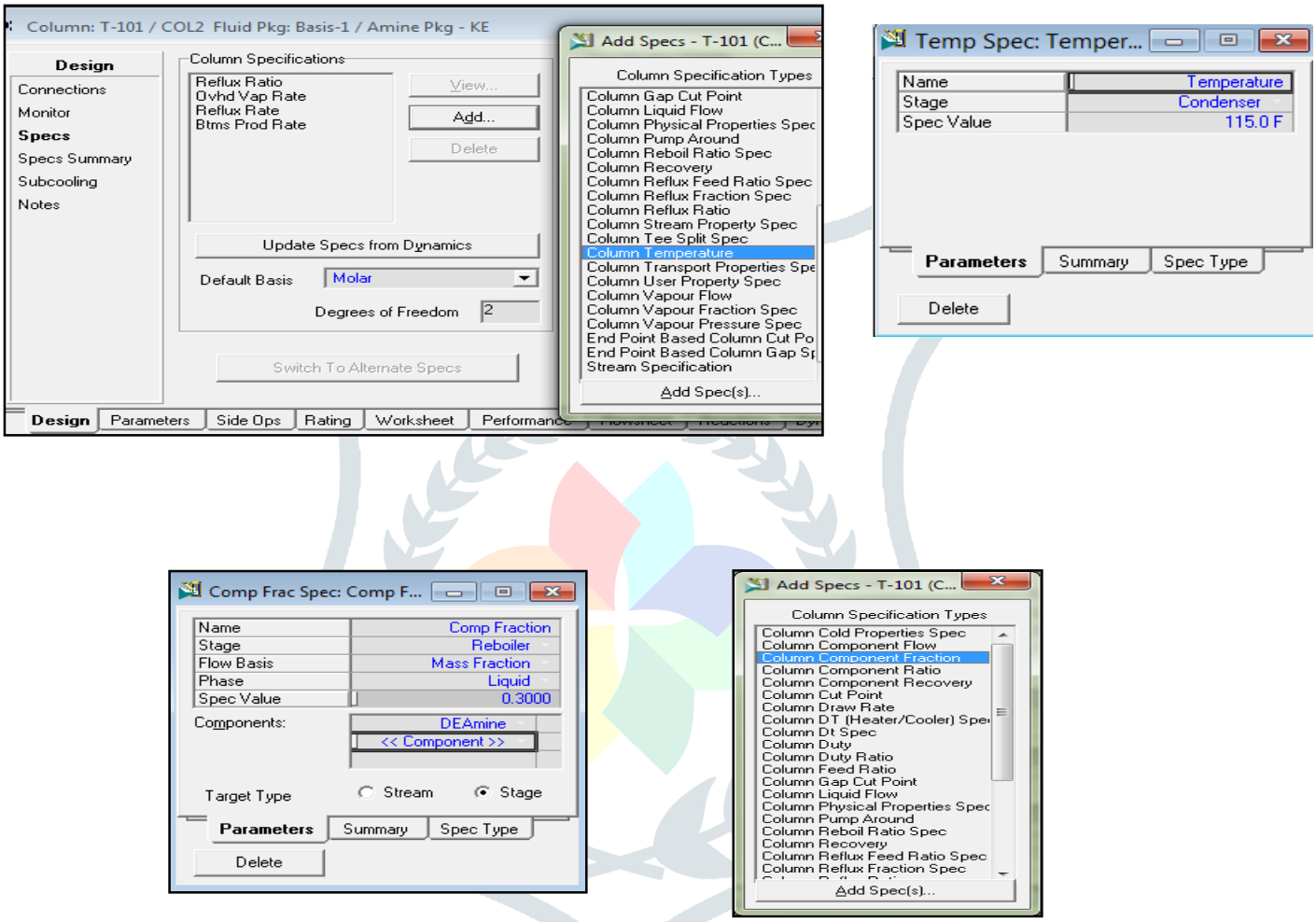
And leave blank for the top and bottom temperatures, let the reflux ration blank also.



At the design specs, add

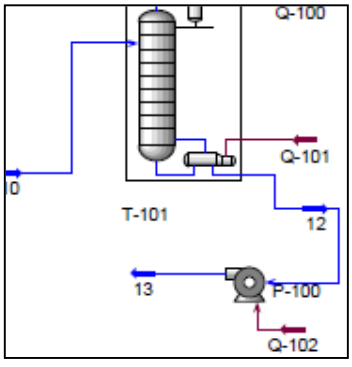
1- Column temperature value at the condenser (top) is about **115 °F**,

2- Column component fraction for DEA solution is **0.3 mass fraction**. And then make these two specs as an active in the monitor window and press the run bottom it will start the distillation calculation.




So, the green converged sine will appears declare that this distillation column calculation is done correctly.

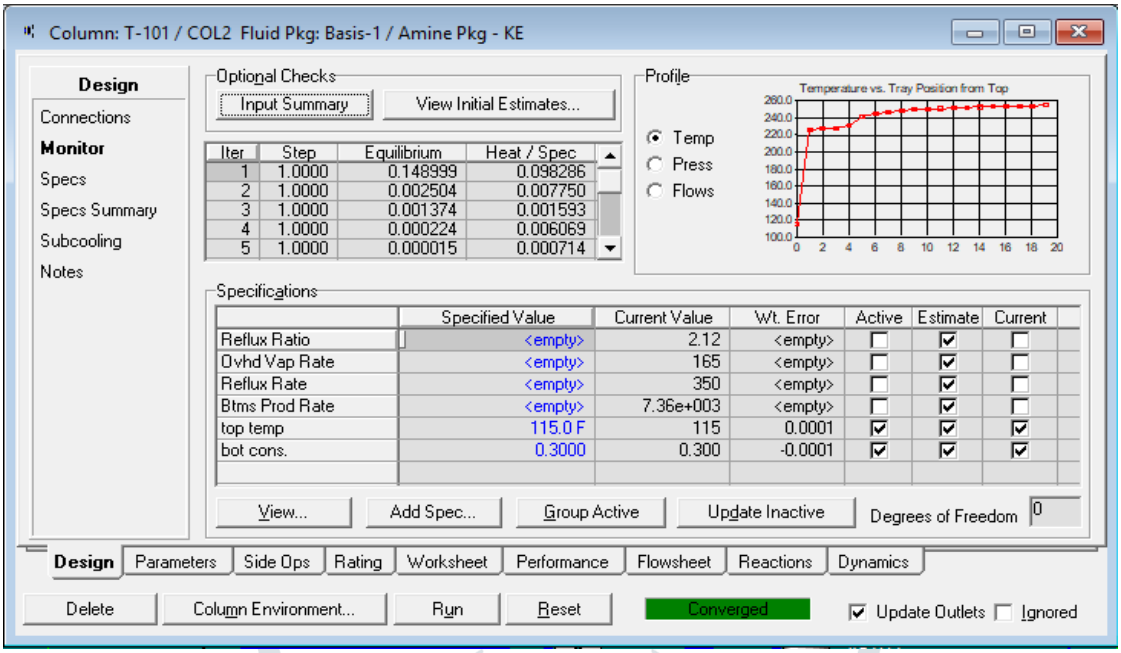
We note that the top stream is the undesired gases like $CO_2$ and $H_2S$ also sensible amount of water vapor will go out to the flare, and at the bottom produce a lean solution of DEA but at high temperature **(256.1 °F)**.



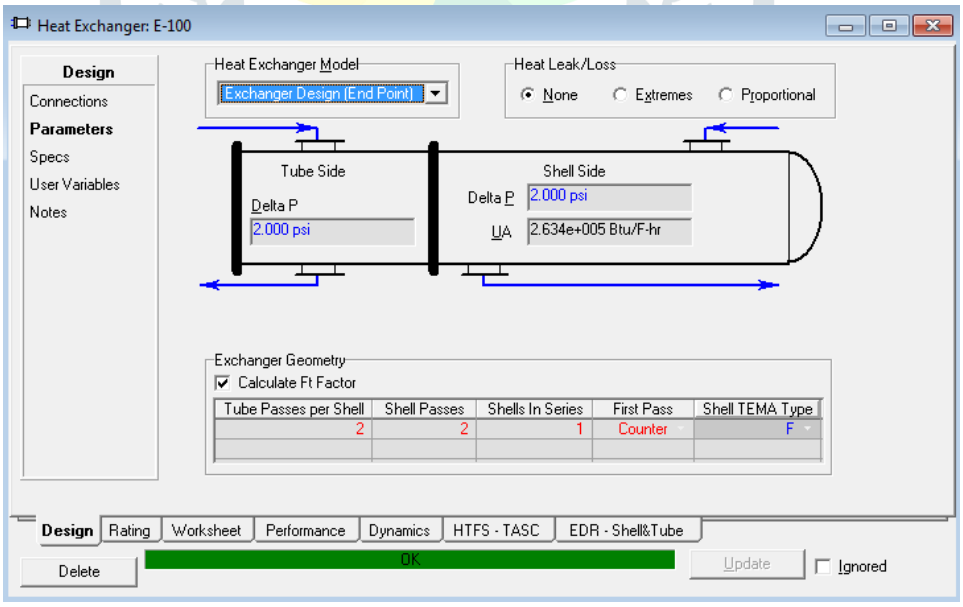

**Note:** the reflux ratio is 2.21 and it is acceptable but you can improve that to reach 0.672 reflux ratio if you use 32 trays with feed tray location at tray 4.

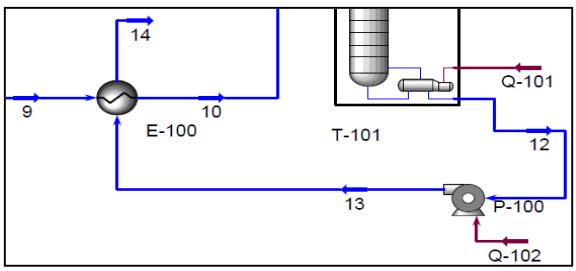
**Step 5:** the lean amine solution now is regenerated and all the dissolved gases are removed, but its pressure is very low to flow over

next equipment so we need a pump just to reach to the operational conditions, so we need a pump to reach the lean amine solution to **100 psia**.




**Step 6:** The bottom product of the distillation column is hot, so we can return it back to the previous heat exchanger as a heating media, in the beginning a yellow massage shows that "**Ft Correction Factor is Low**" and that mean that the exchanger could be not efficient at all, to solve it, we can change the shell type from **E to F**; were E is one pass shell, F is two pass shell.



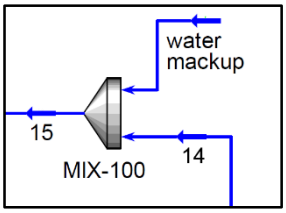
**Step 7:** this stream (stream 14) is the lean solution that return to the absorber but the mole flow of stream 14 is **7359 Ib.mole/hr** it should be equal to the Amine solution input line (Stream 4) but it's not, because of a water vapor is evaporated in the re-generator, so we need to add water to keep the concentration correctly.

| Stream Name | 14 |
|---|---|
| Vapour / Phase Fraction | 0.0000 |
| Temperature [F] | 187.8 |
| Pressure [psia] | 98.00 |
| Molar Flow [lbmole/hr] | 7358 |
| Mass Flow [lb/hr] | 1.767e+005 |
| Std Ideal Liq Vol Flow [USGPM] | 344.3 |
| Molar Enthalpy [Btu/lbmole] | -9656 |
| Molar Entropy [Btu/lbmole-F] | 22.62 |
| Heat Flow [Btu/hr] | -7.105e+007 |
| Liq Vol Flow @Std Cond [barrel/day] | 1.166e+004 |

Material Stream: 14

| | Mass Fractions |
|---|---|
| i-Pentane | 0.0000 |
| n-Pentane | 0.0000 |
| n-Hexane | 0.0000 |
| Nitrogen | 0.0000 |
| H2S | 0.0003 |
| CO2 | 0.0009 |
| H2O | 0.6988 |
| DEAmine | 0.3000 |

This lean amine solution (stream 14) should be the same of the input amine stream (4) molar flow **is 7370 Ib.mole / hr**, but there is a deference about **11** to **12 Ib.mole / hr**, and the missing was in the water content, so we need a water line makeup is added with the stream 14 to add the missing water, so name it **Water makeup**.

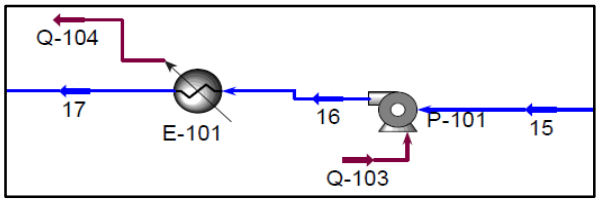



Stream water makeup will be just water only and stream 15 is the mixed stream, to do so, we have to define the water makeup stream first **but without flow rate**, just temperature (**77°F**), pressure (**98 psia**), and composition of **100 % water**.

And then define the mixed stream (15) **but this time define the flow rate to be 7370 Ib.mole/hr only**, so the mixer will be defined properly and the HYSYS will calculate the required flow of water makeup.

**Note:** do not try to enter the flow of water makeup by yourself.

**Step 8:** is to increase the pressure to reach the start point pressure of 553 psia (stream 4) by using a pump but it will pass in the cooler with a pressure drop of 2 psi, so the pressure must be 555 psia

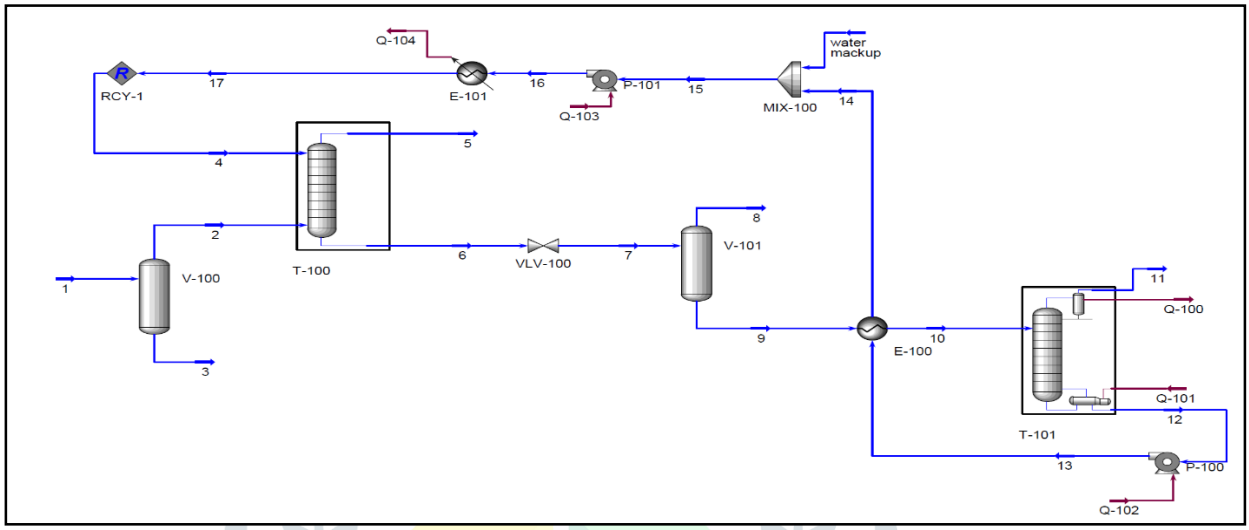


**Step 9:** is to cool down the amine solution to **105 °F** by using a heat exchanger have a pressure drop of **2 psi**.

**Step 10: before going further with this step you have to save your work**.

The lean solution is now ready to recycle to the absorber, to do so we have to use a recycle item and connect stream 17 with stream 4, you will notice that a recalculation will made to achieve full recycle stability.

So the final process is to recycle will be as a circle using recycle process of amine to remove acid gases like $CO_2$ and $H_2S$.




**Final process diagram for natural gas sweetening unit using DEA solution**

**Design of the absorber T-100:**

The aim of the design procedure is to calculate the diameter of the column and all its internal parts specifications.

Each column if it absorber or distillation column is contain some times more than one section, for example; the absorber is consisting of one contact section, but in the distillation column, it has two sections (rectifying and stripping), so we have in this absorber only one section, this kind of calculation is called tray sizing.

This option is one of utilities that could be found as following:

**Tools** menu →**Utility**→**Tray Sizing**→**Add Utility**.

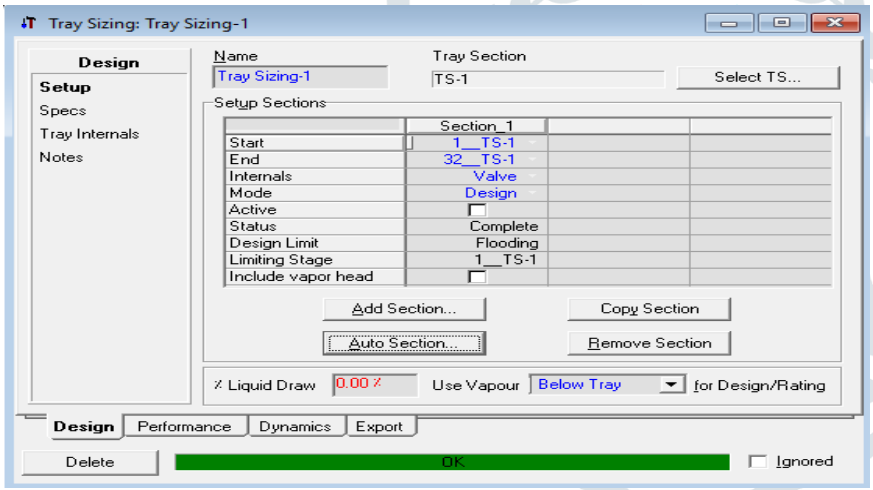
There is a bottom named **Select TS…** it will appear a new table to select a tower, so select *T-100* in the **Flowsheet** items, and then in the **Object** select *TS-1* and press OK.

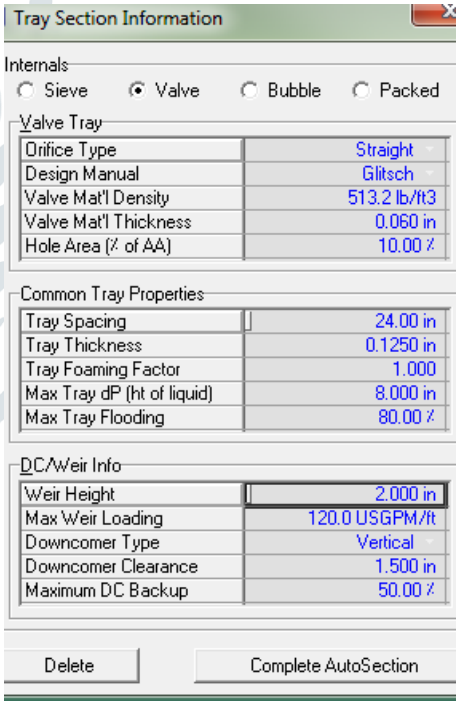
A new two commands will appear **Add Section** and **Auto Section**, these are the section that we talk about earlier, to complete easily this step just click on Auto Section item, then it will appear another window asking the type of the section with an option to select sieve, valve, bubble cup or packed column, in this step we will chose valve and this selection is depending on the gas flow restrictions and that because it's not smooth or stable so to prevent weeping problem in the trays, we have to use valve type that can close if low or no gas flow.

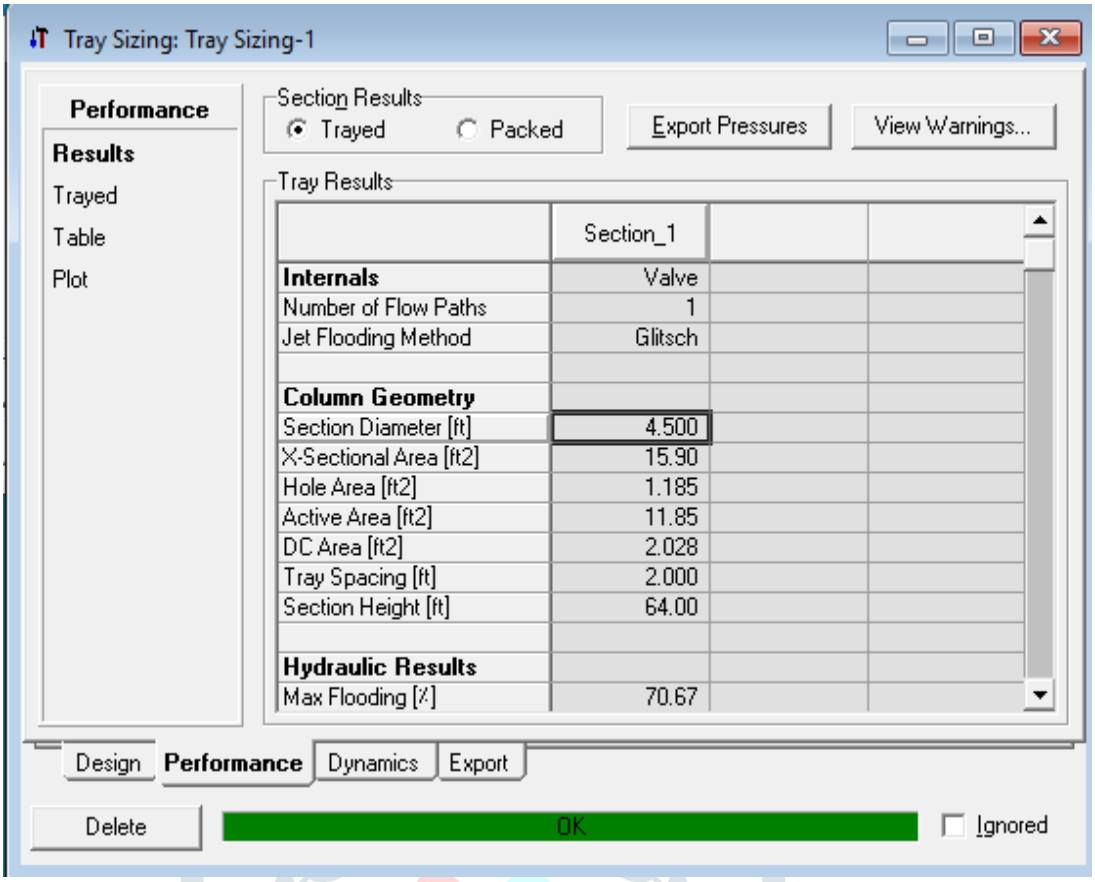
After selection valve just press next, another window appears showing the default setting for the tray internal parts, if you need to change any parameter you can do it in this window, but for now we are going throw the default setting and then press on the command at the bottom of this window "Complete Auto Section" it will calculate and make the design it will give you a Green Bar with OK sign in it to declare this finalization

To prompt the design results just go to the **Performance** tab →**Results**; it will give you a full results.

See the results; the section diameter is 4.5 ft or 1.372 m.






## Results before and after absorber:

### For a composition comparison before and after absorber

| Component | Before Absorber (Stream 2) | After Absorber (Stream 5) |
|---|---|---|
| **$CO_2$** | 105.6 lb.moles/hr | 0.0385 lb.moles /hr |
| **$H_2S$** | 50.6 lb.moles/hr | Nail |

### That is means the absorption percentage will be:

| Component | |
|---|---|
| **$CO_2$** | (105.6-0.0385) x 100/105.6 = 99.95% removed |
| **$H_2S$** | (50.6) x 100 / 50.6 = 100 % removed |
| **$CO_2$** | (0.0385/4755) *10^6 = 8 ppm remaining |
| **$H_2S$** | (0/4755) *10^6 = 0 ppm remaining |

**Results before and after distillation colum:**

| Component | Before Distillation Colum (Stream 10) | After Distillation Colum (Stream 12) |
|---|---|---|
| **$CO_2$** | 105.58 lb.moles/hr | 3.52 lb.moles /hr |
| **$H_2S$** | 50.58 lb.moles/hr | 1.51 lb.moles /hr |

**That is means the Distillation percentage will be:**

| Component | |
|---|---|
| **$CO_2$** | (105.58 -3.52) x 100/105.58 = 96.6% removed |
| **$H_2S$** | (50.58-1.51) x 100 / 50.58 = 97 % removed |

## References

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