Column Optimization for Amine Based Acid Gas Removal Processes

Tavares, Bárbara[a]; Gonnard, Sebastien[a]

[a] IFP Energies Nouvelles, Rond-point de l'echangeur de Solaize BP 3, 69360 Solaize, France

Abstract

This master theses consists in processes optimization for acid gas treatment using amine solvents. This work is focused on getting a gas within a certain specifications and conditions, which are necessary for the gas commercialization and consumption.

The study performed was made for different sources of natural gas. For all these were made a preliminary study of the absorption column process to determine the possible design that can be used to achieve the required specifications. In all designs, it is perform a careful selection in order to selected the best and most profitable designs to be studied. For the previous selection are carried out economic studies, calculation of the CAPEX and the OPEX, for each procedural scheme. These studies allow to select which of the situations can ensure greater reliability and viability of the project, in study.

Additionally, it is performed several sensitivity analysis to the mass transfer parameters in the absorber, this sensitive study is performed to ascertain the most susceptible factor to be change for ensure the optimization of the operational conditions and consequently to obtain a project more economical so cheaper.

From different commercial packings, it is selected the one that allows to reduce the columns dimensions in order to reduce the column price, the absorber price is very important because this equipment is the unit with a greater weight in CAPEX calculation.

Keywords: Absorption, Absorber, Regenerator, Packing, Trays, Acid gas, Economic analysis, Optimization

1 Introdution

Natural gas market is growing due to the global demand for energy. In the oil sector, the use of resources richer in acid gases, contributed to the changing of the environmental constraints and therefore the targeted specifications and this leads to the need of developing new treatments, also the technologies and the treatment used are constantly changing with the technical and economical issues.

The H_2S and CO_2 removal processes have great interest in today's industry so the motivation of this work is the development and improvement of the technical aspects in the gas treating for removal of acid gas using amines processes. The importance of this study is to ensure that this component must be captured either to achieve imposed legislation limits or to meet required specifications and ensure the best profitable situation for the industry. There are diverse types of amine solvents and several structures of packing that the industry can use so it is relevant to make a study of what is the best operational and technical conditions to achieve the different gas specifications for transport and processing, and at the same time ensure the lowest CAPEX and OPEX for the contactor and for the regenerator.

Gas Treating

Gas treating requires different process plants depending on sour gas composition and treated gas specifications. Undesirables components should be removed from gas streams to ensure the security and good operating conditions, since these compounds can be responsible for these different constraints: [1] [2] [3]

- Contamination of the final product;
- Catalyst poison;
- By-product production;
- Corrosion;
- Dew point, unwanted condensation downstream;
- Environmental considerations.

Nowadays the big challenges are related with the emission reduction of carbon dioxide and sulfurs to the atmosphere. Each day that goes by the governments apply more severe environmental legislation so it is important to reduce the percentage of these components in gas stream before being transported or used. So the objective of gas treating facilities is trying to find the most effective solutions in order to make the process more profitable. [3] [1]

When the commercialization of the natural gas is made there are two possible applications, one is the LNG production and other the transportation through pipelines of natural gas. The specifications required in terms of acid gas concentrations are different for each type of application, so in Table 1 the compositions for each application are specified.

Table 1. Specifications for each gas application. [1]

Acid Gas Components	Natural Gas Pipeline Transport	LNG Production
H_2S	$4\,ppm$	$4\,ppm$
CO_2	2%	$50\,ppm$

The gas treating line is affected by the composition of the natural gas and by the application that the gas will have. One should notice that the gas composition (light and heavy hydrocarbons, impurities, metals, water, H_2S, CO_2, etc.) is related with the geographic area where the natural gas reserve is located, and with the time of exploration of the well [3] So it is necessary to use different contactor technologies and/or different type of solvent to ensure that the quantity of CO_2 and H_2S desired in the treated gas is reached.

Overview of different types of processes

Currently, there are three main families of acid gas treatment: [1] [3] [2]

- **Adsorption processes**, which aim to eliminate H_2S or other minor sulfur compounds (COS, RSH, CS_2, light sulfides) suitable for gas with low H_2S levels;
- **Redox processes**, which aim to eliminate the H_2S, suitable for low to moderate H_2S concentration in the gas , and which have the advantage of removing sulfur directly under solid form;
- **Absorption processes**, which aim to eliminate the CO_2 and H_2S, and which use chemical solvents, physical or hybrid. Depending of the gas characteristics can be selected the most appropriate technology to deal with it.

In order to choose between one of the three families of technologies the quantity of sulfur per day ($kg\ S/day$) should be analyzed; if the gas stream has between $50 - 100\ kg\ S/day$ an absorption processes can be used but if the feed gas has up to $10\ ton\ S/day$ it is better to use redox processes. However if the gas has more than $10\ ton\ S/day$ the best technology is the absorption processes. [3]

Global absorption Process by Amines

The design of the absorber depends on the gas volume, inlet concentration, outlet specification, pressure, temperature, liquid circulation rate, solubility of the gas in liquid, number of trays, height, contact time, diameter of column and the presence of other components in the gas. [1]. In some cases, mass transfer must be enhanced by chemical reactions, this is called reactive absorption processes. For gas treatment, amines are widely used to react with undesirables acid gases. A typical process based on an amine solution is shown in the Figure 1. These processes can support large quantities of H_2S economically, and CO_2 may also be controlled if necessary.

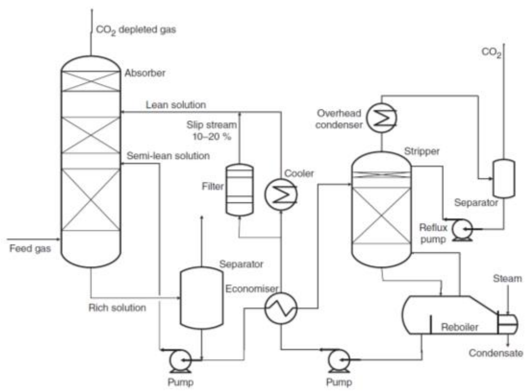

Figure 1. Flowsheet of an absorption process by amines. [2]

Explaining the process shown in the Figure 1 it can be seen that initially the raw gas enters into an absorber column but normally first it is admitted into a gas-liquid separator where the gas is free of any liquid trace for prevent the strong foaming or flooding of the column, this unit isn't represented in the Figure 1. After the feed gas pass through the separator it enters into the bottom of the absorber where the current contacts with the regenerated solvent, lean solvent, which enters at the absorber head. The absorber can be filled with packings or plates and usually operates at high pressures between 50 until 100 bar. The treated gas, without acid gas, exits in the top of the absorber and it is cooled in a heat exchanger, air cooler, and next it passes through a gas-liquid separator for the treated gas stream to be free of any liquid trace, then the gas stream can be sold, transported or storage. The amine-rich acid gases and processed gas condensates are sent to the ball flash operating at medium pressure, the relaxation allows the majority of light hydrocarbons to be vaporized, this step isn't performed if the gas that enters in the unit is at a pressure near to atmospheric pressure, such as in the case of biogas. [1] [2] [3]

The solvent rich in acid compounds is then preheated in an amine-amine heat exchanger using the regenerated solvent, and then it enters the regeneration column operating at low pressure, about 2 bar, where it is thermally regenerated by stripping. As the absorber, the regenerator can be filled or fitted with trays. The acid gas is released in head, and the existent water in the acid gas is condensed by a heat exchanger and then separated in the reflux drum. [1] [2] [3]

The separated water is called reflux and it is reintroduced in the head regenerator. In the bottom of the regenerator, enters the amine reboiler, often type Kettle, where amine is heated and in here the vapor generated returns to the regenerator and the regenerated amine leaves the column and it goes to amine- heat exchanger to be cooled. 10% of the amine flow is led into the filter device and all of the regenerated solvent is cooled and pressurized so it can be reused in the absorber. [2] [3]

Objective

The main objective in this work is the research of more capacitive and efficient packing to optimize the design of the absorption and regeneration columns and study what is the most profitable situation in terms of CAPEX and OPEX in sweeting process.

2 Methodology

Programs

Simulation tools:

- **PME : PROII 9.1.3 →** It is a process simulator program for process design and operational analysis for process engineers in the chemical, petroleum, natural gas, solids processing and polymer industries. It includes a chemical component library, thermodynamic property prediction methods, and unit operations such as distillation columns, heat exchangers, compressors, and reactors as found in the chemical processing industries. Additionally it can perform stationary state Heat and Material Balance (HMB) calculations for modeling continuous processes.
- **Specific in house models : Program A→** Models are dedicated to simulate amine based processes for gas sweetening. It includes a thermodynamic model (properties package and pure component libraries) and rigorous columns unit operations (for absorption and regeneration) using mass transfer rate-based models for acid gas reactions with liquids. A launcher is dedicated to perform sensitivity studies. It should only be used to simulate absorbers equipped with packing. Additionally, in this launcher the study will focus in analyzing the influence of changing the mass transfer parameters on the treat gas, for that it is important introduce a new term, "CCC", which is an adjustment factor that lets the program vary each variable in percentage regarding the standard value defined for the programs used.

Costs estimation tool : Program B

The Program B is designed to quickly and easily assess the cost of a complete process unit from the costs of major equipment requiring a reduced number of data. It used as an input in the design parameters of all the equipment's related with process, the design parameters are obtained with the simulator described previously (HMB) and a *proprietary* program, Program C, the last one makes the design of equipment's using the stream data obtained in PRO II.

Methodology

The methodology is divided in four steps:

1. Cases Selection

The first step consists in the building of a PROII simulation where are present only two equipment's: a scrubber to separate condensate (water and hydrocarbon) from the feed gas to optimize the efficiency of the mass transfer in the absorber and avoid foaming. The second equipment is a rigorous absorber. The PRO II scheme can be seen in the Figure 2. The necessary inputs for the simulation shown in the Figure 2 are the data of the feed gas and lean amine and the operational conditions of the two units. For the absorber column analysis it is needed to follow the next procedure:

1) Design an absorber with conventional trays :
   a) Find the number of trays to reach the specification with specific amine flowrate;
   b) Select the best case.
2) With the selected amine flowrate will be: computed the height of a reference packing (the PACKING 1) to reach the specification:

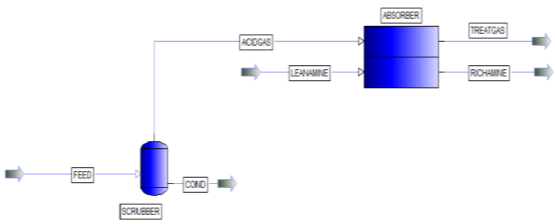

Figure 2. Flowsheet for the scrubber and the absorber.

Posteriorly, all the data obtained in the previous steps give us the variation of the CO_2 and/or H_2S concentration in the treated gas stream between a range of amine flowrates for several number of Trays. Therefore, using the data obtained it was possible to choose which are the most favorable cases for absorbers with Trays and with packing. For the absorber, because of high pressure, it is essential to optimize the diameter to reduce the cost.

2. Economic Analysis

The economic analysis is based on the study of the CAPEX and the OPEX. The CAPEX is a capital expenditure and the OPEX is the money a company spends on an ongoing, day-to-day basis in order to run a business or system. Running the processes simulations it is obtained the composition and the conditions for all the process streams and equipment's, these data are important because in the CAPEX calculation is necessary design and determine the cost of all the equipment's and for that it is necessary the results obtained for the process simulation. The simulations are done in PRO II and an example of the simulation is represented in the Figure 3.

Concluding the CAPEX calculation the next step is to start with the OPEX analysis. The OPEX is given by three parcels, the electricity that is used for the pumps and air coolers, the steam used in the reboiler and at last the solvent stock because in the process there are some solvent losses by degradation or simply for solvent losses in several out streams. Furthermore, for the OPEX calculation it is required the prices of the three parts mentioned, different costs for chemicals and utilities are used but these values are confidential, and it is still necessary to take some assumptions, these are described in the following topics:

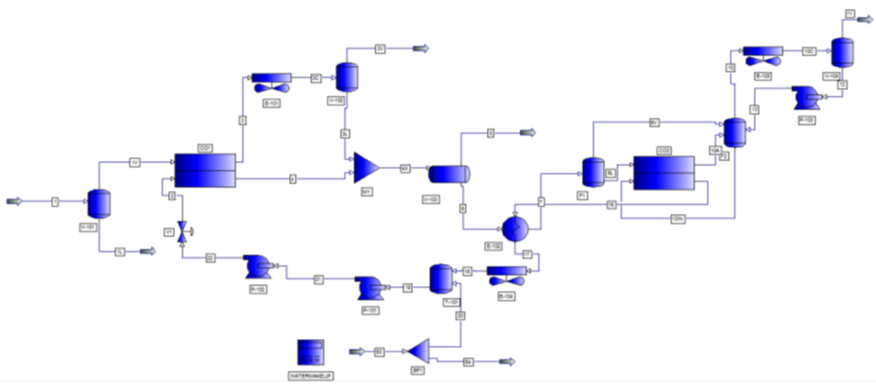

Figure 3. Flowsheet of the gas treatment process in PROII.

- Total solvent losses in a year is given by $X\%$ for the all solvent storage used in the process, so $X\%\ of\ solvent\ losses/year$;
- It is assumed $8000h\ of\ work/year$;
- The solvent price it is given by the pondered average of the prices of each component that the solvent is made.

3. Sensitivity Analysis to the Mass Coefficients and Superficial Area

The coefficients to be studied are the interfacial area, a_i, and the mass transfer coefficients for the liquid k_L and gas phase k_G.The objective of this study is to vary this three parameters and see which ones are critical and which are the best values to minimize the size and the cost of the absorbers. These sensitivity analysis are made in Program A, this launcher allows to realize several sensitive analysis at the same time. The programs inputs are the streams conditions, simulated in *PRO II* for all the process, and one matrix where it is added a range of values for which both the sensitivity analysis is performed. Using the factor "CCC" it is feasible to vary the values of the desired parameters. For each selected process with packing columns multiple sensitive analysis and singular sensitivity analysis will be done, resuming this chapter, the work was split in two phases:

1) Independent study of each variable:
   - $k_G a, k_L a \text{ and } a_i$ → variation between -20% until +100%;
2) Study of k_G impact in the k_L and a_i:
   - $k_G a$ → variation between -20% until +20%;
   - Sensitivity analysis on a_i and $k_L a$, variations between -20% until +100%

Analyzing the data acquired for the two steps it can be concluded which are the best parameters to improve the column design, so now the next objective is to try to select a commercial packing that can fit within these parameters.

4. Selection of the best type of Packing

The main goal in this section is to estimate the cost and the dimensions of the absorber column when it is used a commercial packing. To perform the column height computation it is necessary to obtain some correlations to compute the column diameter for each packing and the adjustment factors "CCC's" for the mass transfer parameters. For this work, a first list of classic different commercial packings have been used. The list is limited since literature data and/or in-house data are needed. The packing's that will be used in the simulations are PACKING 1, PACKING 2, PACKING 3, PACKING 4, PACKING 5, PACKING 6, and PACKING 7. Correlations have been implemented for PACKING 1. For other packings, it was more convenient to adapt CCC coefficients than to implement specific correlations. Using the previous data the main goal is to identify what packing(s) allow to have the smallest and so cheapest column in which the treated gas meet the wanted specifications. This will illustrate the impact of the packing on the process. Having all the inputs, starts up the estimation of the height of the column for each commercial packing. After having the new designs it is calculated and analyzed the erected cost for the absorber column, using the economic tools it can be estimated the cost associated to each column for all the packing's assuming that every packing has the same cost than PACKING 1. However that last assumption isn't really truth because it is already known that there are packing's more expensive than other's (depending on the generation of packing and the production geographic area). But it's really difficult to get price for each commercial packing because those prices depends on the desired volume of packing.

3 Results and Discussion

The methodology explained previously will be applied to three different cases, the first two cases with only CO_2 in the acid gas, the third case where the acid gas has the same quantities of CO_2 and H_2S.

The following topics are related with the results obtained and it is important to refer that for all the cases several values will be hidden or replaced by letters and/or relative values, %, in order to protect confidential data. The values replaced by percentages are the amine flowrates and the packing height's, for each parameters it is necessary consider one value for the 100%, so the criteria used was:

- Amine flowrate → The 100% is the lower flowrate simulated in the absorber;
- Packing Height → The 100% is the height that let us obtain the best design for proposal.

Natural Gas with 7% of $\boldsymbol{CO_2}$

1. Cases Selection

The first study case is where the feed gas has only CO_2 and Hydrocarbons, so in this case doesn't exits any H_2S. The objective is to get $50\,ppm$ of CO_2 in the treat gas so it will be used three types of lean amine solvent: Solvent 1 with $1\,g/L$ of CO_2 , Solvent 2 with 5 g/L of CO_2, and at last a Solvent 3 with 10 g/L of CO_2. Using the methodology and running the absorber can be seen the variation of CO_2 concentration in the treated stream between the plates 20 until 30 and for different amine flowrates. What it is possible to observe for this cases is that in the lean amine 1 g/L and 5g/L of CO_2, it is possible to get the specification, but using the Solvent 3 isn't possible to get the specification within the maximum of 30 plates and an amine flowrate of 200% Sm^3/h. Between the two possible lean amines the ratio $Y^*_{CO_2}/Y_{CO_2}$, this represents the CO_2 in vapor in equilibrium with the solvent, so summarizing the Solvent 1 presents a ratio of $Y^*_{CO_2}/Y_{CO_2} = 0{,}4$ and the other has a ratio of $Y^*_{CO_2}/Y_{CO_2} = 0{,}3$, so the best kind of solvent is the one that lets a CO_2 transfer more close to the equilibrium, thus the best option is the Solvent 1. To select the best case there is the need to understand that when the flowrate increases a lot the absorber diameter will increase and that makes the column price increase too, so the criteria used for the selection of the design for plates absorber is as following:

- Proximity to the equilibrium conditions, so the case with bigger ratio of $Y^*_{CO_2}/Y_{CO_2}$;
- Lowest Column price in stable operating conditions, that means that allows reach the specification decreasing 10% of the flowrate. This represents the best cases for proposal.

Using the results of the sensitivity analysis that ensure the specifications for several combinations of number of stages and the amine flowrate. The selected designs for tray columns are:

- **CASE A1.1**- $Q = 175\%\ Sm^3/h$ and an absorber with 24 plates, in this situation it is expected the lowest column price.
- **CASE A1.2**- $Q = 115\%\ Sm^3/h$ and an absorber with 28 plates, this case exihbit a bigger value of $Y^*_{CO_2}/Y_{CO_2}$.

Applying the same methodology, in other words use the simulator to do a sensitivity analysis to the packing height for several amine flowrate and see for which combinations of height and amine flowrate can be achieved the specifications. It is possible to select two designs:

- **CASE B1.1 -** $Q = 100\%\ Sm^3/h,\ H_{packing} = 100\%\ m$, in this situation the lowest column price is expected, but in this case it is obtained an absorption height superior to the height obtained than using an absorber with trays.
- **CASE B1.2 -** $Q = 115\%\ Sm^3/h,\ H_{packing} = 72\%\ m$, this situation was select because with a 5% increase on flowrate an height decreased of ~38% is obtained. And contrary to the CASE B.1 the absorption height is lower than the packing case when compared with the trays case.

2. Economic Analysis

The Figure 4 and Figure 5 represents the determinate values for the CAPEX and OPEX using all the steps explained in the methodology.

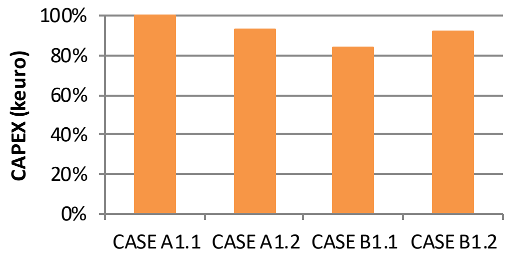

Figure 4. The CAPEX cost for each case, for the feed gas with 7% of CO_2.

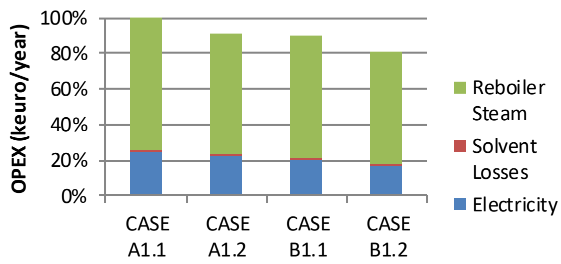

Figure 5. The OPEX cost for each case, for the feed gas with 7% of CO_2.

So in conclusion the processes with PACKING 1 are better because they need less absorption height, less flowrate and they are cheaper. But now the decision between the two conditions with packing is more complex because the CASE B1.1 have a bigger CAPEX and OPEX, basically the CASE B1.1 as a gain in 10% and 4% respectively, although in the CASE B1.2 when compared with the CASE B1.1 it is possible to observe a gain of 29% in the height of the column. So the case selected was the CASE B1.2, this case is chosen despite being the packing case with worst economic value because between the CASE B1.1 and the CASE B1.2, the first one is the most instable and because of that it is safer to choose a stable case even if it is more expensive.

3. Sensitivity Analysis to the Mass Coefficients and Superficial Area

Several sensitivity analysis to the mass coefficients and interfacial area related with the absorption phenome will be performed. The data obtained let us to conclude that the a_i is the most sensitive parameter, so with more interfacial area the packing height can be smaller and then the column price is lower. Between the k_L and the k_G, the last one doesn't have a significant impact in the absorption, so the gain in k_L can be useful but not so useful comparing with the gain in a_i.

4. Selection of the best type of Packing

Computing the new designs with commercial packing allows to acquire results comparable to the values already applicable to the case of PACKING 1. Thus the new designs obtained are represented in the following figures, Figure 6 and Figure 7. In these the relative values for the height and diameter for each design are shown, using like reference the PACKING 1.

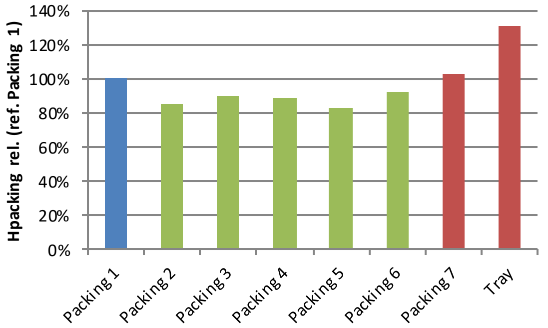

Figure 6. Bed height comparison for different packing using PACKING 1like reference, for the feed gas with 7% of CO_2.

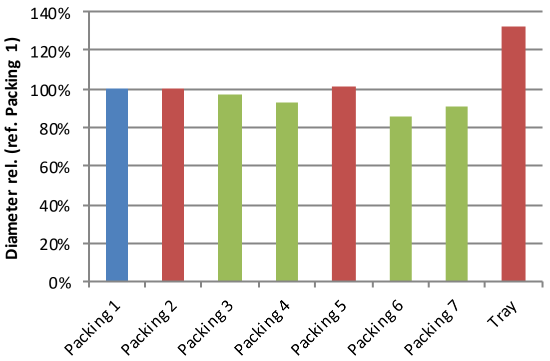

Figure 7. Diameter comparison for different packing using PACKING 1 like reference, for the feed gas with 7% of CO_2.

To complement this study it was made an economic study to see the absorber price where all packings have the same price than PACKING 1, using the *Program B* and *Program C* to make the design of each column. Concluding when compared with the PACKING 1 the best packing's are the PACKING 6, PACKING 3 and the PACKING 4. Therefore the PACKING 2 has a good efficiency but it is very expensive and it has a lower capacity when compared with the others. The PACKING 5 I has the best efficiency but it is the second more expensive design, and the first is the absorber with PACKING 1. The PACKING 2 and the PACKING 5 also lead to an increase of the column diameter. The PACKING 7 has a good capacity and column cost however is the worst in terms of efficiency and leads to an increase in the column height.

Natural Gas with 3% of CO_2

1. Cases Selection

This study is similar to last situation, a feed gas with 7% of CO_2. The difference between this and the other situation is the gas composition, because in this the natural gas has less CO_2 however it is used the same lean amine that in the previous case because it is the solvent that give us a lower $Y^*_{CO_2}/Y_{CO_2}$ratio. In the sensitive analysis can be observed that it is possible to reach the specifications for several designs, each design has different number of stages and the amine flowrate. To select the best designs was used the same criteria than used for the natural gas with 7% of CO_2. So using the simulation data and considering the selection criteria, it can be selected two best designs:

- **CASE A2.1**- $Q = 150\%\ Sm^3/h$ and an absorber with 24 plates, , in this situation it is expected the lowest column price.
- **CASE A2.2**- $Q = 112\%\ Sm^3/h$ and an absorber with 28 plates, this case exihbit a bigger value of $Y^*_{CO_2}/Y_{CO_2}$.

Selected the tray cases, the same study was done for a PACKING 1 absorber. So applying the same methodology from the results obtained, one case can be selected:

- **CASE B2.1**- $Q = 112\%\ Sm^3/h,\quad H_{packing} = 100\%\ m$, this situation was select because this case has a absorption height lower than the absorption height in the CASE A2.2 and better ratio $Y^*_{CO_2}/Y_{CO_2}$ than trays designs.

2. Economic Analysis

The OPEX and CAPEX results are compiled in the following Figure 8 and Figure 9.

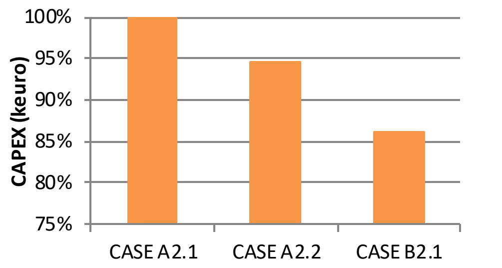

Figure 8 The CAPEX cost for each case, for the feed gas with 3% of CO_2..

Figure 9 The OPEX cost for each case, for the feed gas with 3% of CO_2..

In conclusion, as in the other case, the process with PACKING 1 is better because this needs less absorption height and less flowrate so this process is cheaper when compare with processes with tray absorber. So the case selected was the CASE B2.1.

3. Sensitivity Analysis to the Mass Coefficients and Superficial Area

The results obtained for this feed gas are very close to the results obtained for the natural gas with 7% of CO_2. Resulting from the sensitivity analysis can be observe that the a_i is the most sensitive parameter, so with more interfacial area the packing height can be smaller and then the column price is lower. Between the k_L and the k_G, the last one doesn't really impact the absorption and the gain in k_L can be useful but not so useful comparing with the gain in a_i.

4. Selection of the best type of Packing

Enforcing the same methodology, the PACKING 1 was used like reference so computing the new designs with commercial packing allows us to acquire results comparable to the values already applicable to the case of PACKING 1. The new designs obtained are represented in the following figures:

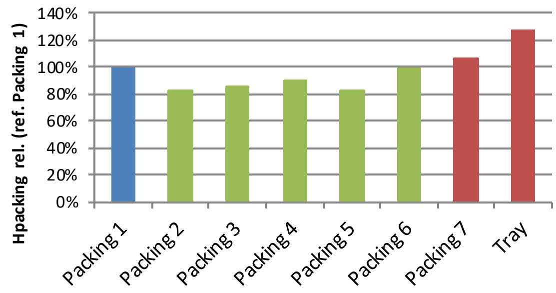

Figure 10. Bed height comparison for different packing using PACKING 1 like reference, for the feed gas with 3% of CO_2.

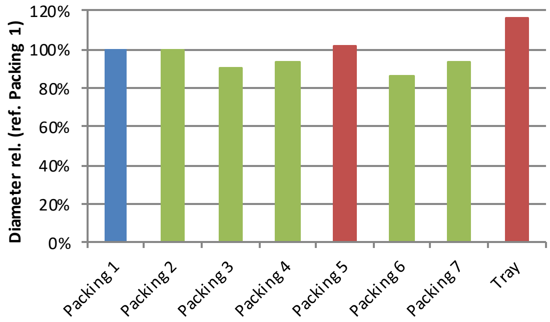

Figure 11. Diameter comparison for different packing using PACKING 1 like reference, for the feed gas with 3% of CO_2.

To complement these results, it was made an economic study to see the absorber price for each commercial packing. So when compared with the PACKING 1 the most suitable packing's are the PACKING 6, PACKING 3 and the PACKING 4. Therefore the PACKING 2 has a good efficiency and has an attractive column price. The PACKING 5 has the best efficiency but it has lower capacity and its column cost isn't very attractive in comparison with other options. The PACKING 7 has a good capacity however is the worst in terms of efficiency and in terms of column cost. This packing also leads to an increase in the column height.

Natural gas with 3,5% of $\boldsymbol{CO_2}$ and 3,5% of $\boldsymbol{H_2S}$

1. Cases Selection

The natural gas that will be treated in this section has a composition a little different from the previous cases due to the fact that this has CO_2 and H_2S in its composition, unlike the previous cases in which the feed gases only contained CO_2.The objective is to obtain the specifications shown in the Table 1, in other words the goal is to obtain a treated gas with 50 ppm of CO_2 and 4 ppm of H_2S. However, it is important to notice that in here the goal isn't only the removal of CO_2 but also the removal of H_2S, so should be respected the specifications for the two components. The lean amine used for this case has CO_2 and H_2S in its composition, in more detail that solvent has $1\ g/L$ of CO_2 and $0.11\ g/L$ of H_2S. The first thing possible to notice from the results it is the existence of a limiting component, because considering the same columns designs, in other words the same combinations of amine flowrate and number of trays, the results obtained for the H_2S removal show the possibility of use more designs for ensure the specification in the treated gas when compare with the data obtained for the CO_2 removal. So in this case the CO_2 is the limiting component, which means that during the absorption process occurs a selective removal of H_2S. Looking carefully to the results can be selected one best tray design:

- **CASE A3.1**- $Q = 137\%\ Sm^3/h$ and an absorber with 25 plates, in this situation it is expected the lowest column price. So this is the best design for proposal.

Selected the tray case, shall be done the same kind of study for packing absorbers. Having the desired flowrate for the column design the next step is simulate a packing column and so for what height the specification of the acid component can be ensured. The design selected was:

- **CASE B3.1**- $Q = 137\%\ Sm^3/h$, $H_{packing} = 100\%\ m$, this situation was select because this case has a absorption height lower than the absorption height in the CASE A3.1.

2. Economic Analysis

The economic results are compiled in the following Figure 12 and Figure 13.

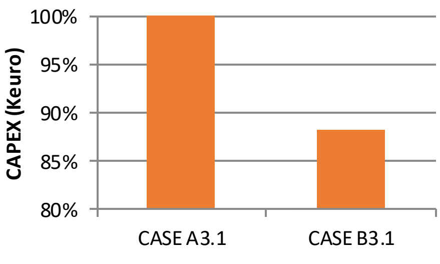

Figure 12 The CAPEX cost for each case, for a feed gas with 3.5% of CO_2 and 3.5%of H_2S.

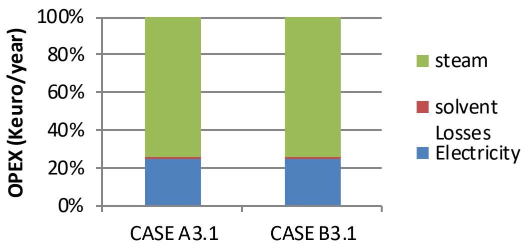

Figure 13. The OPEX cost for each case, for a feed gas with 3.5% of CO_2 and 3.5%of H_2S.

Concluding the best design selected is the CASE B3.1 because the design with PACKING 1 is better than trays, so for the same flow and operational conditions it is needed less absorption height which leads to the achievement of a cheaper process.

3. Sensitivity Analysis to the Mass Coefficients and Superficial Area

For this case the selection of the most sensitive parameter need to be an average between all the factors for the CO_2 and H_2S, but the principal criteria is ensure the minimum concentration of the two components in the treated gas. Overall, the interfacial area is the parameter that has a bigger influence in the absorption process. It is also observable that the changes in the k_G by $\pm 20\%$ doesn't have big impact in the results obtained, so increasing the k_G could add a little gain but not really significant

4. Selection of the best type of Packing

The new designs obtained are represented in the Figure 14 and Figure 15. In these the relative values for the height and diameter for each design are shown, using like reference the PACKING 1.

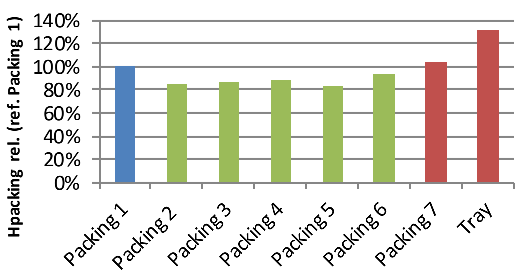

Figure 14. Bed height comparison for different packing using PACKING 1 like reference, for the feed gas with 3.5% of CO_2 and H_2S.

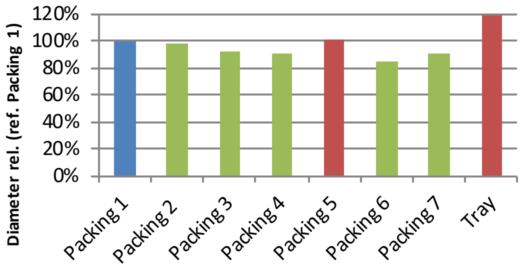

Figure 15.Diameter comparison for different packing using PACKING 1 like reference, for the feed gas with 3.5% of CO_2 and H_2S.

As in the other cases was made an economic study to see the absorber price for each commercial packing. Concluding when compared with the PACKING 1 the most suitable packing's are the PACKING 6, PACKING 3 and the PACKING 4. The PACKING 6 has the better capacity and better column cost however its efficiency isn't the best one. The PACKING 4 looks very attractive because it has good efficiency, capacity and it is one of the cheapest designs. The PACKING 3 can be a good compromise because it has a good column price and its capacity and efficiency are in the middle of the table. The PACKING 2 presents a good efficiency but it isn't the best in terms of capacity and column cost. Therefore the PACKING 5 and PACKING 7 are packing's that have bigger column cost. Although the PACKING 5 is the packing with better efficiency and worst capacity and the PACKING 7 is the worst in terms of efficiency but one of the best in terms of capacity.

4 Conclusions

The optimization for several sweetening processes has been developed. Four process optimizations were conducted, the main difference between each process is the feed gas composition. These were mainly biogas and natural gas ,with only CO_2 or CO_2+H_2S and the specification to achieve. Concerning several process configurations were studied what are the best absorber designs for each feed gas. The results obtained allow to conclude that the use of PACKING 1 designs are more competitive and efficient than trays designs, observing the results obtained for all the cases the PACKING 1 designs allow to obtain columns with lower diameter and lower absorptions heights, which leads to the CAPEX reduction. The improvement of the absorber column it is essential because it represents the equipment that has a bigger weight in CAPEX calculation, more specifically the absorber represents $17-25\%$ of CAPEX. Several sensitivity analysis to the mass transfer parameters has been done, these are important for the project because changes in these parameters could provide same gain on absorption height, resulting in a decrease of the CAPEX. The previous results show that globally the interfacial area is the most sensitive factor, increasing this parameter allows us to decrease enough the absorption height. In some cases the k_L influence could be very interesting but not so attractive as the influence of the interfacial area, except for the biogas case. For the biogas, an increase in the k_L has a similar effect when compare with an a_i increase. In all the cases, k_G variations between $\pm 20\%$ doesn't have a big impact in the absorption process. For the natural gas with H_2S and CO_2, it is observe that the CO_2 is the limiting component, because the removal of this component it is more difficult when compare with the H_2S removal. Globally for all the cases, the packings that fit better with the specification are the PACKING 3, PACKING 2, PACKING 4 and PACKING 6. The conclusions only takes into account the results associated to the process analysis, and should be discussed with the project team about chemical engineering considerations to ensure that the results obtained can be applied to project conditions.

5 Bibliographie

[1] D. M. Dr. Robert N. Maddox, Gas Conditioning and Processing, Fourth éd., vol. 4, U.S.A, 2008, p. 500.

[2] D. A. EIMER, Gas Treating: Absorption Theory and Practice, 2004.

[3] J. M.-D. Sebastien Gonnard, «Traitement du gaz naturel,» p. 28, 10 Novembre 2015.

[4] IFP, *Natural Gas processing Course,* 2009.