# SUPPRESSION OF AMINE CARRY OVER AT THE HEAD OF ACID GAS REMOVAL COLUMNS IN 5P AND 6P LNG UNITS OF GL1K PLANT

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**ABSTRACT**

Our proposal was carried out in Skikda; particularly in the gas treatment sections of 5P and 6P LNG units in witch carbon dioxide is removed.

Since the construction of 5P and 6P units, gas treatment sections encountered the problem of solvent (amine) carried over at the head of acid gas removal columns.

The consequences of this problem are very serious for the remaining of the GNL liquefaction operations. This starts by a simple impact as troubles of the gas driers process, freezing out on the cryogenic exchangers, corrosion of the downstream equipment of the acid gas absorbers, substantial solvent losses and reduction of production unit's load. This may lead to shut-down of the liquefaction units.

Our analysis shows that the problem came primarily from the solvent used for acid gas absorption (tendency to foam, presence of hydrocarbons and solid particles), in addition to the under-sizing of the acid gas removal columns.

In order to eliminate definitively this problem, we proceeded to the acid gas removal section improvement by achieving the following changes:

1. Substitution of the existing column trays by structured packing.
2. Installation of a drain drum under the natural gas condensers downstream of the acid gas absorption columns.
3. Installation of a new liquid-gas coalescer downstream of the existing one.
4. Improvement of the amine filtration system.
5. Substitution of the existing washing pumps by others of bigger capacities.

Finally, the results obtained following these changes were very satisfactory and since that, the problem of amine carry over was definitively resolved.


**Figure 01: 6P LNG unit with the new modifications**

**INTRODUCTION**

The natural gas feeding a unit of liquefaction must preliminarily undergo a treatment in order to remove the traces of acid gas capable to be frozen during cooling; one of these traces is the carbon dioxide (C02).

Several processes exist to eliminate this component and among the most frequently used is the treatment with Monoethanoleamine (MEA) with a concentration about 15 % weights.

The study is based primarily on the acid gas removal section which plays a significant role in the continuation of the liquefaction operations.

Among the problems encountered in this section, we find the MEA carry over at the head of the acid gas absorbers in 5P and 6P LNG units of GL1K plant.

When designing these sections, the manufacturer considers secondary equipments to resolve this problem (amine purifying, amine filtration and an injection antifoam system). Moreover, several modifications were carried out to reduce this phenomenon (suppression of the higher trays «11 trays» and installation of a new total amine filtration) but the results obtained were unsatisfactory.

By leading the acid gas removal sections in this way during several years, the plant underwent a serious lack of production caused by the dysfunction of the equipments located downstream from the acid gas absorption columns, substantial amine losses  and the frequent shut-down of the liquefaction units.

Our effort was initially devoted to find the causes of this problem, then to give the solution that can resolve it, while comparing this investment with the lack of production, the autoconsumption excess and the additional loads generated following this problem during the operating time remaining for these units.

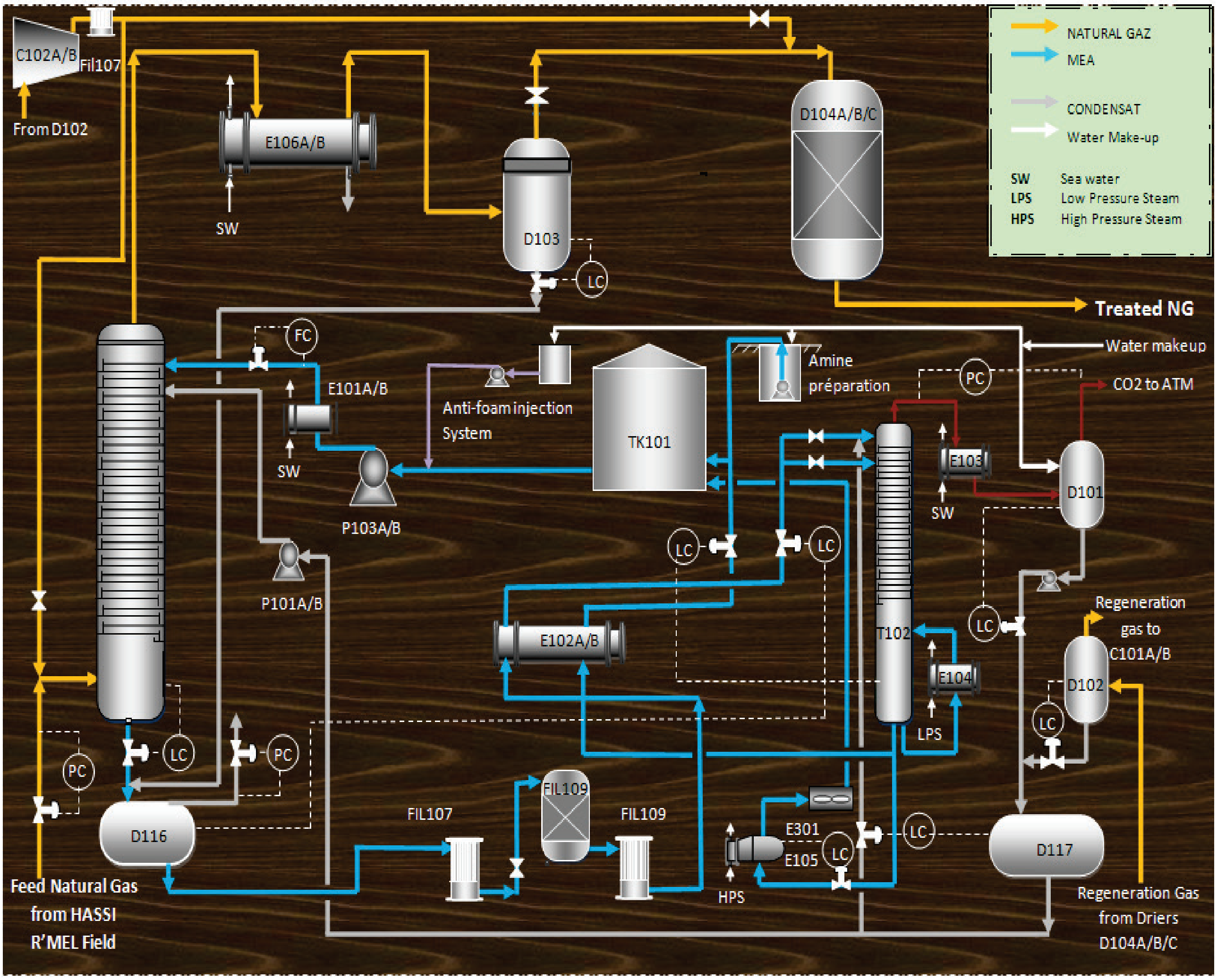



**Figure 02: Acid gas removal section without changes**

**PROBLEM**

The problem of amine carry over at the head of the absorbers of the 5P and 6P LNG units existed since their starting at the beginning of the Eighties [1].

When designing these sections, the manufacturer considers secondary equipments to solve this problem (amine purifying, amine filtration and an antifoaming injection system).

During the renovation, some actions were launched by the contractor, such as the installation of a total amine solution filtration, and the sending of driers regeneration gas downstream of acid gas absorbers and upstream of driers. Other modifications were carried out by the plant such as the removal of the first ten (11) trays and the prolongation of the MEA supplying pipe inside the column until the tray n°12. These actions led to a slight improvement but failed to solve the problem definitely.

The gas treatment section, following this problem, was characterized by a passage of liquid droplets (amine and water) with the gas stream towards the equipment located downstream of the acid gas removal column. In this way, the unit will exhibit various characteristics including the following:

- Fast rise of the level in the coolers of treated natural gas.
- Fast rise of the level in the gas-liquid separator.
- High amine losses and amine carry over into equipments downstream of the absorber (separator, driers and cold boxes).
- Decrease of acid gas removal system efficiency and Increase of the CO2 content in treated natural gas.
- High differential pressure across the absorber.
- Loss of level in amine tank.
- Increase in the pressure drop across the drier in service.
- Freezing out in the cryogenic exchangers.

Indeed, the problem of amine carry over was the principal cause of the 5P & 6P LNG units' frequent shutdowns and the originator of the breakdown of the strategic equipments and carry away to the following consequences:

- Reduction in the unit capacity until 80% of the design capacity ;
- Excessive MEA consumption ;
- Corrosion of the equipment located downstream of the acid gas removal column;
- Contamination of the molecular sieves contained in the driers;
- Premature renewal of the driers loads ;
- Total units shutdown for the defrosting and the drying of cryogenic exchangers;
- Replacement and repairs of several cold boxes cores ;
- Several interventions of maintenance.

The annual averages of the lack of production, the autoconsumption Excess and the additional loads generated following this problem can be classified in the following table:

| Designation | Measuring unit |
|---|---|
| Lack of production | **300 000** m3 de GNL |
| GN autoconsumption Excess | **3 000 000** Cm3 de GN |
| MEA overconsumption | **15 000** litres of MEA |
| Molecular sieve overconsumption | **32 400** kg of MS |
| Maintenance Interventions | **520** hours |
| Equipments renewal | **1** core |

Due to persistence of this phenomenon which constitutes a bottleneck of the production, it was decided to prepare an in-depth study, by calling the experts in the gas industry sector in order to resolve definitively this problem.

**PRINCIPAL CAUSES**

Our study with the collaboration of some experts has been able to examine the problem of amine carry over at the head of the acid gas absorbers of 5P and 6P LNG units and showed that its origin is stable foam in the columns.

Effectively, foaming of amine solutions is probably the most common operating problem in amine treating units. It is most frequently encountered in the absorbers. Foaming may result in excessive amine losses, off-specification product gas and reduced operating rates.

The presence of foams involves a premature flooding of the trays and overflows. Consequently, a higher pressure drop across the acid gas absorption columns. This phenomenon is due primarily to the following factors:

- Contaminants.
- Under-sizing of the acid gas absorbers.

**1- Contaminants:** [2]

Foaming in an amine units is caused by solution contaminants, since uncontaminated amine solutions will not form stable foam.

The contaminants generating the phenomenon of foaming prevent the coalescence of the bubbles the ones with the others. These contaminants come from several sources:

**a. The natural gas, such as:**

- **Dissolved heavy hydrocarbons:** (e.g., entrained compressor lubricating oil in the feed gas or hydrocarbon condensation within the acid gas absorber).
- **Solid particles finely divided conveyed with natural gas:** contaminants (e.g., mill scale, corrosion products, and rust) contained in the feed gas. Those contaminants concentrate at the liquid/gas interface and stabilize the foam by increasing the surface viscosity and thereby retarding film drainage.

**b. Contaminants generated by the amine solution, such as:**

- **Degradation products of the MEA resulting from a thermal decomposition** [3]: The degradation of the MEA by thermal decomposition is a problem when the MEA is subjected to high temperatures. This problem occurs in the rebouiller, where the high temperatures can cause localised overheating. Under the action of heat, the MEA decomposes and gives in particular Ethylene Oxide which is extremely reactive. The ethylene oxide can be polymerized and react with the MEA, and the anti-foam used. The products of these reactions, which they are solid or liquid, deactivate the MEA solution and favour the effect of corrosion and foaming of the amine solution
- **Degradation products of the MEA by formation of the non-regenerable products**: In addition to the reaction of the MEA with CO2 where it forms regenerable products, the MEA also reacts irreversibly with CO2. The reactions are very slow and very complexes.
- **Corrosion products**: carbon steel used for the manufacture of the equipment reacts with the carbonic acid by forming soluble bicarbonate. An additional heating of the solution of the MEA can release CO2 and precipitate insoluble iron.

  Corrosion products settle on the column trays and cause an inflexibility of the valves which are constrained in their movement by a fibrous texture, that, limit the flow of the liquid and increase the speed of gas, generating possible aerosols thus favouring the formation of stable foam.
- **Fine activated carbon particles**: A bad filtration downstream from the activated carbon filter can carry away fine particles and causes the problem of foaming.

— **Bad quality of the makeup water to amine solution**: The MEA oxidizes quickly in contact with the air and gives corrosive organic materials able to initiate foaming. This problem is observed at the time of the MEA makeup in the amine solution preparation drum where this one was exposed to the free air.

The MEA being considered as a weak base reacts with the strong mineral acids where it forms a stable and a very water-soluble salt. This problem occurs in particular if the water of MEA solution preparation contains relatively a content of mineral compounds (presence of $cl^-$ and $So4^=$).

Generally:

— Any species which tends to decrease the surface tension of the solution will increase the tendency to foaming.

— The presence of surface-active, finely divided solids or polymers can strongly foam the system.

— Any species which tends to increase the viscosity of the solution will stabilize formed foam.

— Any species settling on the trays of exchange limits the liquid and gas flows and increases the speed of gas and the pressure drop and generates aerosols as well as foaming problems.

**2- Under-sizing of acid gas removal column:** [4] [5] [6]

Carry over in tray columns represents that liquid droplets are carried at high gas velocities with the vapor from a tray to the tray above. By this effect lower volatile liquid is withdrawn to the tray above where liquid with higher volatility is present. It is detrimental in that the tray efficiency will be reduced. Carry over is also detrimental when nonvolatile impurities are carried upward to contaminate the overhead product from the column.

The gas flows with certain velocity through the column. With increasing gas flowrate the gas velocity increases. At the flooding point the liquid cannot flow down but is withdrawn by up streaming gas phase.

Many experimental studies of carry over were conducted and showed that the dominant variable affecting carry over is gas velocity through the two-phase zone on the tray.

The carry over is a significant factor in determining the limits of flooding of a column. So to size a column and to avoid its flooding, it is necessary to know the maxima flows of gas and the liquid which can be introduced into the column, therefore, the speed of gas at the flooding of the column.

The speed of gas at flooding requires the knowledge of the surface tension, the foaming factor, the geometry of the trays and the liquid and vapor flows as well as properties of each one of these phases.

In our case, the fluids entering the column generate foam. Glitsch recommends using the coefficient of 0.73 correspondents to a significant foaming (absorption with the amines).

For optimal value, the speed of gas must be below the value for which the flooding occurs. In general, it is recommended to operate at 85% of the conditions of the flooding.

The column diameter is obtained then, by knowing the gas flowrate, the selected speed (at 0.85 the speed of vapor at flooding) and to the tray active section.

With an aim of ruling definitively on the dimensional aspect of the acid gas removal columns, we proceeded to calculation of their dimensions by using the industrial processes simulator «HYSYS» while following the following stages:

— Open a new case, add a component list contains: (N2, He, CO2, MEA, H2O, C1, C2, C3, iC4, nC4, iC5, nC5, nC6, nC7, nC8), select amine package and enter simulation environment;

— By using the palette, select six streams and name them respectively NG (natural gas), RNG (regenerated natural gas), LMEA (lean monoethanoleamine), Wwat (washing water), DNG (decarbonated natural gas) and RMEA (rich monoethanoleamine). Select an absorber T-101 and connect to it the six streams.

— Set the following data in the input streams and in the absorber:

| stream | NG | RNG | LMEA | Wwat | T-101 | |
|---|---|---|---|---|---|---|
| Flowrate (kg/h) | 209805 | 29998 | 42851 | 287 | | |
| Temperature (°C) | 38 | 57 | 46 | 35 | | |
| Pressure (bar.abs) | 42.8 | 43 | 42.8 | 42.8 | 42.4 | 42.1 |
| Trays number | | | | | 34 | |
| Composition | (%mole) | (%weight) | (%weight) | (%weight) | | |
| N2 | 5.80 | 5,79 | | | | |
| CO2 | 0.21 | 0.01 | 0.10 | | | |
| He | 0.19 | 0.19 | | | | |
| C1 | 83.00 | 82.93 | | | | |
| C2 | 7.10 | 7.09 | | | | |
| C3 | 2.25 | 2.25 | | | | |
| iC4 | 0.40 | 0.40 | | | | |
| nC4 | 0.60 | 0.60 | | | | |
| iC5 | 0.12 | 0.12 | | | | |
| nC5 | 0.15 | 0.15 | | | | |
| nC6 | 0.10 | 0.10 | | | | |
| nC7 | 0.06 | 0.06 | | | | |
| nC8 | 0.02 | 0.02 | | | | |
| H2O | 00 | 0.28 | 84.90 | 100 | | |
| MEA | 00 | 0,00 | 15.00 | | | |

After running the absorber, so, you can find the simulation results as indicated below:

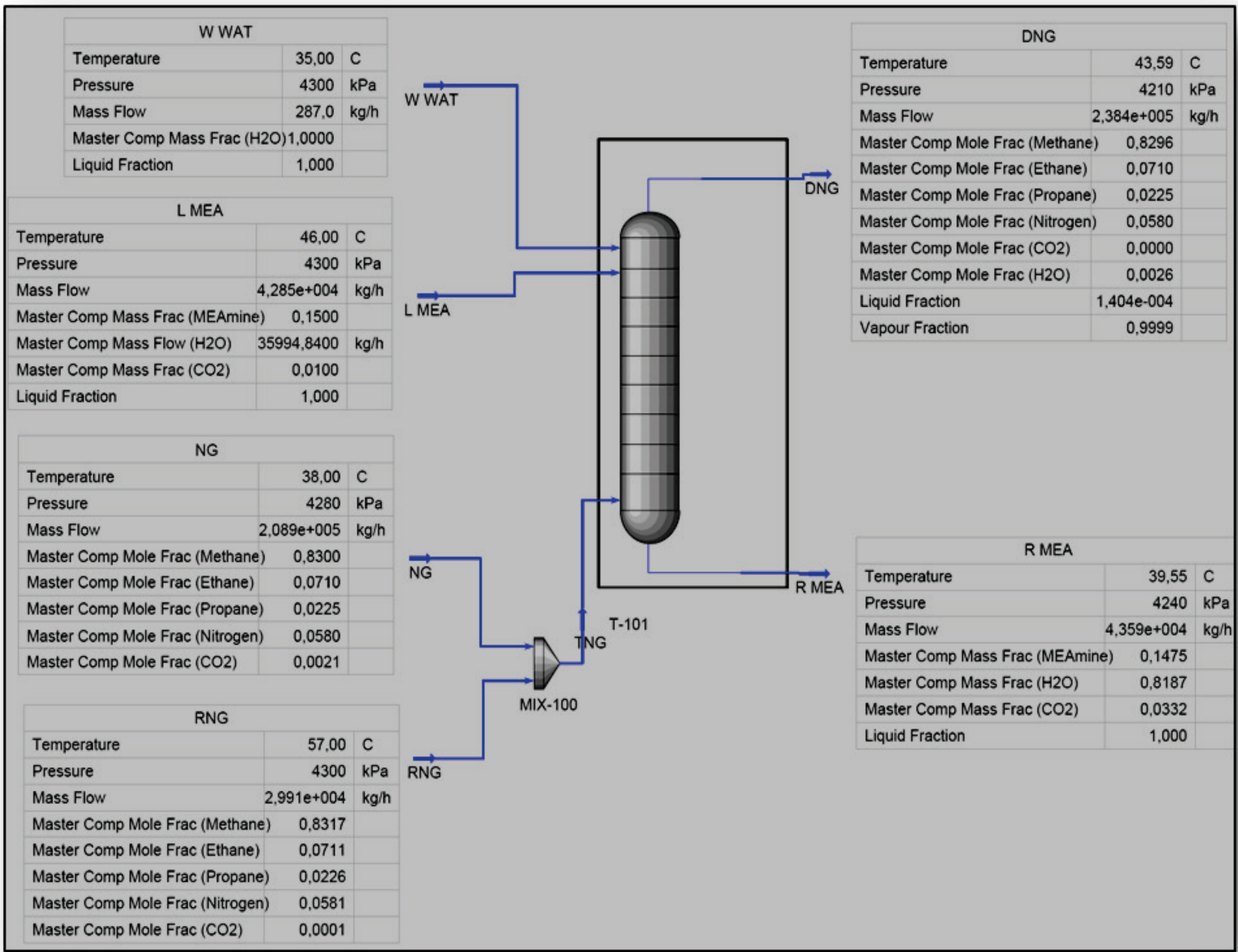
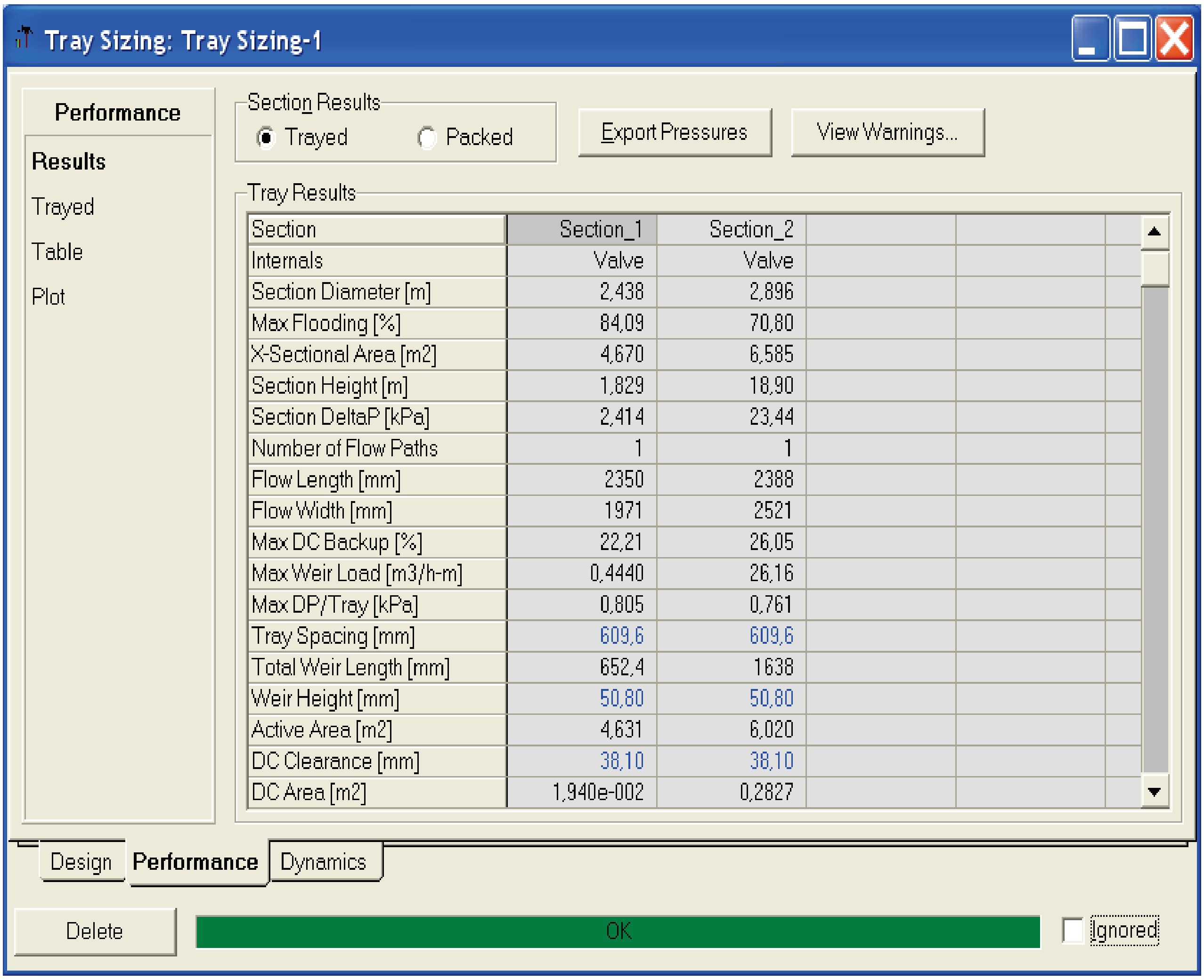



**Figure 03: simulation results of the absorber**

In order to size the column, press the tools button, utilities, and tray sizing utility, add utility, select tray section, select the absorber T-101, and run the auto section button; so, the results of sizing appear by pressing performance button as indicated below:




| Section | Section_1 | Section_2 |
|---|---|---|
| Internals | Valve | Valve |
| Section Diameter [m] | 2,438 | 2,896 |
| Max Flooding [%] | 84,09 | 70,80 |
| X-Sectional Area [m2] | 4,670 | 6,585 |
| Section Height [m] | 1,829 | 18,90 |
| Section DeltaP [kPa] | 2,414 | 23,44 |
| Number of Flow Paths | 1 | 1 |
| Flow Length [mm] | 2350 | 2388 |
| Flow Width [mm] | 1971 | 2521 |
| Max DC Backup [%] | 22,21 | 26,05 |
| Max Weir Load [m3/h-m] | 0,4440 | 26,16 |
| Max DP/Tray [kPa] | 0,805 | 0,761 |
| Tray Spacing [mm] | 609,6 | 609,6 |
| Total Weir Length [mm] | 652,4 | 1638 |
| Weir Height [mm] | 50,80 | 50,80 |
| Active Area [m2] | 4,631 | 6,020 |
| DC Clearance [mm] | 38,10 | 38,10 |
| DC Area [m2] | 1,940e-002 | 0,2827 |

**Figure 04: Sizing results of the absorber with trays**

In the following table, we can find the column sizing results of HYSYS simulator and the dimensions of existing column:

| Description | Tray spacing (mm) | All section height (m) | Section diameter (m) | Max flooding (%) | Section Delta P (bar) | CO2 in GND (ppm) |
|---|---|---|---|---|---|---|
| Existing column | 609.6 | 20.73 | **2.60** | 85 | **272** | **<50** |
| HYSYS sizing results | 609.6 | 20.73 | **2.89** | 85 | **258** | **<50** |

According to the results indicated on the table above, it proved that the diameter of the existing column is lower compared to that calculated, and consequently, it is concluded that the existing column is under-sized.

Indeed, and for the natural gas Flowrate used, the use of the column with a reduced diameter causes the gas speed increase, reaching easily the maximum speed at flooding.

**PROPOSAL [7]**

In the aim of removing definitively the amine carry over at the head of acid gas absorbers of 5P and 6P units, we examined well the source of the problem which can be only due to an abnormally significant foaming which is certainly caused by the bad quality of amine and of the column under-sizing. These constraints can be eliminated only by significant modifications including the intern and the extern from acid gas removal columns. These modifications include the following points:

**1-Substitution of the interns of the acid gas absorber:**

By consulting certain experts in the gas industry field, it was confirmed that the replacement of the existing trays by others more effective couldn't bring an optimal solution to the foaming problem and consequently, to problem of amine carry over.

In front of this situation, we thought that the optimal solution is the use of the structured package considering their advantages [8] adapted with our case:

- Pressure drop much weaker than the trays.
- Occupy fewer diameters compared to the tray columns under the same operating conditions.
- They are well adapted to function in an acid and corrosive environment.
- As the liquid is agitated, it is possible to use the absorbents which tend to foam.
- They can reach a great effectiveness of absorption for several gases
- They have a lower height compared to the tray columns under the same operating conditions.
- Strong limitation of foaming.

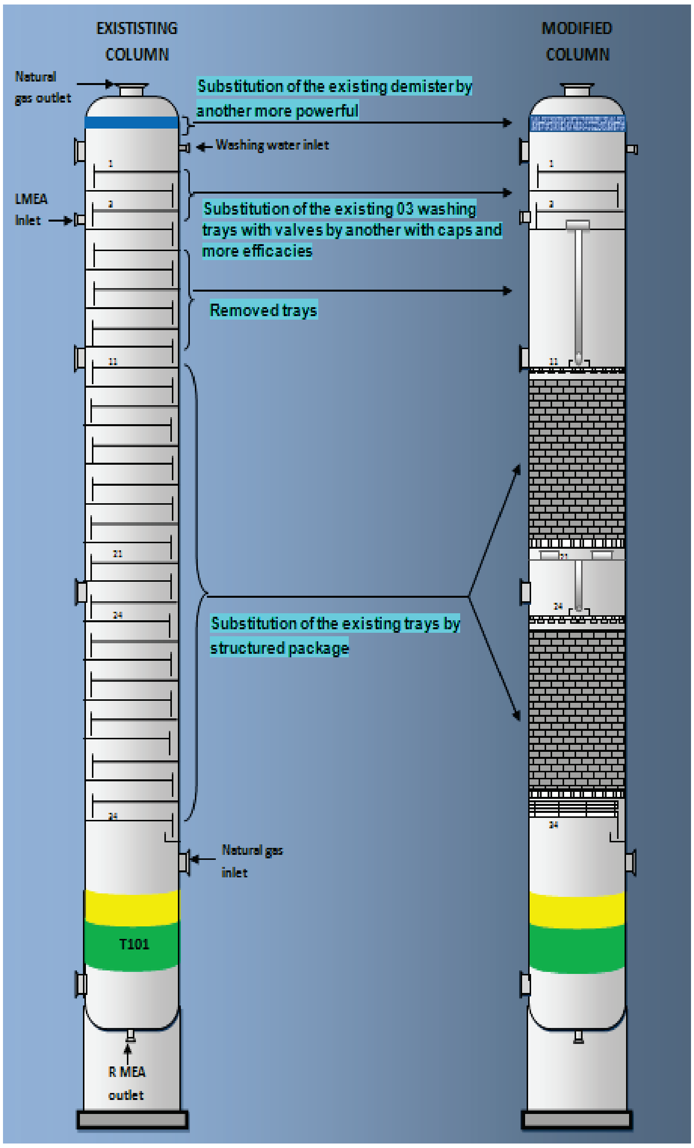


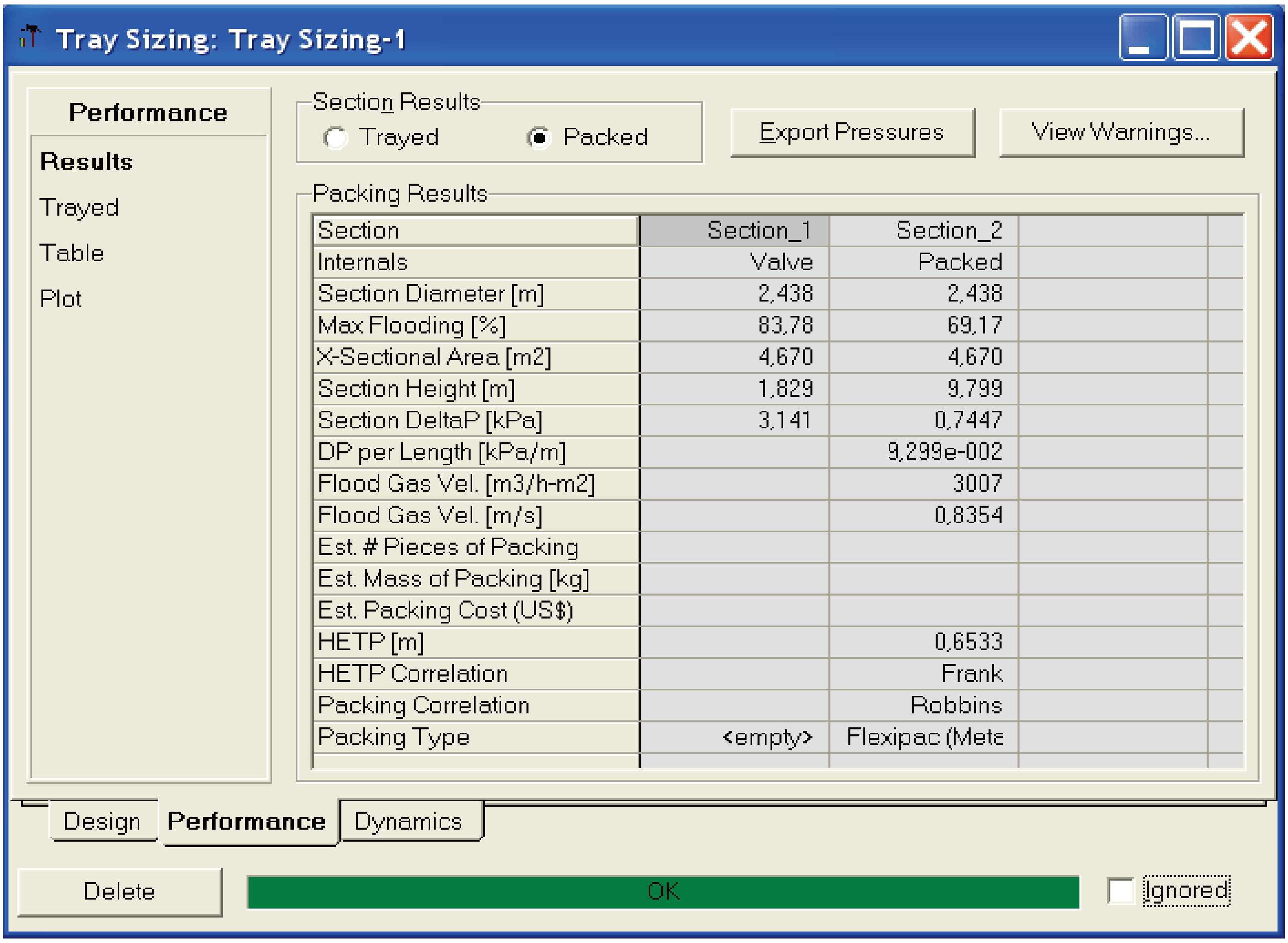

**Figure 05: Substitution of the interns of the acid gas removal column**

Indeed, the KOCH GLITCH company privileged this solution, and by taking account of the existing environment and the operating conditions, it proposed the installation of two beds of structured packed type FLEXIPAC-HC-250Y with 5 meters for each one by taking a safety margin in front of the unit requirements and the malfunctions risks.

In addition, we chose the replacement of the three washing trays with caps by high performance trays with valves.

With the aim of stopping the droplets carried away with the treated natural gas, we proposed the replacement the existing mattress by another with high performance. And in order to dilute these droplets, it is important to increase the washing water flow at the head of the acid gas removal column.

The column sizing with structured package type FLEXIPAC-HC-250Y, using HYSYS simulator and taking account of the conditions quoted before led us to the following results:




| Section | Section_1 | Section_2 |
|---|---|---|
| Internals | Valve | Packed |
| Section Diameter [m] | 2,438 | 2,438 |
| Max Flooding [%] | 83,78 | 69,17 |
| X-Sectional Area [m2] | 4,670 | 4,670 |
| Section Height [m] | 1,829 | 9,799 |
| Section DeltaP [kPa] | 3,141 | 0,7447 |
| DP per Length [kPa/m] | | 9,299e-002 |
| Flood Gas Vel. [m3/h-m2] | | 3007 |
| Flood Gas Vel. [m/s] | | 0,8354 |
| Est. # Pieces of Packing | | |
| Est. Mass of Packing [kg] | | |
| Est. Packing Cost (US$) | | |
| HETP [m] | | 0,6533 |
| HETP Correlation | | Frank |
| Packing Correlation | | Robbins |
| Packing Type | <empty> | Flexipac (Mete |

**Figure 06: Sizing results of the packed column**

In the following table, we can find a packed column sizing results of HYSYS simulator and the existing column dimensions:

| Description | Internals | All section height (m) | Section diameter (m) | Max flooding (%) | Section Delta P (mbar) | CO2 in GND (ppm) |
|---|---|---|---|---|---|---|
| Existing column | valve | 20.73 | **2.60** | 85 | **272** | **<50** |
| HYSYS sizing results | Package/washing tray | 9.80 / 1.82 | **2.43 / 2.43** | 70 / 85 | **38.85** | **<50** |

The results indicated on the table above demonstrate that the diameter of the packed column and pressure drop across the column are lower compared to these of the existing column in the same operating conditions, and consequently, it is confirmed that the problems of the column under-sizing and excess velocity (flooding) will be resolved by a substitution of the trays of existing column by a structured package type FLEXIPAC-HC-250Y.

**2-Installation of a drain drum under the natural gas coolers downstream of the acid gas absorbers:**

The purpose of this drum is:

- ✓ To collect the liquids resulting from the condensation of the water vapour and the amine droplets possibly carried away with treated natural gas to avoid their passage towards the equipments located downstream and consequently to reduce their work and increase their efficiencies.
- ✓ To avoid the rise of level in the coolers in order to increase their efficiency.

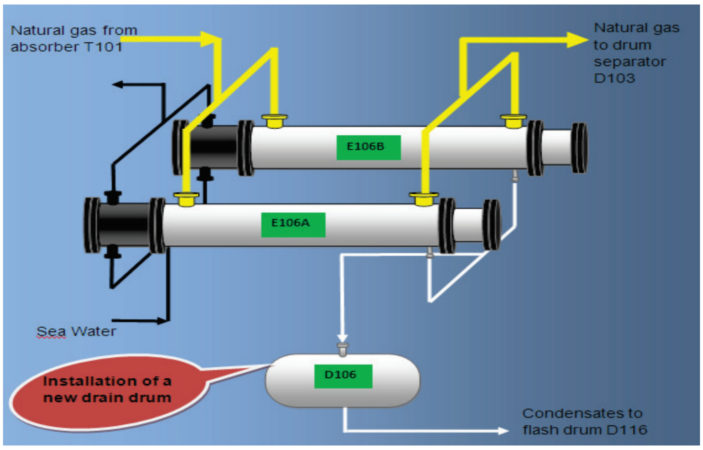



**Figure 07**: **Installation of a new drain drum under the natural gas coolers**

**3-Installation of a new liquid-gas coalescer downstream of the existing one:**

Among the direct impacts of the amine carry over is the contamination of the molecular sieves contained in the driers of natural gas which are located downstream of the gas-liquid separator. To avoid this problem an increase in the capacity and the effectiveness of separation become necessary by the installation of another separator in series with that exists ensuring an elimination of the liquid aerosols and the finest particles (lower than 0.3 microns) [2]. The objective of this solution is as follows:

- A double capacity of liquid retention.
- To make maintenance work of separation drums more flexible, by insulating only the targeted separator, without stopping the unit.
- The new vision in the separators design called upon a combination between various techniques of separation liquid / gas (separation by gravitation, separation by demister (particles > 3µm) and separation by the coalescent cartridges (particles = 0.3µm).

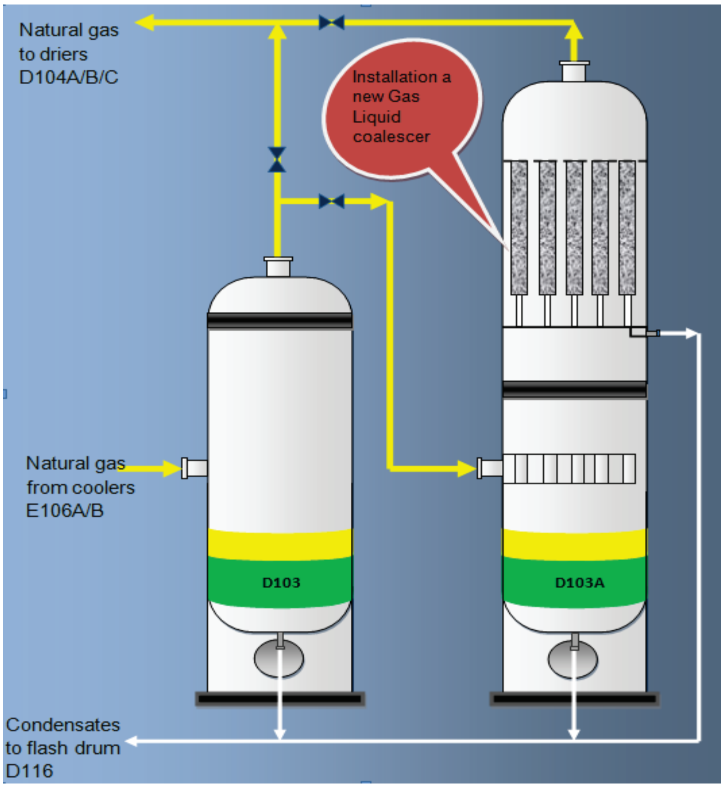



**Figure 08**: **Installation of a new liquid-gas coalescer**

Indeed, company PALL privileged this solution while taking into account the existing operating conditions, where it proposed the installation of a separator equipped with three levels of separation (gravitation, demister and coalescent cartridges).

For the same purpose, it was proposed the change of the existing separator demister by another of high performance.

**4-Substitution of the existing washing pumps by others of bigger capacities:**

The purpose of the washing water pumps is to dilute the droplets of MEA carried away with a natural gas and to prevent them from being carried over at the head of the column, so, to avoid the corrosion of the equipments downstream of the column, in particular the tubes of the natural gas coolers. The pumps used cannot satisfy this objective following the low water flow of washing. So we thought of the substitution of these pumps by others of greater capacities for decreasing amine concentration in the condensates collected in the gas-liquid coalescer.

**5-Improvement of the amine filtration system:**

The analysis of the foaming problem implies the examination of three specific contaminants:

The elimination of the solid particles of the dimensions exceeds or equalizes to 10 μm by the installation of a particulate filter downstream of the existing one.

The elimination of the hydrocarbon liquid aerosols in the amine solution by the installation of a liquid – liquid coalescer located upstream of existing activated carbon filter.

The elimination of the dissolved and soluble contaminants contained in amine solution by the replacement of the load of the activated carbon by another new.

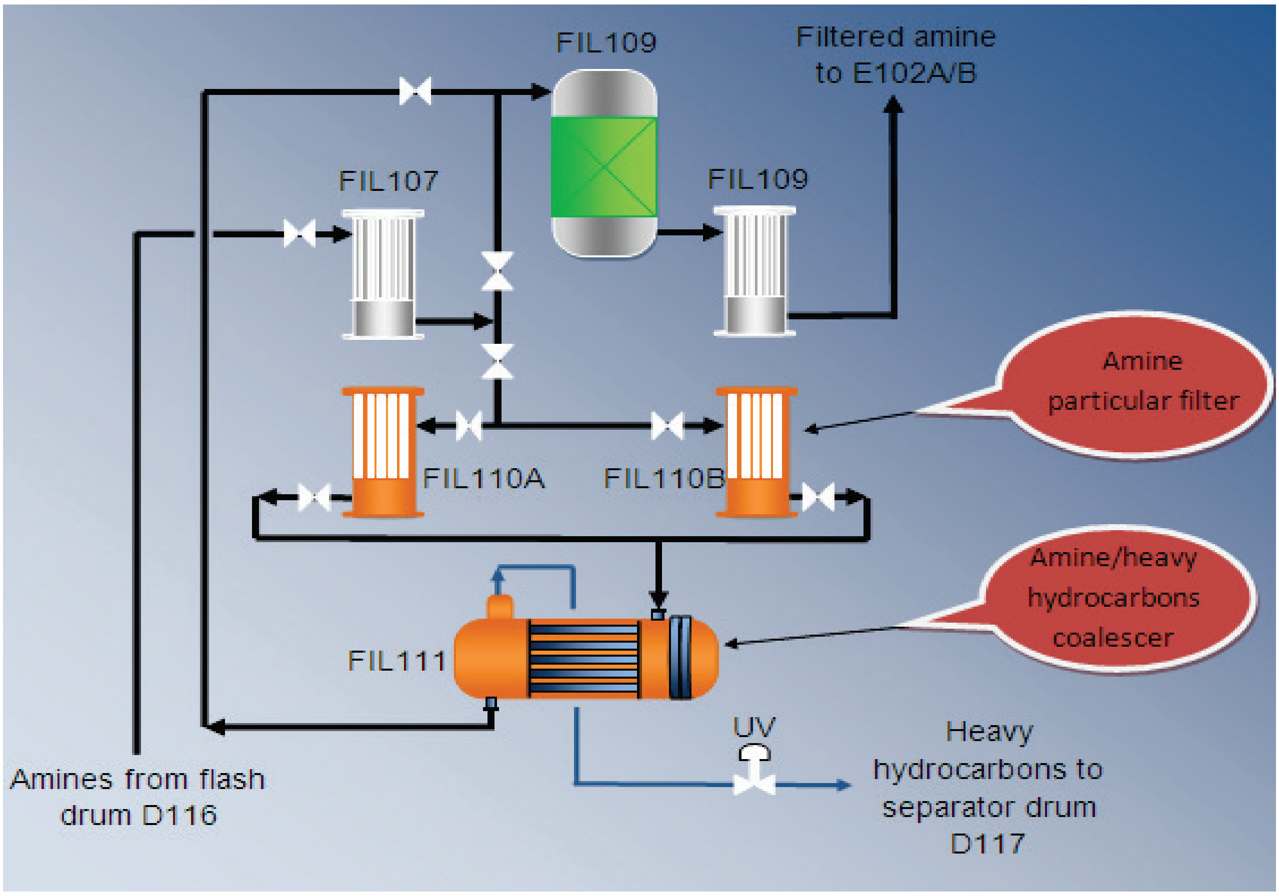



**Figure 09**: **Improvement of the amine filtration system**

**6- Chemical scrubbing of the of amine section:**

The chemical procedure of scrubbing of the amine section recommended uses the chemico STD-SBE-113-4 method like reference for cleaning of fouling and the corrosion products of MEA system. The chemical procedure of scrubbing can be carried out in two stages:

- **Alkaline cleaning:** this phase consists of circulating through the amine section a solution of 1% mass trisodium phosphate $Na_3PO_4$ and 1% mass of sodium carbonate $Na_2CO_3$ at 80°C. The idea is to raise the pH to saponify the grease and oils of the system.
- **Acid scrubbing:** this phase consists to make circulate through the amine section a sulphamic acid solution at 80°C in order to remove the carbonate salt deposits and the corrosion products which adheres to equipments surfaces.

**7- Depollution of the amine system:**

The purpose of the amine section depollution is double. First, it makes possible to improve, by a direct effect, the process productivity of gas absorption by controlling the degree of circuit cleanliness of gas-amine exchange in the unit. Second, it makes possible the purification of the amine section before the installation of the new equipments.

The operation of depollution consists to circulate the amine solution through all the equipments and piping of amine system by means of the amine pumps. The solution then, passes through the existing particulate filters equipped with the disposable filter elements in order to retain the solid particles present in the solution.

## PROJECT PROFITABILITY EVALUATION

The decision rather to invest or not is generally based on its economic interest evaluation and consequently, its profitability.

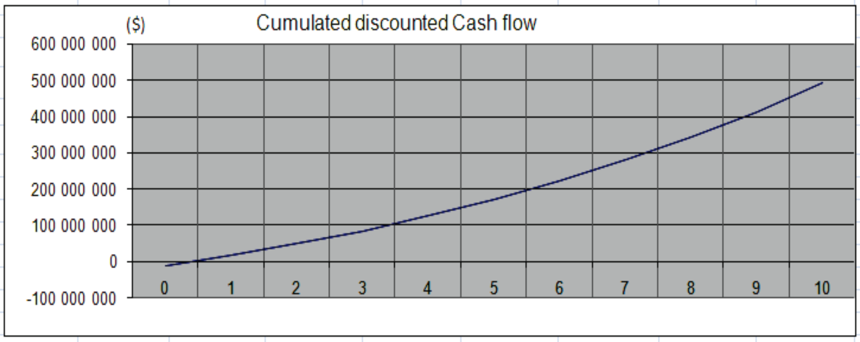
The project profitability depends in one hand on the expenditures (capital and operating costs), and in the other hand on the profits that it gets over the 10 years of exploitation. If the cumulated discounted cash-flows is positive, then we say that the project is profitable.

Noting that the total construction cost of the «suppression of amine carry over at the head of acid gas removal columns in 5P and 6P LNG units» project was estimated at $12,222,222 “lump sum turn key contract”, and supposed that it will be depreciated in ten years [7].

The table below summarizes the economic study of our project as well as the results obtained:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tax rate (t) | 27% | | | | | | | | | | |
| Number of years (N) | 10 | | | | | | | | | | |
| Discount rate (i) | 10% | | | | | | | | | | |
| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Residual value of the investment | 12 222 222 | 11 000 000 | 9 777 778 | 8 555 556 | 7 333 333 | 6 111 111 | 4 888 889 | 3 666 667 | 2 444 444 | 1 222 222 | 0 |
| Discount coefficient | 1 | 1,10 | 1,21 | 1,33 | 1,46 | 1,61 | 1,77 | 1,95 | 2,14 | 2,36 | 2,59 |
| Capital Expenditures (I) | 12 222 222 | | | | | | | | | | |
| Depreciation | | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 | 1 222 222 |
| Operating Expenditures ( Energy, Maintenance, consumable, ... etc.) | | 8 400 000 | 8 484 000 | 8 568 840 | 8 654 528 | 8 741 074 | 8 828 484 | 8 916 769 | 9 005 937 | 9 095 996 | 9 186 956 |
| Other costs generated by the amine carry over | | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 | 2 473 180 |
| Loss of production due to the Amine problem | | 300 000 | 345 000 | 396 750 | 456 263 | 524 702 | 603 407 | 693 918 | 798 006 | 917 707 | 1 055 363 |
| LNG price ($/m3) | | 161 | 171 | 181 | 192 | 204 | 216 | 229 | 242 | 257 | 272 |
| Turnover | | 48 375 000 | 58 969 125 | 71 883 363 | 87 625 820 | 106 815 875 | 130 208 551 | 158 724 224 | 193 484 829 | 235 858 006 | 287 510 910 |
| Profit before Tax | | 42 448 180 | 52 958 305 | 65 787 703 | 81 444 472 | 100 547 981 | 123 853 247 | 152 280 634 | 186 952 072 | 229 235 190 | 280 797 133 |
| Taxable profit | | 41 225 958 | 51 736 083 | 64 565 481 | 80 222 249 | 99 325 759 | 122 631 024 | 151 058 412 | 185 729 850 | 228 012 968 | 279 574 911 |
| Tax | | 11 131 009 | 13 968 742 | 17 432 680 | 21 660 007 | 26 817 955 | 33 110 377 | 40 785 771 | 50 147 059 | 61 563 501 | 75 485 226 |
| Cash flow | -12 222 222 | 31 317 171 | 38 989 563 | 48 355 023 | 59 784 464 | 73 730 026 | 90 742 870 | 111 494 863 | 136 805 012 | 167 671 689 | 205 311 907 |
| Discounted Cash flow | -12 222 222 | 28 470 156 | 32 222 779 | 36 329 845 | 40 833 593 | 45 780 545 | 51 221 984 | 57 214 494 | 63 820 548 | 71 109 164 | 79 156 628 |
| Cumulated discounted Cash flow | -12 222 222 | 16 247 934 | 48 470 713 | 84 800 557 | 125 634 151 | 171 414 696 | 222 636 681 | 279 851 175 | 343 671 723 | 414 780 887 | 493 937 515 |

| | |
|---|---|
| Net Present Value ($) | 493 937 515 |
| Internal rate of return (%) | 281% |
| Pay-Out Time (year) | 1 year |
| Profitability index (%) | 40,41 |




The results obtained show that the net present value is positive and great widely enough to take the investment decision and that the capital expenditures will be recovered in less than one (01) year, which gave a clear idea that this investment is largely profitable and consequently, it was accepted by the plant managers.

**PROJECT REALIZATION [7]**

After being convinced, the GL1K plant launched an open national and international invitation to tender for the realization of the modifications suggested by its engineering departments.

After treatment of the technical and commercial offers of the several tenderers, that of PROCESS SYSTEM was retained. In April 2008, a common agreement was established between the two parts to realize the work described in the invitation to tender while putting like guarantee of performance the following conditions:

- A content of $CO_2$ in treated natural gas in exit of the acid gas absorbers 51/61 T101 lower than 100 ppm mole for 2100 ppm mole of columns entry.
- A content of free liquid carried with treated natural gas in exit of the new separator 51/61 D103A lower than 0.5 ppm weight under the process conditions, for 10 000 ppm weights in separator entry.
- A pressure at the entry of driers 52/62-D104 A/B/C lower than or equal to 41.7 bars abs.
- A content of 100 ppm weight of hydrocarbons in the amine solution in exit of liquid-liquid coalescer 51/61FIL111, with the top of solubility at the temperature of 40 °C (based on a content of 600 ppm weight of hydrocarbons in the MEA at the coalescer entry).

**Chemical Scrubbing of the Amine Section:**

Before beginning the work indicated in the invitation to tender, the GL1K plant while benefitting from the programmed shutdown of 5P and 6P units in 2009, took the initiative to carry out the chemical scrubbing of the amine system. This operation is unrolled under good conditions, with analysis of the samples of the alkaline and the acid solution in continuous, in front, at the moment and after the operation. At the end of each stage, it was preceded of the solution neutralization before its injection towards the rejection to drain. After having finished all the chemical scrubbing operation, a circulation of the demineralized water through all the amine section took place several times until the cleaning complete of the amine section.

The results obtained were satisfactory and showed that the contaminants (oils, greases, carbonate salt deposits and the corrosion products) which adhere to surfaces equipment were eliminated.

**Start Up of the Project Construction:**

**1- 6P Unit:**

After having carried out the civil engineering work before the programmed shutdown of 6P unit, a common agreement was established between the contractor "Process System" and the GL1K plant for the opening of the building site and the beginning of the realization of work at the programmed shutdown of the 05/05/2010.

Indeed, during 45 days, the contractor has been able to realize all the work required by GL1K plant as indicated below:

- Substitution of the absorption existing trays of the acid gas removal column 61T101 by structured package,

- Substitution of the existing demister at the head of the acid gas removal column 61 T101 by another more powerful,

- Substitution of the existing 03 washing trays with valves of the acid gas removal column 61 T101 by another with caps and more efficacies.


**Figure 10: Substitution of the acid gas removal column 61T101 interns by structured package**

- Installation of the liquid-gas coalescer 61 D103A in series with the existing separator 61 D103,
- Replacement of the demister of the existing separator 61 D103 by another of better effectiveness.

**Figure 11: Installation of a new liquid-gas coalescer 61 D103A**

- Replacement of the existing washing pumps 61 P101A/B by others of greater capacities.

**Figure 12: new washing pumps 61 P101A/B**

- Installation of a new drain collector drum 61D106 under natural gas coolers 61 E106 A & B

**Figure 13: new drain collector drum 61D106**

- Installation a new liquid-liquid coalescer 61FIL111,
- Installation of two particulate Prefilters 61FIL110 A/B of protection of new liquid-liquid coalescer ,
- Replacement of the activated carbon load of the filter 51/61 FIL108.


**Figure 14: new filters 61FIL111 and 61FIL110 A/B**

- Depollution of the amine system of which the purpose and the procedure were described in the preceding chapter.

**Figure 15: amine solvent obtained during the depollution operation**

After three days of the amine system depollution, the amine solvent obtained was clear and clean (see the photo taken during the depollution operation)

**Unit start-up and Performance Tests:**

After the completion of all work, the GL1K plant carried out the start-up of 6P unit to see the behavior of the unit with these modifications. Indeed, after stabilization, the contractor made some corrections and removed all the reserves considered to be suspensive by the maitre of the work.

After three 03 months of stable running with a relatively significant mode (approximately 90 % of a design capacity), it was decided to start the performance tests of gas treatment section to check the performance guarantee parameters.

Indeed, from the 23/10/2010, the origin design production capacity was reached and that during 72 hours without interruption, while checking all the operational parameters including the performance guarantees. This operation was followed thoroughly while carrying out the analyses necessary in order to rule definitively on the unit effectiveness with the new installations. The table below illustrates the results of the performance tests:

| Designation | Obtained Results |
|---|---|
| A content of CO2 in treated natural gas in exit of the acid gas absorbers 61 T101 | lower than 50 ppm mole |
| Pressure drop across acid gas removal column 61-T101 (including entry and exit pipes) | lower than 160 mbar |
| Water flow rate of new washing pumps 61 P101A/B | 900 liters |
| Content of MEA in the condensate collected in the new balloon 61 D106 | lower than 0.04 % |
| A content of free liquid carried with treated natural gas in exit of the new separator 61 D103A | lower than 0.5 ppm weight |
| A content of hydrocarbons in the amine solution in exit of liquid-liquid coalescer 51/61FIL111 | Lower than 50 ppm weight |
| Pressure at the entry of driers 52/62-D104 A/B/C. | lower than 41.7 bars abs |

According to these results indicated above, it was concluded that the modifications made in the gas treatment section satisfied the performance conditions.

**2- 5P Unit:**

As the same manner, and after the success observed in 6P unit, it was proceeded to the realization of the second section of the project relating to the 5P unit during the programmed shutdown of the 11/01/2011 and that during 45 days.

After completion of work, the unit restarting, the operation parameters stabilization and the removing of the suspensive reserves, it was carried out to the performance tests from 19 until the 23/04/2011. The results obtained were very satisfactory and seem almost identical to those obtained in 6P unit.

Noting that, after the completion of the performance tests of each section, it was carried out to the inspection of the interns of the all equipments. The results of the inspections were satisfactory and confirmed the success of the work.

After one year of stable run of 5P and 6P units, it was noticed that the problem of amine carry over did not appear any more. So the two parts (PS and SH) jointly signed the final acceptance of the work.

Finally, after this period of 5P and 6P units run, it is concluded that the problem of amine carry over at the head of the acid gas removal columns is definitively resolved.

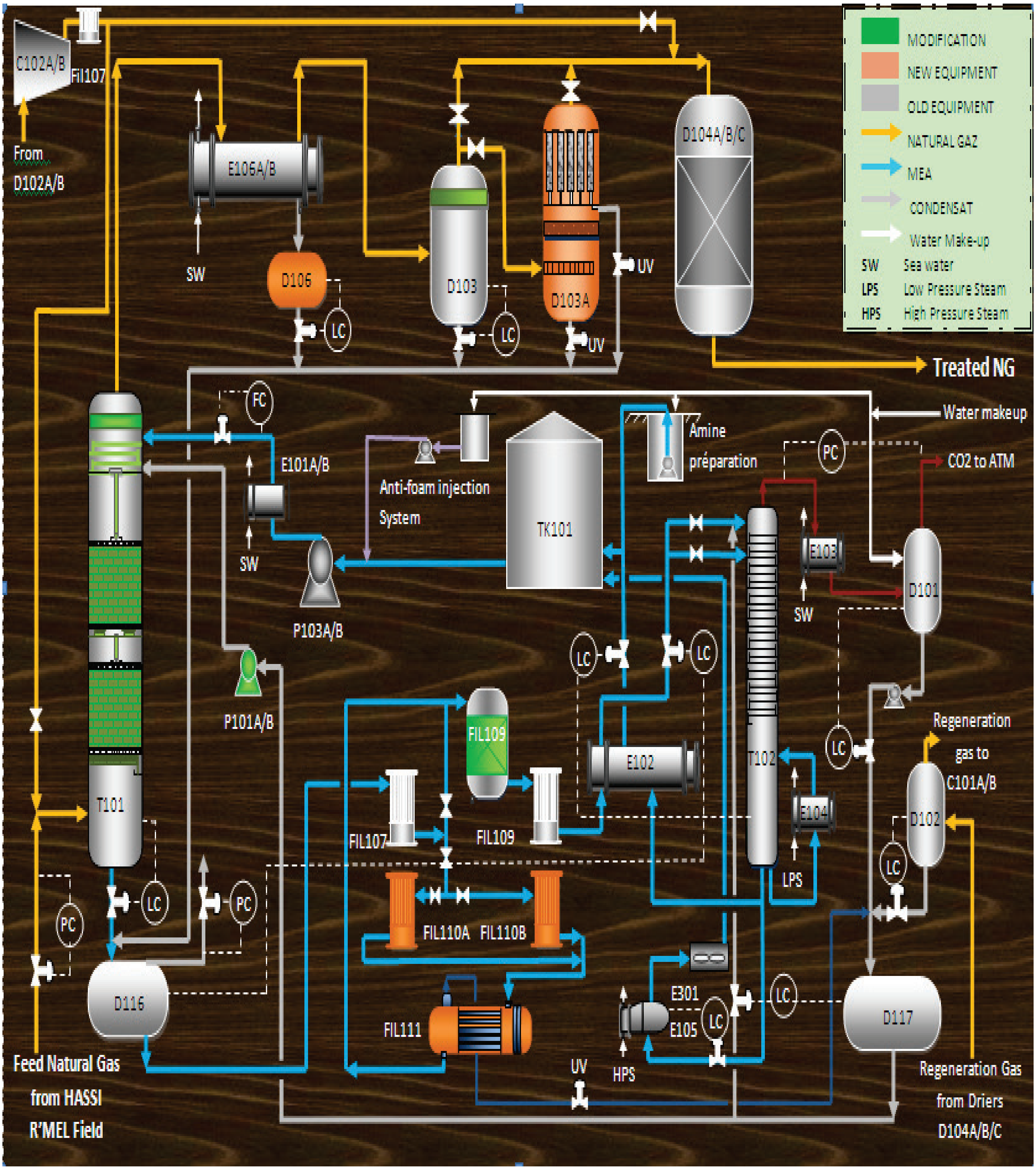



Figure 16: 6P acid gas removal section with the new modifications

**CONCLUSION**

Our study has just shown the problem of amine carry over at the head of the acid gas removal columns of 5P and 6P LNG units of GL1K plant and the generated consequences.

GL1K plant managed to examine this problem, identified its causes and became convinced that its resolution can be only obtained by significant modifications including the internal and the external of acid gas removal columns.

After the realization of these modification, the acid gas removal sections were started under satisfactory conditions and reached the expected performances

Indeed, the structured package replacing the trays of the absorbers showed its flexibility, its effectiveness of absorption and its limitation of amine carryover problem.

The improvement of the filtration system managed to inhibit the effect of the amine contaminants and limited the stable foam formation.

The improvement of the liquid-gas separation system indeed prevented the carryover of finely divided droplets towards the equipments located downstream of the absorbers and consequently, avoiding their destruction

Generally, the results obtained following these changes were very satisfactory and since that, the problem of amine carry over was definitively resolved.

Finally, the project investment value was paid in less than one (01) year and the Cumulated profit during ten (10) years will reach almost five hundred million dollars ($ 500 000 000).

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