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SIMULTANEOUS REINJECTION OF SOUR GAS AND WATER WITH A MULTIPHASE FLOW PUMP

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ABSTRACT

When sour gases (CO_2 and H_2S) are disposed into the ground, they are usually injected as a dense gas phase and sometimes in combination with water. Three cases of reinjection of sour gas with water have been identified in Canada, using single phase flow equipment. This paper presents a solution with a Two Phase (TP) flow pump for simultaneously, pressurising a gas - liquid mixture and dissolving a large fraction of the gas phase. This type of pump provides several advantages compared to single phase flow equipment: reduction in dimensions, weight and investment, also, higher reliability and safety. Concerning the sour gas supply, more gas may be dissolved by a TP flow pump downstream a methanol based sweetening unit than an amine based sweetening unit due to higher inlet and discharge pump pressures.

The kinetic of the dissolution in a TP flow pump needs to be better known. For this reason, it will be measured, mid of this year, in a multiphase flow test loop for several conditions of solubility. In the mean time, methods for optimising the compression - dissolution process are being analysed (stabilisation, recycling, heat exchange, hydraulics, control) and studies carried in the thermodynamic field for predicting the properties of a sour gas - water mixture at equilibrium conditions. Technico economical studies are also being done to evaluate the benefit in using TP flow pumps.

Introduction

Thirty per cent of hydrocarbon fields contain, in significant quantities, acid gases, mainly carbon dioxide and hydrogen sulphide. In most cases, at the production stage, the sour gas is separated in a sweet gas and an acid gas. In small quantity, acid gases are rejected into the atmosphere, particularly in the case of carbon dioxide. However, national and international regulations tend nowadays to limit the amount of gas which can be disposed into the atmosphere. In large quantity, sulphur products may be processed in a Claus unit to produce sulphur. However, the world demand for this product tends to reduce regularly.

Alternatively, carbon dioxide may be reinjected into a reservoir as a dense gas to enhance oil production, also, carbon dioxide or hydrogen sulphide may be reinjected into an aquifer after they have been dissolved in water. Three cases of reinjection of sour gas with water have been identified in Canada (« Disposal of acid gases with oilfield produced water » - Canadian Gas Processors Association - October 3, 1996 and « Underground disposal of acid gas in Alberta » - SPE35584) using single phase flow equipment and mixers to activate the gas dissolution into an aqueous phase (figure 1).

The sour gas - water reinjection installations in Canada include the plants of Thompson Lake (22 % H_2S and 78 % of CO_2; injection pressure of 80 bar; 35 000 Nm^3/d of gas and 5 000 m^3/d of water), Mirage Halfway B (68 % H_2S and 24 % of CO_2; 4 200 Nm^3/d of gas and 400 m^3/d of water) and Hansmann Lake (30 % H_2S and 70 % of CO_2; injection pressure of 75 bar; 12 000 Nm^3/d of gas and 11 000 m^3/d of water). In all cases, the acid gas is provided by an amine treatment unit and the reinjection units were commissioned in 1995.

The reinjection of a sour gas - water mixture may be provided by a two phase flow pump (figure 2). Some solutions for optimising the combined compression - dissolution process are also presented in this document.

Two main types of sweetening gas treatment main be used upstream single or two phase flow compression or pumping units. These treatment units may be based on a chemical solvent, for instance, amines (MEA, MDA or MDEA) or on a physical solvent, for instance, methanol. In the first case, the gas is saturated with water and provided at relatively high temperature, 30 to 50 °C, and low pressure, 1.5 to 2 bar abs. In the second case, the gas is dry and provided at relatively low temperature, below 0 °C, and high pressure, of the order of 10 bar abs.

1. Rotating machinery

1.1. Single phase flow pumps and compressors

In the sour gas - water reinjection plants of Canada, the gas is compressed from the supply pressure of an amine treatment (1.5 to 2 bar abs) till the reinjection pressure level with some pressure margin for pressure control and allowance for pressure drop in the discharge line (figure 1). The sour gas compressors are either of the screw type when the pressure differential is not too high or of the piston type (volumetric machine: mechanical energy converted directly to pressure) when the suction volume flow is not too high. If the efficiency of reciprocating machines is relatively high, their reliability, dimensions, weight and induced vibrations are generally considered as serious drawbacks. For these reasons, when the gas flow is sufficiently high, centrifugal or axial compressors (rotodynamic machines: mechanical energy converted to pressure through kinetic energy) are often preferred to reciprocating compressors. Whatever, the type of compressor used; gas cooling is required when the compression ratio exceeds 3 or 4.

Centrifugal pumps are required to pressurise the liquid phase from the storage tank pressure to the injection pressure. Sometimes a high pressure pump is used to boost the liquid from the outlet of a gas - liquid mixer to the injection pressure. However, precautions must be taken to ensure full dissolution of the gas in the liquid at the pump entrance to avoid cavitation and performance degradation.

1.2. Multiphase flow pumps

Multiphase flow pumps range in two main categories: volumetric pumps (reciprocating, screw, membrane) and rotodynamic pumps using helico-axial impellers. An example of a helico - axial compression cell and pump is shown on figure 3.

Among these two types of pumps, only the rotodynamic type can fulfil the following functions for a sour gas - water reinjection duty: compress the gas, pressurise the liquid, prevent gas overheating during compression and mix efficiently the two phases. The mixing property is provided at the interface between rotating (impeller) and static (diffuser) elements where the phases are sheared and broken in small particles enhancing the dissolution of the gas into the liquid. The mixing properties are comparatively greater with rotodynamic than with volumetric pumps.

2. Helico axial multiphase flow pumps

2.1. Two phase flow pump performance

In an actual two phase flow compression, where separation losses occur, the two-phase manometric head transmitted to the gas - liquid flow (corresponding to the actual pressure rise DP_{act}) is given by: $Hd_{act} = X_g \frac{P_{in}}{\rho_g} \ln\left(\frac{P_{in} + DP_{act}}{P_{in}}\right) + \left(1 - X_g\right)\frac{DP_{act}}{\rho_l}$ where X_g , ρ_g , ρ_l designate, respectively, the gas mass fraction and the gas and liquid densities.

The two phase flow efficacy of the compression, $Eff_H = \frac{Hd_{act}}{Hd_{ideal}}$, is defined by the ratio between the manometric head actually transmitted to a two phase flow and the head which could be transmitted to a single phase flow with an equivalent average density. A typical example of two phase efficacy variations for helico axial hydraulics is provided on figure 4.

From this figure, it can be seen that the value of the two phase efficacy depends mainly on the Gas Liquid volume flow Ratio (GLR) and the Gas Liquid Density Ratio (GLDR). More precisely, it shows that when the GLR tends towards 0 (only liquid) or 1 (only gas), the two phase efficacy tends towards 1, representing the upper two phase flow performance limit (equal to single phase flow performance). The figure also shows that when the GLDR tends towards 0 or 1 (respectively, very low and very high pressure), the two phase efficacy tends towards, respectively, 0 and 1.

2.2. Oil and gas applications

The first field experiences started more than 10 years ago with:

- The P300 pump tested over 5000 hours in Tunisia in 1991 and 1992, following a comprehensive test campaign at the IFP industrial test centre (at Solaize near Lyon - France).
- The subsea SMUBS pump for the Draugen field (Norske Shell) in 1993 - 1994 producing 3800 b/d
- The P301 pump operating on the Gullfaks platform (Statoil) since 1994 providing an increase in oil production of the order of 6000 b/d (1997)
- The P302 pump operating on the Pecorade field (Elf Aquitaine) since 1994 for marketing low pressure gas

Since 1997, 17 additional pumps have been ordered, some of them being now in operation. These pumps handle larger flow (up to 3000 m^3/hr) and larger absorbed power (4000 kW in the case of the Dunbar pumps and 6000 kW in the case of the Youkos pumps).

2.3. Sour gas - water applications

Helico axial pumps may be used at least till 5 000 m^3/hr. This figure corresponds rather to present needs for oil and gas applications than to a technological limit. Considerably larger volume flows could be handled in the future by this type of multiphase flow pump if there was a demand for it.

Gas and liquid flowrates which can be transported by a two phase flow pump for sour gas - water reinjection depend, mainly, on inlet volume flow, saturation conditions at discharge pressure and the type of sweetening process preceding the multiphase flow pump. Examples of multiphase flow pump performance are illustrated on table 1, based on an inlet volume flow of 5 000 m^3/hr. They have been established in assuming that there was almost no gas dissolution during compression, representing a conservative pump operation situation (minimum discharge pressure and maximum absorbed power) and for the following conditions:

a) a 12 stage pump

b) two values of inlet pressure, 1.7 and 10 bar abs, representing the cases where the sour gas is provided by, respectively, amine and methanol treatment units,

c) two types of gas (pure CO_2 and pure H_2S),

d) and two values of inlet GLR in the case of an amine treatment.

From table 1, it can be seen that the pump operating conditions vary considerably with the inlet pressure, the type of gas and the GLR.

In case A1 (CO_2 & 1.7 bar abs) - GLR = 12, the discharge pressure is relatively important, approaching 100 bar while the condition of gas saturation in the liquid phase at the pump discharge is far from being reached (59 %). Increasing the inlet GLR to 16 permits to increase the gas saturation to 91 % but reduces the discharge pressure by approximately 30 bars due to a lower average fluid density.

In case A2 (H_2S & 1.7 bar abs) - GLR = 12, the discharge pressure is lower by approximately 20 bar compared to the equivalent case with CO_2 due to a lower density of the gas, providing a lower average density and lower efficacy. Increasing the inlet GLR to 16 reduces the discharge pressure by more than 30 bars due to a lower average fluid density. The condition of saturation of the gas in the liquid phase is lower than in the previous case due to a higher solubility of H_2S in water compared to CO_2.

In cases A1 and A2, the absorbed power is of the order of 5 000 kW, being mainly dependant on the number of stages. It is however greater when the inlet GLR is smaller (total mass flow greater).

In case A3 (CO_2 & 10 bar abs) - GLR = 3.3, the discharge pressure is very high, of the order of 160 bars due to very favourable pumping conditions: high gas density and low GLR. The condition of saturation of the gas in the liquid phase is relatively easily reached (96%). The results in case A4 (H_2S & 10 bar abs) - GLR = 4.0 are comparable to the results in case A3. In cases A3 and A4, the absorbed power is considerably greater compared to cases A1 and A2, due to considerably larger mass flowrates (mainly, water mass flowrate - 3 to 4 times).

3. Thermodynamic properties of a sour gas - water mixture

The thermodynamic parameters required for the performance calculation of a multiphase flow pump are:

a) the number of thermodynamic phases at a given operating condition

b) the amount of sour gas dissolved in the aqueous phase, the amount of water vapour in the gas phase and the composition of the sour liquid phase

c) the density of thermodynamic phases

d) the heat of dissolution

e) the formation of hydrates

These parameters are provided by a thermodynamic programme at equilibrium conditions. The actual conditions of operation in a two phase pump are obtained following corrections of the equilibrium parameters by a kinetic coefficient dependent on the two phase operating conditions and the pump geometry.

IFP has started in 1999 some works regarding the collection of thermodynamic data for sour gas and water mixture then determined the zones where experiments were required. The collected data have been used to verify the suitability of thermodynamic models for a sour gas - water mixture.

3.1. Phase equilibrium

A phase equilibrium calculation provides the number of thermodynamic phases, the type and the composition of each phase.

In a two component system, such as, water with carbon dioxide or hydrogen sulphide, the number of thermodynamic phases may be reduced to one (liquid phase), equal to two (gas - liquid or liquid - liquid) or even equal to three in case of formation of a sour liquid phase depending on temperature and pressure conditions, but also, on the molecular fraction for each component. In a three component system including water, carbon dioxide and hydrogen sulphide, the number of thermodynamic phases is similar to the two component system, the sour liquid phase being not miscible with the aqueous phase. In a multi component system, including the above three components and hydrocarbons, four thermodynamic phases may be obtained (excluding the formation of hydrates): a gaseous phase, an aqueous phase, a sour liquid phase and a hydrocarbon liquid phase.

The model of Soreide and Whitson, an extension of the equation of state of Peng Robinson, is used for determining the phase composition at equilibrium conditions. This model is also suitable for taking into account the presence of salts in the water phase.

The model has been verified extensively against experimental data corresponding to a pure water, carbon dioxide and hydrogen sulphide mixture. The work is continuing with mixtures including salty water and hydrocarbons in addition to sour components.

3.2. Density and enthalpy

The density of the gas phase is obtained directly from the Peng Robinson equation of state.

The heat of dissolution corresponds to the heat generated by the transfer of a pure sour component, in a thermodynamic gas or liquid phase, into the aqueous phase. The calculation includes the fugacity parameters and uses the features of Henry law.

3.3. Hydrates

Conditions of formation of hydrates have been known for long.

In presence of pure carbon dioxide, below 40 bars, hydrate formation depends on both pressure and temperature. Above 40 bars, the limit is mainly defined by the temperature, hydrates forming when the temperature is lower than 10 °C. Similarly, in presence of pure hydrogen sulphide, below 20 bar, hydrate formation depends on both pressure and temperature while above 20 bar, hydrate formation only occurs when the temperature is lower than 30 °C.

In presence of a carbon dioxide - hydrogen sulphide mixture, hydrate formation occurs at an intermediate temperature compared to the ones corresponding to pure gases, the temperature depending on the concentration of each gas.

3.4. Water salinity

Experiments will be carried out in laboratory in order to evaluate the salinity effect on sour gas dissolution. Experiments will be based on different types of salts and with different concentrations.

4. Process optimisation

Considering that the dissolution of the gas in the liquid phase during compression is not instantaneous and, therefore, that the amount of actually dissolved gas is lower than the one predicted by thermodynamic calculations at equilibrium conditions, methods for enhancing the dissolution have been analysed. They include:

- stabilisation of the dissolution at an intermediate stage of compression
- recycling a fraction of the liquid phase in the first stages of compression
- combining hydraulics of a different type
- exchanging heat with the sour gas - liquid mixture
- using a variable speed driver

- adapting hydraulics to a compression - dissolution duty

4.1. Stabilisation of the dissolution during compression

This arrangement is represented on figure 5. With this arrangement, the two phase flow leaving the pump at an intermediate stage is sent to a mixer in order to stabilise the dissolution then resent to the pump for final compression. A second stabilisation step could be added, however its benefit would be smaller compared to a single stabilisation. The stabilisation of the dissolution provides the following advantages:

- it reduces the gas flow, therefore, the GLR and increases the average density, two factors tending to increase the two phase compression efficacy,
- it transfers a fraction of the mass flow from the compressible phase to the incompressible phase, a phenomena which tends to reduce the input energy.

Calculations have been carried out on the following basis: assuming that the dissolution of the gas occurs only at the stabilisation stage, two GLR values (10 and 16), a pump with 12 stages, an inlet pressure of 1.7 bar abs and for several positions of the stabilisation.

Results indicate that the maximum pressure rise is of the order of 16 and 10 bar, respectively, for GLR values of 10 and 16, representing, in both cases, a pressure increase of 15 %. In both cases, the pressure rise corresponding to an optimised stabilisation is half way between situations representing, respectively, a no dissolution case and an instant dissolution case. Stabilisation of the dissolution permits either to increase the discharge pressure based on constant absorbed power or to reduce the absorbed power based on constant discharge pressure.

4.2. Liquid recycling

This arrangement is presented on figure 6. The two phase flow leaves the pump at an intermediate compression stage. The liquid is roughly separated from the gas in a drum. A fraction of the liquid phase is sent to the two phase pump entrance while the rest of the liquid phase is used to dissolve a fraction of the gas, through a mixer, under equilibrium conditions before returning into the pump. This solution permits to increase the density of the two phase flow in the first pump stages, therefore, to increase the pressure ratio of the pump to a level significantly greater than if there was only stabilisation of the dissolution. This solution permits to increase the amount of dissolved gas for the same number of hydraulic stages.

As an example, in the case of a pump with 12 stages and a GLR of 10, the recycling of 30 % of the liquid phase on the first 4^{th} pump stages permit to increase the discharge pressure by 30 bar (30%) and the absorbed power by 1030 kW (16%). Alternatively, recycling of the same fraction on the first 3^{rd} pump stages, provides increases of, respectively, 24 bar (23%) and 710 kW (11%) while recycling of the same fraction on the first 5^{th} pump stages, provides increases of, respectively, 35 bar (34%) and 1240 kW (20%).

4.3. Hybrid pump

This arrangement is presented on figure 7. The association, in a single pump body, of radial hydraulics to compress the low pressure gas and of helico axial hydraulics to compress downstream the two phase flow provides the following advantages:

- it reduces the number of machines under certain conditions of gas flow and type of gas treatment : a single hybrid two phase pump instead of several conventional two phase flow pumps mounted in parallel or a single hybrid two phase pump instead of one gas compressor and one liquid pump or a single hybrid two phase pump instead of one LP gas compressor and one HP two phase pump
- it permits to enter at least three times the volume flow limitation of a conventional two phase flow pump
- it increases significantly the discharge pressure, particularly at high GLR (9, 20 and 38 %, respectively, for GLR = 12, 14 and 16).
- it reduces significantly the absorbed power (26, 24 and 21 %, respectively, for GLR = 12, 14 and 16)

The above numerical examples apply to the comparison between a two phase pump with 10 helico axial stages and a hybrid pump with 3 radial and 7 helico axial stages, for an inlet pressure of 1.7 bar abs (supply pressure of an amine treatment). Less benefit of a hybrid pump would be found downstream a methanol treatment.

In conclusion, the hybrid pump may only be used for certain conditions of gas flowrates. It is more advantageous at high GLR and downstream an amine treatment unit.

4.4. Heat exchange during compression

This arrangement is presented on figure 8. It combines on the figure the case of an intermediate stabilisation of the dissolution and of a heat exchange with an external fluid.

With carbon dioxide, cooling of the two phase flow permits to increase the capacity of water to dissolve a larger amount of gas.

The situation with hydrogen sulphide is more complex, cooling of the two phase flow being more beneficial at low pressure. However, heating of the gas - liquid mixture is preferable at high pressure to increase the dissolution capacity. As an example, at 120 bars, 1 m^3 of water may dissolve up to 42 Nm^3 of pure H_2S at 40 °C. This limit may be brought up to 60 Nm^3 at 100 °C.

4.5. Speed of rotation

Increasing the speed of rotation provides an increase in the manometric head proportionally to the square of the speed of rotation and approximately with the same effect on the pressure rise in the case of a fluid with little compressibility. An increase in the speed of rotation may therefore be a solution to ease the dissolution during compression.

Speed adjustment may also be used to control the operation of a two phase pump for injection pressure control and proper hydraulic operation of the two phase compression stages.

5. Testing of a two phase compression with dissolution

To evaluate the kinetic of the dissolution during two phase compression, testing will be carried out in a two phase flow loop. The following tests have been planned:

1) test with water for single phase flow performance characterisation

2) test with water and nitrogen for two phase flow performance characterisation (using single phase flow results of item 1), the gas being almost not soluble into the liquid phase

3) test with water and carbon dioxide for characterisation of the kinetic of the dissolution (using the two phase flow results of item 2), the gas being relatively soluble into the liquid phase

4) test with liquid fuel and carbon dioxide for validation of the kinetic law (established in item 3), the gas being very soluble into the liquid phase

The test campaign will start mid 2000. It will consist in measuring pressures and temperatures at various locations, absorbed power and individual gas and liquid flowrates at pump entrance. The kinetic of the dissolution will be evaluated in measuring the volume fraction of the gas at the pump discharge using a density meter. The pump performance will be measured for various conditions of gas - liquid volume flow ratio and density ratio (two key parameters for evaluating two phase flow performance) but also for various values of inlet volume flow and speed of rotation.

6. Economics

Economics for sour gas - liquid injection have been analysed in the past at IFP, showing a significant advantage in capital cost by using a two phase flow pump rather than single phase flow equipment. Following the positive results of the preliminary study, a more comprehensive economical evaluation is now being carried out for different types of application and in collaboration with an engineering company. Below is a brief description of the study cases to be analysed.

1) CASE A: the existing installation of Thompson Lake in Canada using a four stage reciprocating compressor is analysed with a two phase flow pump. Suction and discharge pressures: 1.7 and 80 bar abs. Gas is saturated with water at inlet. The dry gas includes 78 % of CO_2 and 22 % of H_2S. Gas and liquid flow rates: 210 m^3/hr and 1460 Nm^3/hr.

2) CASE B: a two phase pump is used downstream a methanol gas treatment. Inlet and outlet pressures: 9.5 and 50 bar abs. The gas includes 33 % of C02, 50 % of H_2S and hydrocarbons. Gas and liquid flow rates: 1 600 m^3/hr and 50 000 Nm^3/hr.

3) CASE C: a two phase pump is used downstream a LP centrifugal compressor, itself, downstream an amine gas treatment. LP compressor inlet pressure: 1.9 bar abs. TP pump inlet and outlet pressures: 20 and 50 bar abs. The gas at main inlet includes 40% of CO_2, 51 % of H_2S and water. Gas and liquid flow rates: 2 500 m^3/hr and 75 000 Nm^3/hr. In this case, the TP pump is compared to a high pressure centrifugal compressor.

4) CASE D: a hybrid pump (with radial and helico axial stages) is used downstream a methanol gas treatment. Inlet and outlet pressures: 9.5 and 50 bar abs. The gas includes 33 % of CO_2, 50 % of H_2S and hydrocarbons. Gas and liquid flow rates: 2 600 m^3/hr and 80 000 Nm^3/hr. In this case, the TP pump is compared to a centrifugal compressor.

7. Conclusions

Two phase helico axial pumps may be used for reinjecting simultaneously a sour gas - water mixture. These pumps present several advantages compared to single phase flow equipment: reduced dimensions, weight, vibrations and capital cost, also, higher reliability and safety.

A thermodynamic programme has been set up, providing thermodynamic properties for a carbon dioxide, hydrogen sulphide and pure water mixture and for temperature and pressure conditions ranging from 0 to 100 °C and 1 to 150 bars. Further work is continuing to incorporate hydrocarbon properties and water salinity effect.

To evaluate the kinetic effect of gas dissolution during two phase compression, two phase flow tests will be carried out mid of this year. The tests will be carried out with different types of fluids, in order to measure pump two phase flow performance, the kinetic effect of the dissolution and to verify the suitability of kinetic laws to several conditions of solubility.

Means for optimising a combined two phase compression - dissolution process have been evaluated. They include: stabilisation of the dissolution at an intermediate stage of the compression, recirculation of a part of the liquid flow, association of single and two phase flow hydraulics and the use of heat exchangers. Their benefit is dependent on the type of application, mainly, inlet pressure, GLR and gas type.

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Figure 1 - Compression and dissolution of a sour gas - water mixture with single phase flow equipment: pumps and compressors

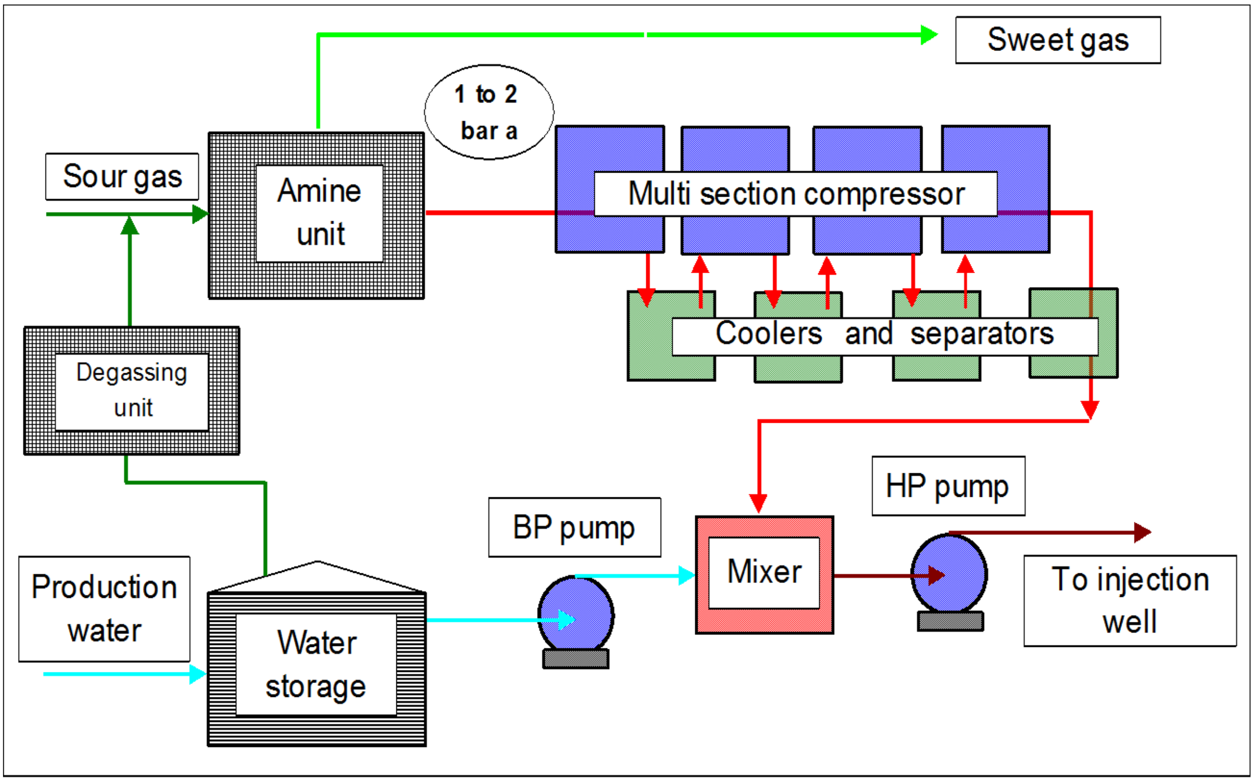

Figure 2 - Compression and dissolution of a sour gas - water mixture with single phase flow equipment: pumps and compressors

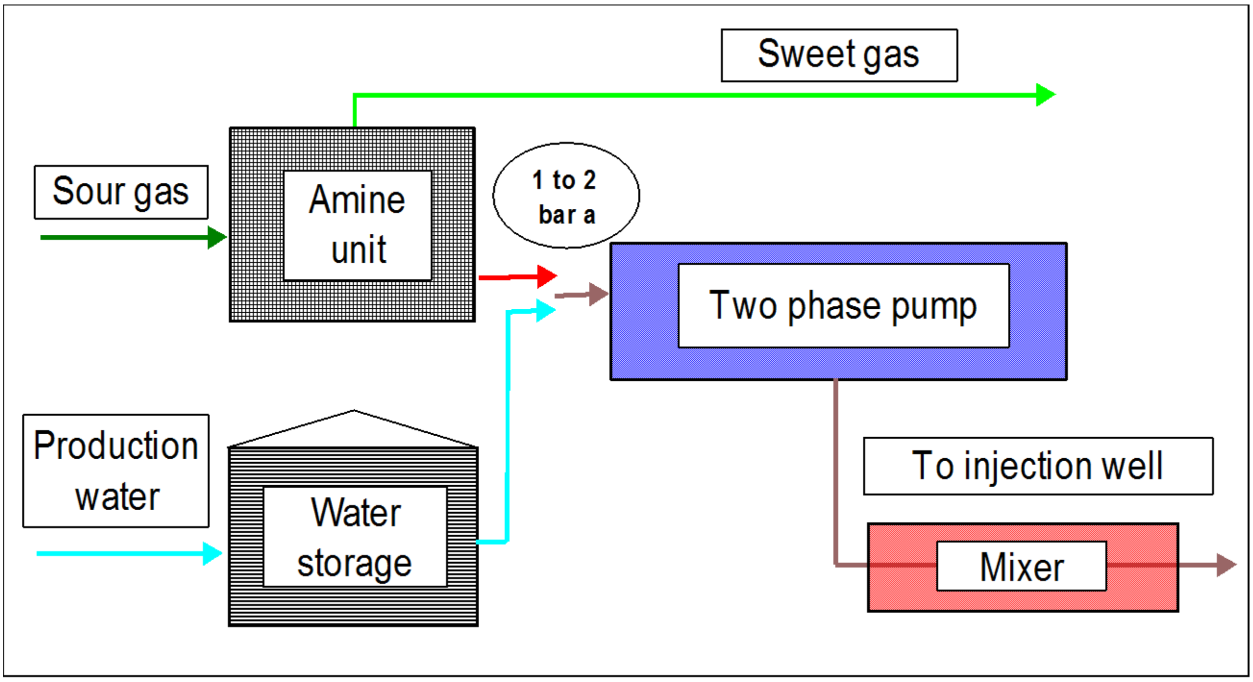

Figure 3 - Two phase rotodynamic pump

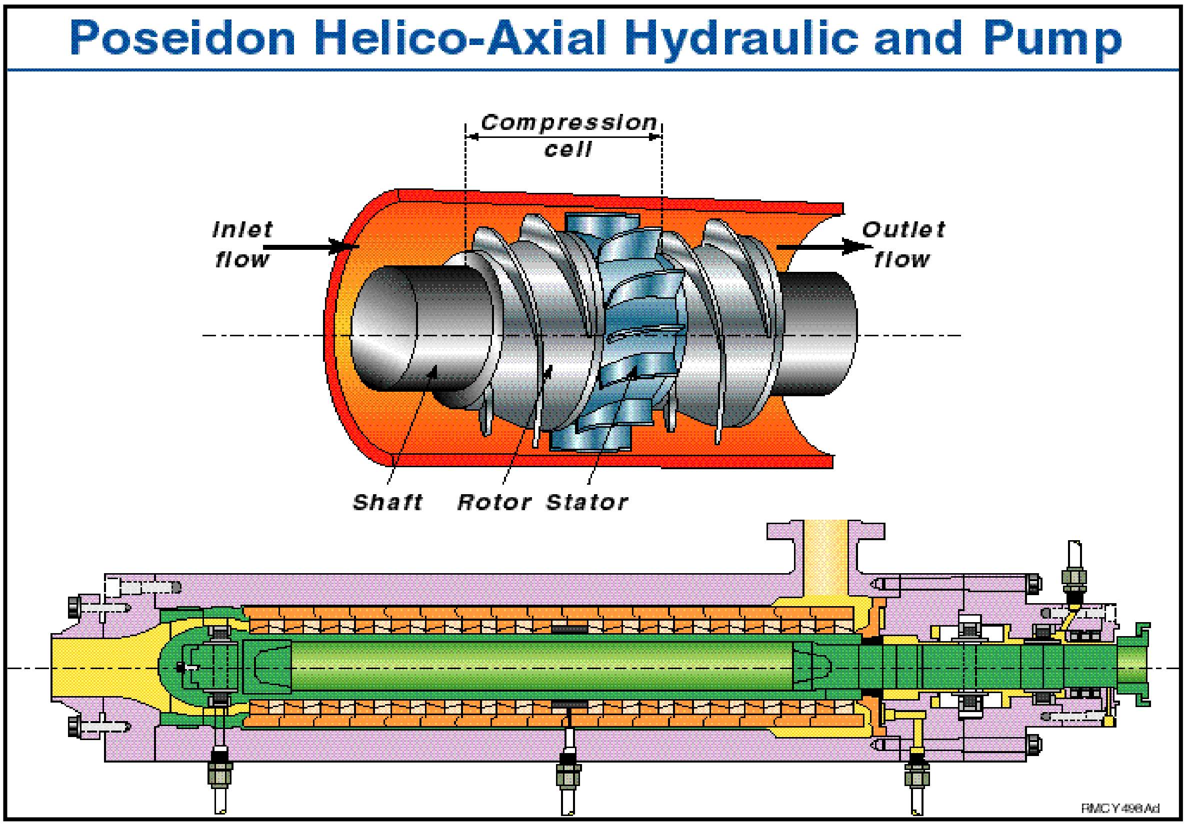

Figure 4 - Typical two phase efficacy for helico axial pumps

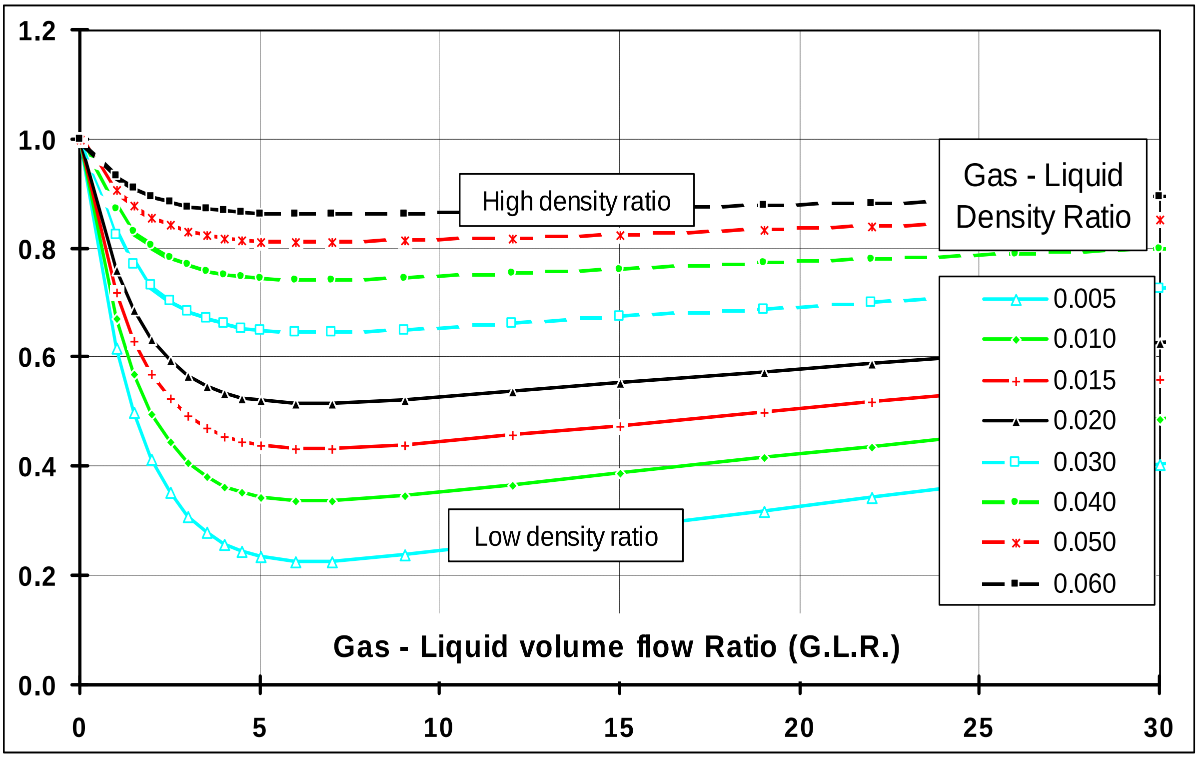

Table 1: Sour gas - water reinjection with a two phase flow pump

A1 - Pure CO_2 ; *Amine treatment* Tgas=40°C, Twat.=20°C, ***Pin=1.7 bar a***		**A2 - Pure H_2S** ; *Amine treatment* Tgas=40°C, Twat.=40°C, ***Pin=1.7 bar a***	
59 % (1)	91 % (1)	44 % (1)	59 % (1)
Ql = 380 m^3/hr Qg = 6 700 Nm^3/hr **GLR in = 12** P out = 97 Bar abs Power = 5 500 kW	Ql = 300 m^3/hr Qg = 7 000 Nm^3/hr **GLR in = 16** P out = 68 Bar abs Power = 4 600 kW	Ql = 380 m^3/hr Qg = 6 700 Nm^3/hr **GLR in = 12** P out = 78 Bar abs Power = 5 600 kW	Ql = 300 m^3/hr Qg = 7 000 Nm^3/hr **GLR in = 16** P out = 45 Bar abs Power = 4 700 kW

A3 - Pure CO_2 ; *Methanol treatment* T gas= 0°C, T wat=20°C, ***Pin=10 bar a***	**A4 - Pure H_2S** ; *Methanol treatment* T gas= 0°C, T wat=40°C, ***Pin=10 bar a***
96 % (1)	99 % (1)
Ql = 1 100 m^3/hr Qg = 36 000 Nm^3/hr **GLR in = 3.3** P out = 160 Bar abs Power = 14 100 kW	Ql = 1 000 m^3/hr Qg = 39 500 Nm^3/hr **GLR in = 4.0** P out = 138 Bar abs Power = 13 500 kW

Note (1): gas saturation of the liquid phase at pump discharge

Figure 5 - Stabilisation of the dissolution during compression

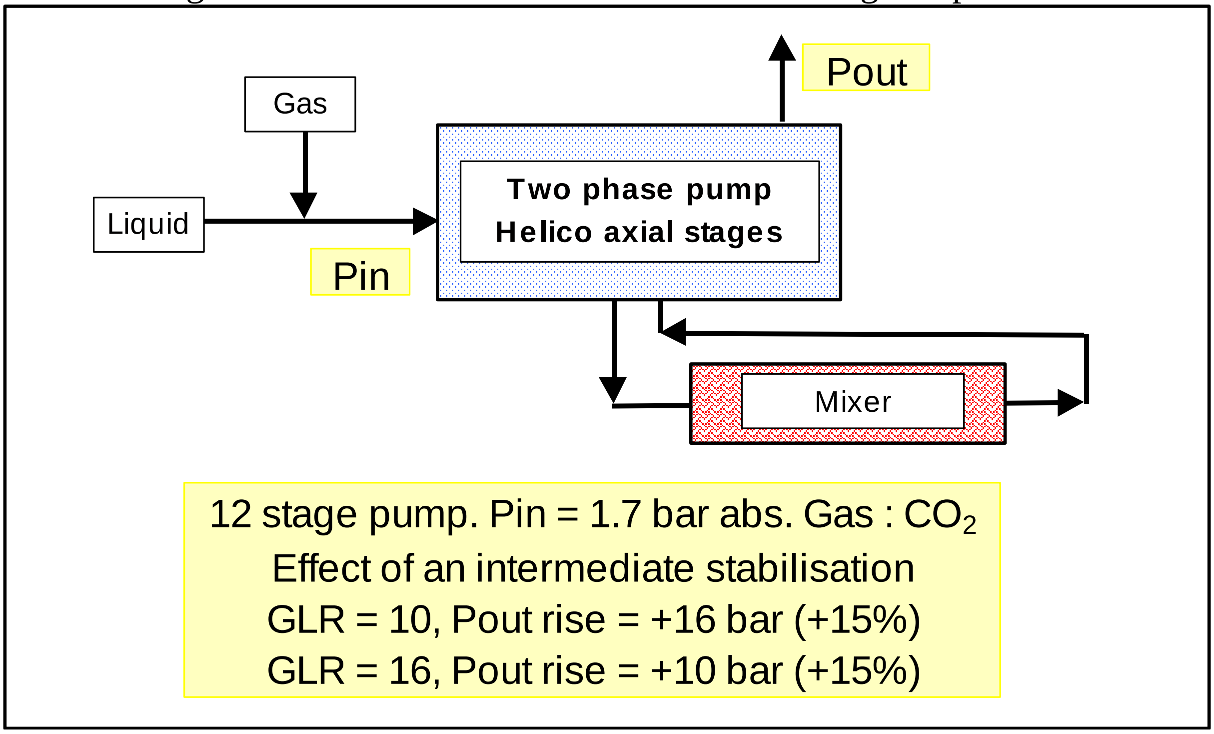

Figure 6 - Inlet liquid recycling with stabilisation of the dissolution

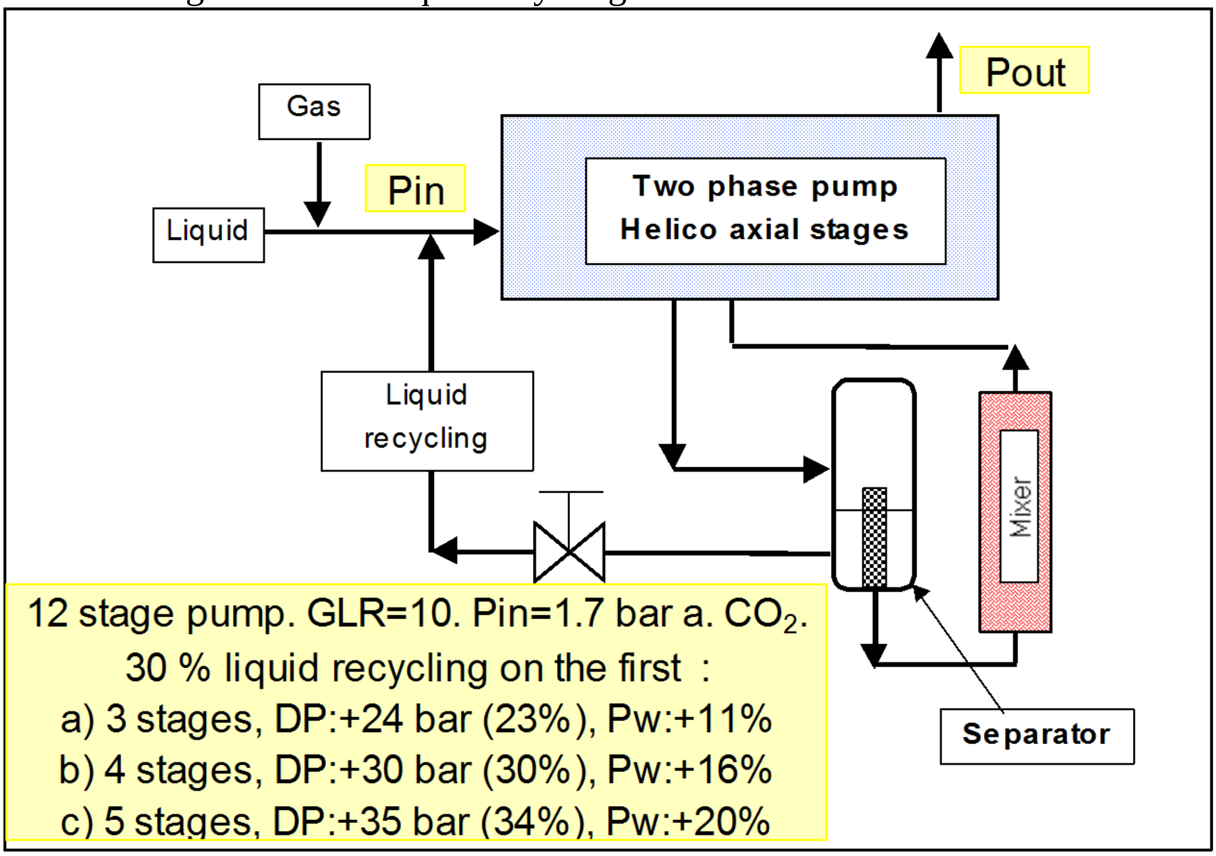

Figure 7 - Hybrid pump with stabilisation of the dissolution

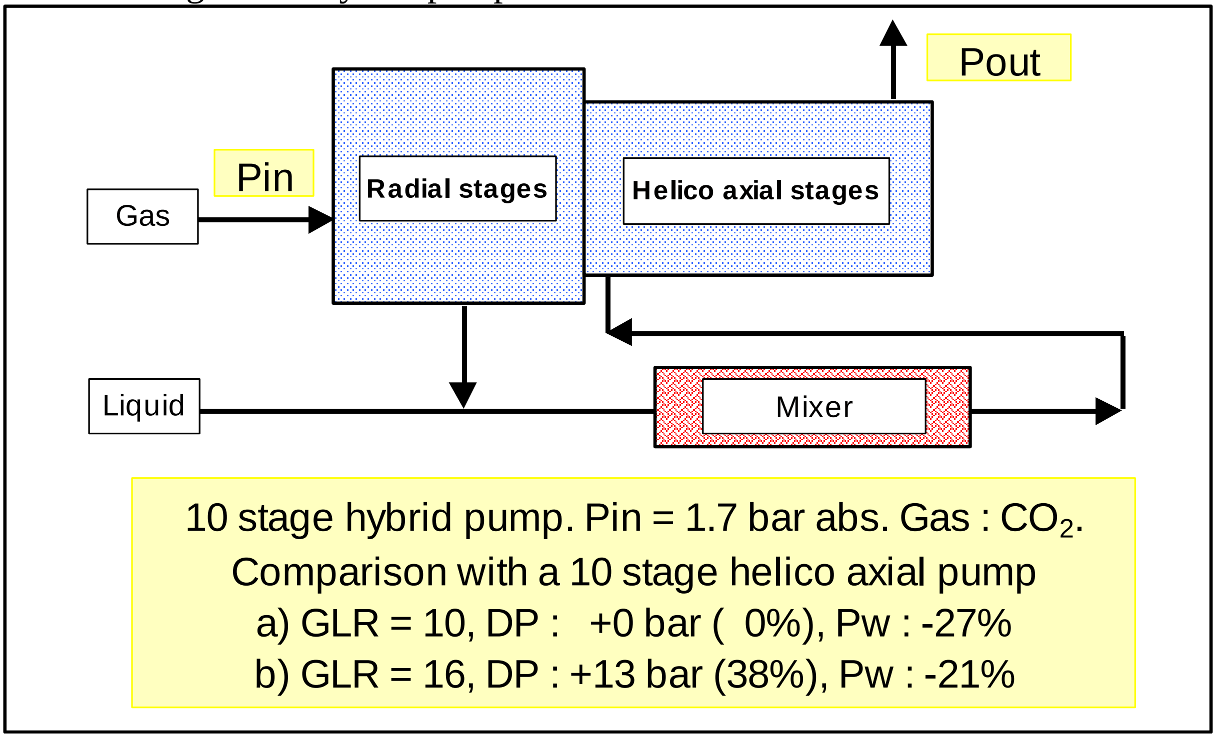

Figure 8 - Stabilisation of the dissolution and heat exchange