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(57) Abstract: An aqueous CO₂ absorbent comprising a combination of a sterically hindered amine and a monoalkanolamine, wherein the concentration of the sterically hindered amine is from 10 to 35 % by weight and the concentration of the monoalkanolamine is from 10 to 35 % by weight, is described. Additionally, a method for removal of CO₂ from an exhaust gas using the absorbent, is described.



Title of invention

Amines

Field of invention

- 5 The present invention relates to an improved method for capturing of CO₂ from a combustion gas, and to an improved amine absorbent for CO₂.

Background

- 10 Capture of CO₂ from a mixture of gases in an industrial scale has been known for decades, i.e. for separation of natural gas and CO₂ from sub terrain gas wells to give natural gas for export and CO₂ for return to the sub terrain structure.

- The growing concern on environment and the greenhouse effect of CO₂ from combustion of fossil fuels has caused a growing interest in CO₂ capture from
15 major points of emission of CO₂ such as thermal power plants.

- US 5.618.506, and EP 0 558 019, both to The Kansai Electric Power Co., Inc., and Mitsubishi Jukogyo Kabushiki Kaisha, and the citations indicated therein, give a general background of process and absorbents for capturing of CO₂.

20

- Industrial CO₂ capturing plants include an absorber, in which a liquid absorbent is brought into countercurrent contact with the gas to be treated. A "purified" or low CO₂ gas is withdrawn at the top of the absorber and is released into the atmosphere, whereas a CO₂ rich absorbent is withdrawn from the bottom of the
25 absorber. The rich absorbent is regenerated in a regeneration column where the rich absorbent is stripped by countercurrent flow with steam that is generated by heating of regenerated absorbent at the bottom of the regeneration column. The regenerated absorbent is withdrawn from the bottom of the regeneration column and is recycled into the absorber. A CO₂ rich gas, mainly comprising steam and
30 CO₂ is withdrawn from the top of the regeneration column. The CO₂ rich gas is treated further to remove water, and compressed before the CO₂ is sent for deposition or other use.

Capture of CO₂ is, however, an energy demanding process, as the binding of

CO₂ to the absorbent is an exothermal reaction and the regeneration is an endothermal reaction. Accordingly, heat is lost in the absorber and heat is to be added to the regeneration column to regenerate the absorbent and release the CO₂. This heat demand is a major operating cost for a plant for CO₂ capture. A reduction of the heat requirement for regeneration of the absorbent is therefore sought to reduce the energy cost for the CO₂ capture.

Amines having a less exothermic reaction when absorbing CO₂ do, however, normally have slower reaction kinetics and will thus require a longer contact time between the CO₂ containing gas and the absorbent. A longer contact time will require a larger absorber for the same gas volume.

Many different amines and combinations have been suggested as absorbents for CO₂, the different amines having CO₂ absorption capabilities, see e.g. the above mentioned patents. Examples of suggested amines for the aqueous solutions to be used as absorbents are alkanolamines such as e.g. monoethanol amine (MEA), diethanol amine (DEA), triethanol amine, dimethyldiethanolamine, diisopropanol amine, diglycol amine, methyl monoethanol amine (MMEA), 2-amino-2-methyl-1-propanol (AMP). MEA is also commonly used as a reference absorbent in tests for possible new absorbents.

The reaction kinetics, heat demand, heat of reaction, amine equilibrium loading, degradation, stability, solubility in water and absorption capacity of the different amines are of interest when selecting a potential absorbent for industrial scale CO₂ capture.

The objective of the present invention is to provide an improved absorbent and an improved method for capturing of CO₂ from a CO₂ containing gas, where the improved absorbents has improved characteristics compared with the prior used absorbents, such as exemplified with the MEA reference absorbent. Specifically, it is an object to provide an absorbent having a lower energy demand for regeneration of the absorbent, at the same time as acceptable reaction kinetics and absorption capacity is obtained. It is also an object to provide a method for use of the new absorbent.

Summary of the invention

According to a first aspect the present invention relates to an aqueous CO₂ absorbent comprising a combination of a sterically hindered amine and a monoalkanolamine, wherein the concentration of the sterically hindered amine is from 10 to 35 % by weight and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

The sterically hindered amine is, according to one embodiment, 2-amino-2-methyl-1-propanol (AMP).

According to another embodiment the monoalkanolamine is methylmonoethanolamine (MMEA) or monoethanolamine (MEA)

According to a second aspect, the invention relates to a process for removing CO₂ from a CO₂-containing gas, comprising the step of bringing the CO₂-containing gas in contact with an aqueous solution of a sterically hindered amine, and a monoalkanolamine, where the concentration of the sterically hindered amine is from 10 to 35 % by weight and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

The sterically hindered amine is, according to one embodiment, 2-amino-2-methyl-1-propanol (AMP).

According to another embodiment, the monoalkanolamine is methylmonoethanolamine (MMEA) or monoethanolamine (MEA).

Short description of the figures

Figure 1 is a graph illustrating reaction rate as a function of concentration of CO₂ for different CO₂ absorbents,

Figure 2 is a graph illustrating absorption rate versus loading for different absorbents,

Figure 3 is a graph illustrating desorption rate versus loading for different absorbents,

Figure 4 is a graph illustrating desorption rate versus concentration for different absorbents,

Figure 5 is a graph illustrating absorption rate in lean loading versus net absorption capacity for different absorbents,

- 5 Figure 6 is a graph illustrating equilibrium data for 30 % by weight of MEA at different temperatures,

Figure 7 is a principle drawing of a pilot plant used for testing absorbents,

Figure 8a and b illustrates loading and gas inlet concentration of CO₂, respectively, for different runs, and

- 10 Figure 9 is a graph illustrating the results for the specific reboiler duty versus loading.

Detailed description of the present invention

- The present invention relates to an improved amine absorbent for CO₂ capture
15 and a method for capturing CO₂ using the improved amine absorbent.

The invention is based on mixing two different amines having different reaction kinetics, one being a sterically hindered amine, such as e.g. 2-amino-2-methyl-1-propanol (AMP) and the other being a monoalkanolamine, such as e.g. methyl
20 monoethanolamine (MMEA) or monoethanolamine (MEA). Examples on sterically hindered amines are given e.g. in "Sartori, G., Savage, D.W. (1983), "Sterically hindered amines for CO₂ removal from gases", Ind. Eng. Chem. Fundam., Vol 22, No 2."

- 25 AMP, being a sterically hindered amine, is known to have low energy requirement for regeneration of the absorbent but the slow reaction kinetics have a negative impact in the absorber as it requires a longer contact time between the CO₂ containing gas and the absorbent in the absorber.

- 30 MMEA and MEA at the other side, are known to have high energy requirement but faster reaction kinetics.

It is known to combine an absorbent having slow reaction kinetics with a minor amount, such as e.g. 1 to 5 % of the total amine, of absorbents having faster

reaction kinetics to increase the rate of absorption by AMP and other "slow" but energy efficient absorbents. It was therefore surprising to find that mixing substantially equimolar amounts of AMP with MMEA or MEA results in an absorbent having fast reaction kinetics and significantly lower energy demand.

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According to the present invention it is found that an aqueous CO₂ absorbent comprising from 10 to 35 % by weight of a sterically hindered amine and from 10 to 35 % by weight of a monoalkanolamine has a substantially lower energy requirement than the industry standard absorbent MEA. Additionally, the novel
10 absorbent shows good reaction kinetics and absorption capacity.

It is preferred that at least 15% by weight, such as e.g. at least 20 % by weight or at least 25 % by weight, such as about 30 % by weight, of the sterically hindered amine is present in the absorbent. It is also preferred that at least 15% by weight,
15 such as e.g. at least 20 % by weight or at least 25 % by weight such as about 30 % by weight, of the monoalkanolamine, is present in the absorbent.

The above mentioned concentrations of the amines corresponds to a weight ratio of sterically hindered amine to the monoalkanolamine from 10:35 to 35:10, such
20 as e.g. 15:35 to 35:15, 20:35 to 35:20, 25:35 to 35:25, or 30:35 to 35:30, such as e.g. 35:35.

Below, different tests of examples of absorbents according to the present invention and comparative examples using MEA alone have been performed.
25 The experimental part is divided in a first introductory part of screening experiments for a preliminary relative comparison of important characteristics of different test absorbents, such as rate of absorption, absorption capacity, viscosity and absorption equilibrium, and second part including tests run in a pilot plant.

30

Screening experiments

A series of screening experiments were performed for an initial screening of possible absorbent mixtures for further examinations. The objective of screening tests is to carry out simple mass transfer absorption and stripping tests of

candidate absorbents as alternatives to 30% (5M) mono-ethanol-amine (MEA). The rate of absorption is a measure of the mass transfer enhancement properties of an absorbent, which is directly related to the height required for the absorber. With a faster reacting absorbent the absorber tower height can be reduced. The screening tests give only relative data for the absorption/stripping process.

The tests were performed at an apparatus designed to give a fast relative comparison of the rate of absorption and the absorption capacity of solvents with a potential for utilization in an industrial absorption process. The method of comparison has been used for comparative studies since 1993 (see e.g. Erga et al., 1995). Being an apparatus for relative comparison, the interpretation of results relies on the specification of a base-case amine with a specific concentration.

The rate of absorption is a measure of the mass transfer enhancement properties of an absorbent, which is directly related to the height required for the absorber. With a faster reacting absorbent the tower heights can normally be reduced. The absorption capacity of the solvent is an important property as a premise for a high cyclic capacity of the process. Additional observations from the screening experiments can be made regarding the extent of foaming, possible precipitation, and discoloration upon CO₂ loading which may be indicative of solvent degradation. In this project the purpose of the screening is to select appropriate concentration levels of both AMP and MMEA / MEA.

Different concentrations of MMEA/AMP and MEA/AMP were tested, and compared with 5M (30% by weight) MEA. The reproducibility has been controlled by reproducing the 30% MEA test.

The absorption capacity of the solvent is an important premise for maximizing the cyclic capacity of the process. With MEA and MMEA the capacity for absorption is limited by the reaction stoichiometry to about 0.5 mole CO₂/mole amine at ambient pressure. As AMP is a sterically hindered amine and forms bicarbonate, it can be loaded to more than 0.5 mole CO₂/mole amine depending of the CO₂ partial pressure with a theoretical maximum loading of 1.0. It must, however, be

noted that for the cyclic capacity to be high, a high CO₂ equilibrium pressure at desorption conditions is also necessary.

Additional observations from the screening experiments can be made regarding the extent of foaming with no by-products present and possible problems linked to precipitation.

The mass transfer screening apparatus is used to measure the absorption rate of CO₂ at 40°C followed by desorption rate measurements with nitrogen at 80°C. The gas is distributed through the diffuser of sintered glass which creates gas-bubbles rising up through the liquid. From the surface of these bubbles, CO₂ is first absorbed into the liquid at 40°C until 95% of equilibrium, corresponding to 9.5% CO₂ in the effluent gas, is obtained. Afterwards the rich solution is heated to 80°C, and desorption starts with pure nitrogen until the CO₂ concentration in the effluent gas decreases to 1 vol%. A computer controls the solenoid valve system for gas supply and cooling or heating of the water bath.

The CO₂-content of the effluent gas is measured by an IR CO₂ analyzer. After each experiment the accumulated weight of liquid is measured and compared with the net absorbed amount of CO₂. This is to assure that no solvent is lost by evaporation. Samples of the solvent are also taken for CO₂ analysis after the absorption and desorption sequence.

Results for AMP, AMP+MMEA and MEA

Figure 1 illustrates the reaction rate vs. concentration of CO₂ of 5 M (30% solution) of MEA compared to solutions of 2 M AMP, 2M AMP+2M MMEA, 2M AMP 1M MMEA, 3M AMP + 1M MMEA and 3M AMP + 2M MMEA.

From figure 1 it is seen that two of the solvents have comparable reaction rates and capacity compared to 5M MEA, the 3M AMP + 2M MMEA, and 2M AMP + 2M MMEA. They were quite similar, and since 3 M AMP is close to the upper concentration limit where, based on earlier experience, solid formation may occur, it was decided to use the 2M AMP + 2M MMEA and the a slightly more concentrated 2.5M AMP + 2.5M MMEA for further testing.

Results for MEA and AMP+MEA

Figures 2 illustrate the results for absorption rate vs. loading and absorption rate vs. concentration, respectively, for 30% MEA and different combinations of AMP and MEA. The highest absorption rate is measured for 30% MEA when the comparison is made on a CO₂ loading basis. However, when the total amine concentration is increased by adding 20% AMP to 30% MEA, the absorption capacity is increased from 2.5 mole/l to 3.5 mole/l when the feed gas contains 10 vol% CO₂ (as shown in Figure 3). It must be noted that the loading for all mixtures are limited to about 0.5 mole CO₂/mole amine even though AMP forms bicarbonate due to the low inlet CO₂ partial pressure

Figures 3 and 4 show desorption rate vs. loading and desorption rate vs. concentration, respectively, for the 5 different MEA/AMP mixtures compared with 30% MEA. The stripping curves indicate the achievable net CO₂ absorption capacity (rich-lean CO₂ concentration) for the tested solvent. The mixture 20% AMP + 30% MEA and 25% AMP + 25% MEA seem to be promising alternatives as the net CO₂ capacities are higher than for 30% MEA. Also the mixture 30% AMP + 20% MEA shows to be promising.

Mass transfer

To evaluate the potential of the tested solvents, the net CO₂ capacity (rich-lean CO₂ concentration) are compared with the absorption rate at lean loading resulting from the desorption screening experiments. The results for tests of promising combinations of AMP + MEA are shown in Figure 5.

The highest absorption rate is measured for 30% MEA when the comparison is made on a net CO₂ loading basis. However, when the total amine concentration is increased by adding AMP to MEA, the net absorption capacity is increased from 1.38 mole CO₂/l (30% MEA) to 1.73-2.18 CO₂/l for the AMP/MEA mixtures. This is a favorable and important factor to reduce the heat requirement and pump duty. The absorption rate is reduced by about 10% compared with 30% MEA, but is at the same level for all the AMP/MEA mixtures. It must be noted that the loading for all mixtures are close to about 0.5 mole CO₂/mole amine even though

AMP forms bicarbonate. This is according with theory for MEA, while sterically hindered AMP might be loaded to a higher level depending on the CO₂ partial pressure.

5 Estimation of energy requirements based on equilibrium data.

The chemical equilibrium between the CO₂ in the gas phase and the reacting aqueous amine solution is essential in all types of absorption/desorption process calculations. Consequently it is very important to provide good experimental data as basis for equilibrium models for all the potential amine blends.

10

The equilibrium data for 30 wt% MEA and the solution 2.5M AMP and 2.5M MMEA were measured at temperatures of 40, 60, 80, 100 and 120°C. These data were used to obtain an equilibrium model, i.e. a model that calculates the partial pressure of CO₂ as a function of loading and temperature. As an example
15 the data for 30wt% MEA is shown in Figure 6 along with the model.

The models for 30wt% MEA and 2.5M AMP and 2.5M MMEA were then used in a simplified calculation of the heat requirements for the desorber. By considering the energy balance over the desorber the total specific reboiler duty in terms of
20 kJ/mol CO₂ can be divided into three terms:

1. Heat of desorption

$$Q_{des} = -\Delta H_{abs} \quad (1)$$

The same amount of heat generated in the absorber has to be supplied in the
25 desorber in order to reverse the reaction. Q_{des} , has the opposite value as ΔH_{abs}

The Gibbs-Helmholtz equation

$$\frac{d \ln p_{CO_2}}{d(1/T)} = \frac{\Delta H_{abs}}{R} \quad (2)$$

is applied to the equilibrium data to estimate the ΔH_{abs} for a specific loading. A mean value over the actual loading range is then used:

$$30 \quad Q_{des} = \frac{1}{\alpha_{rich} - \alpha_{lean}} \int_{\alpha_{lean}}^{\alpha_{rich}} -\Delta H_{abs}(\alpha) d\alpha \quad (3)$$

α_{rich} and α_{lean} are the rich and lean loading in terms of mol CO₂/ mol amine.

2. Sensible heat for liquid heating

Depending of the efficiency of lean/rich heat exchanger there will be a difference
 5 (typically about 10°C) between the lean solvent outlet in the bottom of the desorber and the rich solvent inlet in the top of the desorber.

$$Q_{sens} = \frac{\rho C_p \Delta T}{c_{Am} (\alpha_{rich} - \alpha_{lean})} \quad (4)$$

10 In Eq. (4) the sensible heat is proportional to ΔT , and inversely proportional to the cyclic capacity, the number of moles of CO₂ per litre which is transported by the circulating liquid. defined as $c_{Am} (\alpha_{rich} - \alpha_{lean})$.

3. Minimum steam for stripping

15 The steam used for stripping will be provided by the reboiler. As the vapor moves upwards in the desorber some of the steam condensates because of the heating requirements for Q_{des} and Q_{sens} . In the top of the desorber there must be some minimum steam left in order to meet the equilibrium conditions.

$$20 \quad Q_{strip} = \frac{P_{H_2O}^{sat} (T_{Top, Des}) x_{H_2O}}{P_{CO_2}^* (T_{Top, Des} \alpha_{Rich})} \Delta H_{H_2O}^{vap} \quad (5)$$

$P_{H_2O}^{sat} (T_{Top, Des})$ is the vapor pressure of water at the top of the desorber, x_{H_2O} is the molfraction of water, $\Delta H_{H_2O}^{vap}$ is the enthalpy of vaporization for water, and

$P_{CO_2}^* (T_{Top, Des} \alpha_{Rich})$ is the of CO₂ pressure in the top of the desorber given by the
 25 equilibrium model.

The total steam requirement is then $Q_{tot} = Q_{des} + Q_{sens} + Q_{strip}$.

In order to calculate the three parts, near optimal values for the rich and lean loading are estimated. For rich loading we consider the conditions at the bottom
 30 of the absorber where a temperature of 40°C is assumed. α_{rich} is then set to 90%

of the equilibrium value corresponding to the partial pressure of the incoming exhaust gas. For both 30 wt% MEA and 5M AMP/MMEA this gives a rich loading of 0.44. For this rich loading, the calculations then find the lean loading which gives the minimum specific steam consumption.

5

Results summary and comparison with MEA.

Table 1. Results of the calculations.

	C_{am}	wt%	Q_{des}	Q_{strip}	Q_{sens}	Q_{tot}	Q_{rel}
	mol/l	%	MJ/kg	MJ/kg	MJ/kg	MJ/kg	1
MEA 30wt%	4.96	30.0	1.93	1.72	0.71	4.36	1.00
5M AMP-MMEA	5.00	41.2	1.92	0.85	0.44	3.22	0.74

10

The results of the calculation with a comparison with MEA are shown in Table 1. The most remarkable result is that the specific reboiler duty is only 74 % of the MEA value, i.e. a 26% improvement.

15 Although the calculations are somewhat simplified, the relative value should be quite indicative since the same procedure has been used to both solvents.

Tests on a Pilot Plant

20 Tests were performed at a pilot plant 1 as illustrated in figure 7.

Artificial exhaust gas mainly comprising nitrogen, CO₂ and water is introduced into an absorber 2 through an exhaust gas line 3. The exhaust gas is brought in countercurrent flow to an absorbent to be tested in a contact zone 4 in the absorber 2.

25

The absorbent is introduced through an absorbent line 5 at the top of the absorber, flows through the contact section and absorbs CO₂ from the exhaust gas, and is collected at the bottom of the absorber 2. The CO₂ rich absorbent collected at the bottom of the absorber is withdrawn through a rich absorbent line 30 6 and is heated in a heat exchanger 7 and a cooler 8 before the absorbent is

introduced at the top of a contact zone 9 of a regenerator 10, where the absorbent is brought in countercurrent flow to steam introduced at the bottom of the contact section 9 to strip the absorbent for CO₂.

- 5 The stripped absorbent is collected at the bottom of the regenerator 10 and withdrawn through an absorbent line 11 and introduced into a reboiler 12, heating the absorbent to produce steam that is introduced into the regenerator 10 through a steam line 13. Regenerated, or lean, absorbent is withdrawn from the reboiler 12 through a lean absorbent line 14 and is cooled against the rich
10 absorbent in the heat exchanger 7 before it is introduced into a storage and mixing tank 15.

The lean absorbent is withdrawn through line 5. The temperature of the absorbent in line 5 is controlled by a heater 17 and a cooler 18. The absorbent is
15 thereafter filtered through a coal filter 19 and a particle filter 20 before the lean absorbent is introduced at the top of the contact section of the absorber as described above.

CO₂ and steam are collected at the top of the regenerator 10 and is withdrawn
20 through a line 21. The withdrawn gas is cooled and condensed water is collected in a condenser 22. Water collected in the condenser is withdrawn through a condensate line 23 and is introduced into the reboiler, or is introduced at the top of the contact zone 9 of the regenerator 10 through a line 23'

25 Dried CO₂ is withdrawn from the condenser through a CO₂ line 24 and is recycled in the plant as CO₂ for the artificial exhaust gas as described in more detail below.

CO₂ depleted exhaust gas, here mainly nitrogen, is withdrawn from the top of the
30 absorber 2 through a line 25 by means of a pump 26 and introduced to a washing section 27 for washing of the gas with water that is introduced through a water line 28. The washing water is withdrawn from the bottom of the washing section into a water tank 29. The water in the water tank 29 is recycled to the washing section via water line 28.

The washed gas is leaving the washing section through a line 30, into which CO₂ from the CO₂ line 24 is mixed to make up the artificial exhaust gas. The artificial exhaust gas is heated in a heater 31 before it is introduced into the absorber.

5

Different sampling lines S1 to S6 is provided to take gas or liquid samples for analysis. The sampling point S1 is arranged to withdraw samples for testing the gas in line 3, sampling point S2 is arranged to withdraw liquid from line 6, sampling point S3 is arranged to withdraw gas from line 25, sampling point S4 is arranged to withdraw liquid from line 11, sampling point S5 is arranged to withdraw liquid from line 14, and sampling point S6 is arranged to withdraw liquid from the tank 15.

10

Pilot plant tests

15

1. Estimation of necessary absorber height

A first test campaign of 18 runs using the pilot plant as described above using the 2 M AMP + 2 M MMEA solvent was performed.

20 The pilot absorber only has 4.3 meter of structured packing, and consequently a capture efficiency of 90 % can not be tested directly. The tests were performed such that the upper part of a full size CO₂ column was tested first. The main operational parameter was to have a CO₂-content out from the absorber near 0.4 vol-% (90 % recovery). The lean loading of the liquid and the temperature in the absorber were varied.

25

Then the loading of the liquid was increased, and the middle part of a full scale absorber was tested with lean loading around 0.28 mol CO₂ /mol amine. Finally the lower part of a full scale absorber was tested with an amount of CO₂ entering the absorber around 4 vol-%.

30

Five liquid samples were taken at every experimental point and analyzed as shown in table 2. These samples were liquid in and out of absorber, liquid in and out of stripper and liquid out from the reboiler.

In Figure 8a and b loading and gas inlet concentration of CO₂, respectively, for different runs are depicted.

5

Using the data from the run 2, 11, 17 which have the same liquid flow and almost the same gas flow (run 2 has 3.5% higher gas flow than 11 and 17), the following results were found:

10 Table 2. Data representing the whole loading range.

	mol% CO ₂ in	mol% CO ₂ out	Lean loading	Rich loading
Run 2	1.92	0.20	0.135	0.272
Run 11	3.55	1.96	0.252	0.369
Run 17	4.42	3.37	0.352	0.434

Table 2 shows that these three runs cover the upper part (Run2) the middle part
 15 (Run 11) and the lower part (Run 17). There are only minor mismatches between the different parts (especially, the liquid temperatures for each run do not match exactly, as described below), and we see that an exhaust gas with 4.4% CO₂ (which is 10% higher than normal concentrations) will be captured down to 0.2 % CO₂ which is 95 % recovery of a normal gas of 4%.

20

On the other hand, the liquid temperature into the absorber was 40°C for all these 3 sets. This actually mimics a situation with two intercooling points, and might give a too optimistic absorption rate. Nevertheless, because the column showed more than 90% CO₂ recovery, it might be concluded that an absorber
 25 with about 14-15 meter Mellapak 250Y packing will be adequate for this solvent provided similar superficial gas flow (2.2 m/s) and liquid load (10 m³/m²h).

2. Estimation of specific energy requirement.

30 Four test campaigns using a) 30 wt% MEA b) 2 M AMP + 2 M MMEA, c) 2.5 M AMP + 2.5 M MMEA, and d) 25 wt% AMP + 25 wt% MEA, were thereafter performed in a modified setup of the pilot plant to better elucidate the energy requirement of the solvent. To facilitate a larger difference between rich and lean

loading in the desorber the inlet gas concentration into the absorber was increased stepwise. A range of rich loading values into the desorber could then be achieved.

- 5 In Figure 9 the runs in the most interesting rich loading range, i.e. between 0.35 and 0.55 are shown for the four different absorbents. The data show a smooth decreasing trend for increasing loading. For 2.5M AMP + 2.5M MMEA and for 30 % by weight MEA, a second order polynomial was fitted to the data, which is shown as lines in the figure.

10

The results show that the improvement of using 2.5M AMP + 2.5M MMEA is 23 – 26 % compared to 30wt% MEA. The results for 25 % by weight AMP + 25 % by weight MEA seems to be very close to the results for 2.5M AMP + 2.5M MMEA.

15

Summary of the pilot test campaigns

From the AMP-MMEA campaigns the main focus was to determine the operational performance of this new solvent blend in comparison to MEA

- 20 The pilot plant runs show that an absorber with 14-15 meter Mellapak 250Y packing will be sufficient to attain 90% CO₂ recovery with the AMP-MMEA solvent. This was shown using a superficial gas flow (2.2 m/s) and liquid load of (10 m³/m²/h). This means that the kinetics is only slightly slower than for MEA.

- 25 It is shown that the rich loading attainable (can be seen both from equilibrium data as well as pilot results) is about the same as for MEA.

Few operational problems were observed. Foaming was only observed at very high superficial gas velocities.

30

The solvent is promising with a strong indication of a lower energy requirement compared to MEA. An improvement up to 26% has been demonstrated. This is very similar to the calculations in Table 1 and confirms very well the potential of the new solvents.

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Kohl, A., Nielsen, R., 1997. "Gas Purification", Gulf Publishing Company, Houston, Texas.

10 Sartori, G., Savage, D.W. (1983), "Sterically hindered amines for CO₂ removal from gases", Ind. Eng. Chem. Fundam., Vol 22, No 2.

Patent claims

1.

An aqueous CO₂ absorbent comprising a combination of a sterically hindered amine and a monoalkanolamine, wherein the concentration of the sterically hindered amine is from 10 to 35 % by weight and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

2.

The CO₂ absorbent according to claim 1, wherein the sterically hindered amine is 2-amino-2-methyl-1-propanol (AMP).

3.

The CO₂ absorbent according to claim 1 or 2, wherein the monoalkanolamine is methylmonoethanolamine (MMEA) or monoethanolamine (MEA).

4.

The CO₂ absorbent according to one or more of the preceding claims, wherein the concentration of the sterically hindered amine is from 10 to 35 % by weight, and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

5.

A process for removing CO₂ from a CO₂-containing gas, comprising the step of bringing the CO₂-containing gas in contact with an aqueous solution of a sterically hindered amine and a monoalkanolamine, where the concentration of the sterically hindered amine is from 10 to 35 % by weight and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

6.

The process according to claim 5, wherein the sterically hindered amine is 2-amino-2-methyl-1-propanol (AMP).

7.

The process of claim 5 or 6, wherein the monoalkanolamine is methylmonoethanolamine (MMEA) or monoethanolamine (MEA).

5 8.

The process according to one or more of the claims 5 to 7, wherein the concentration of the sterically hindered amine is from 10 to 35 % by weight, and the concentration of the monoalkanolamine is from 10 to 35 % by weight.

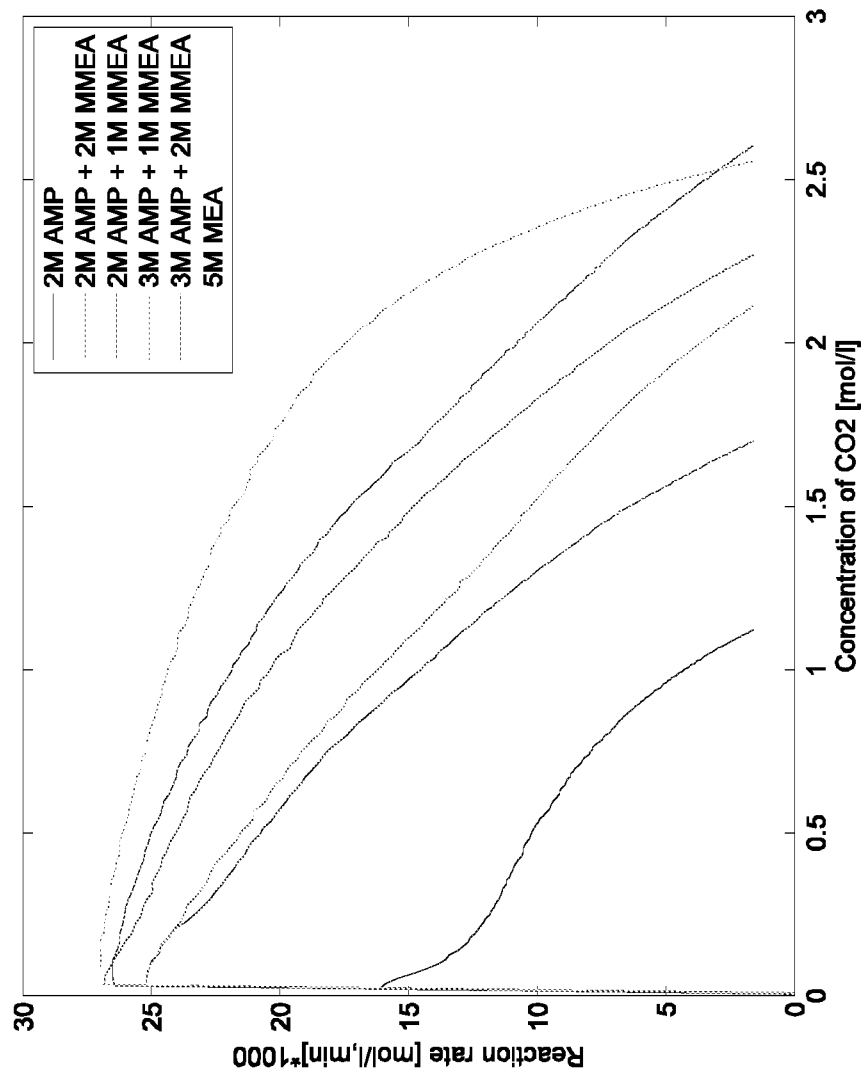


Fig. 1

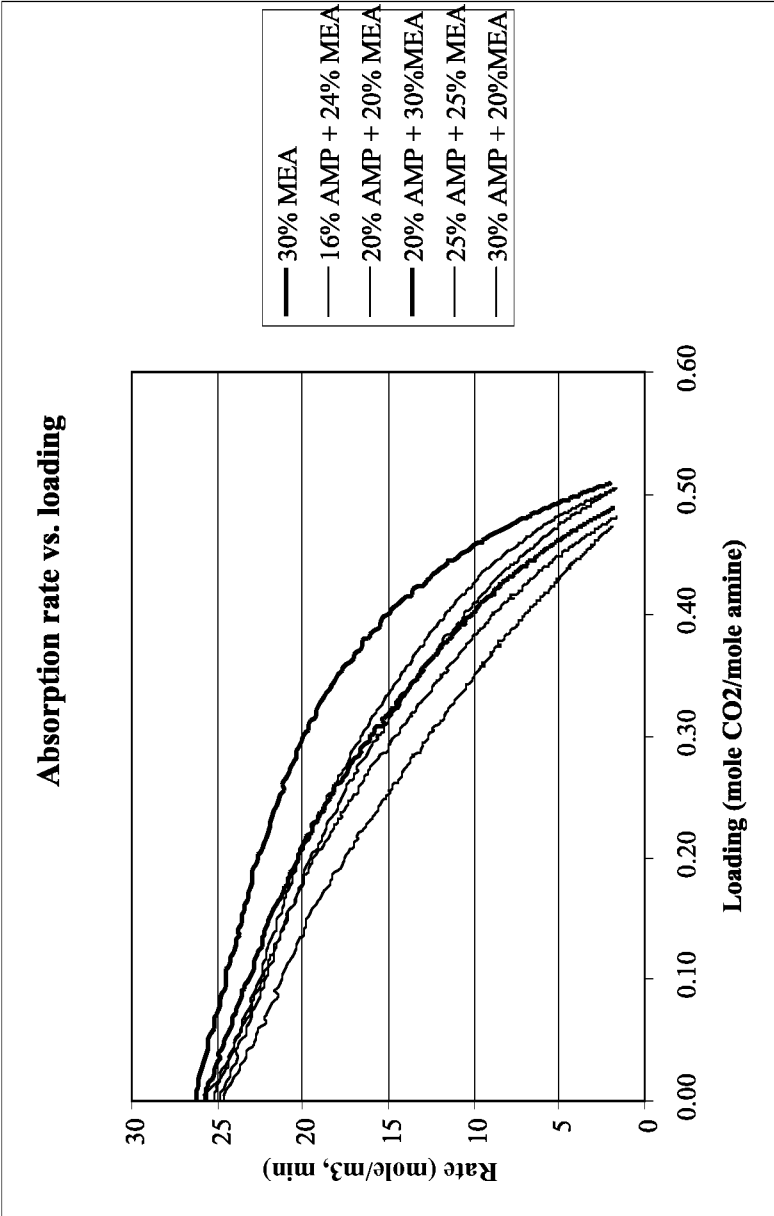


Fig. 2

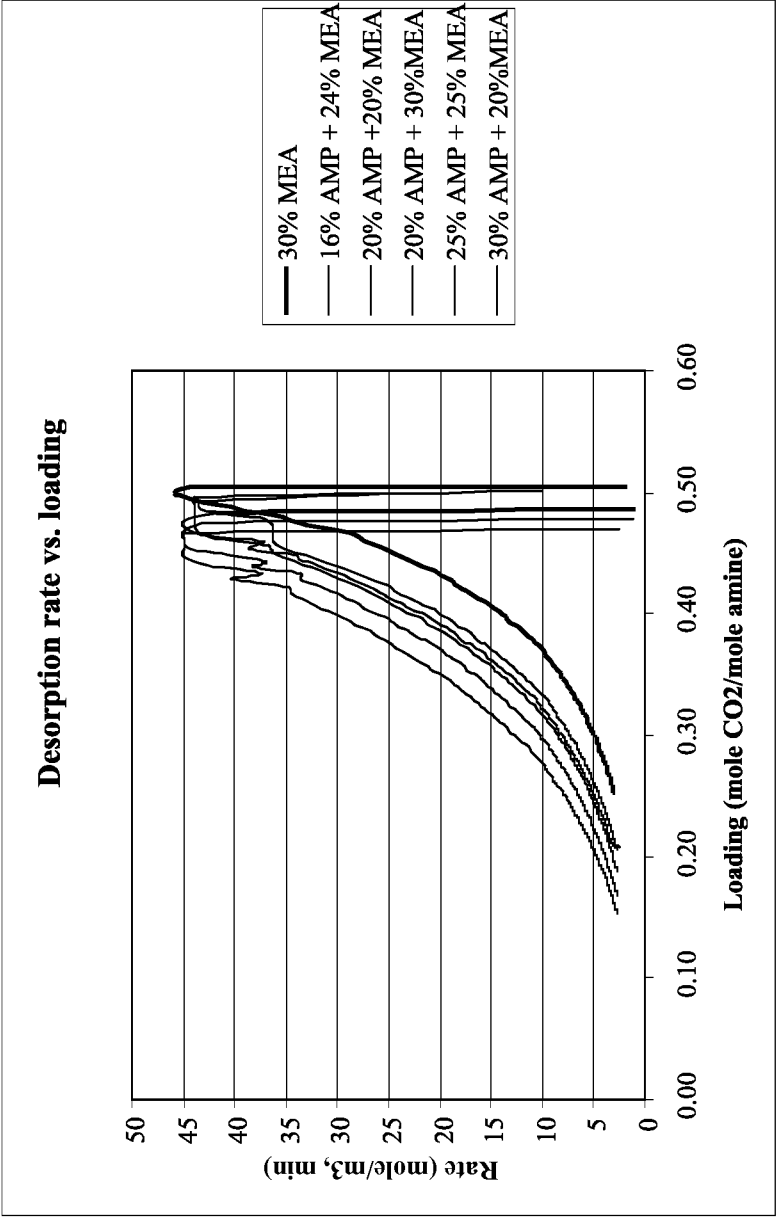


Fig. 3

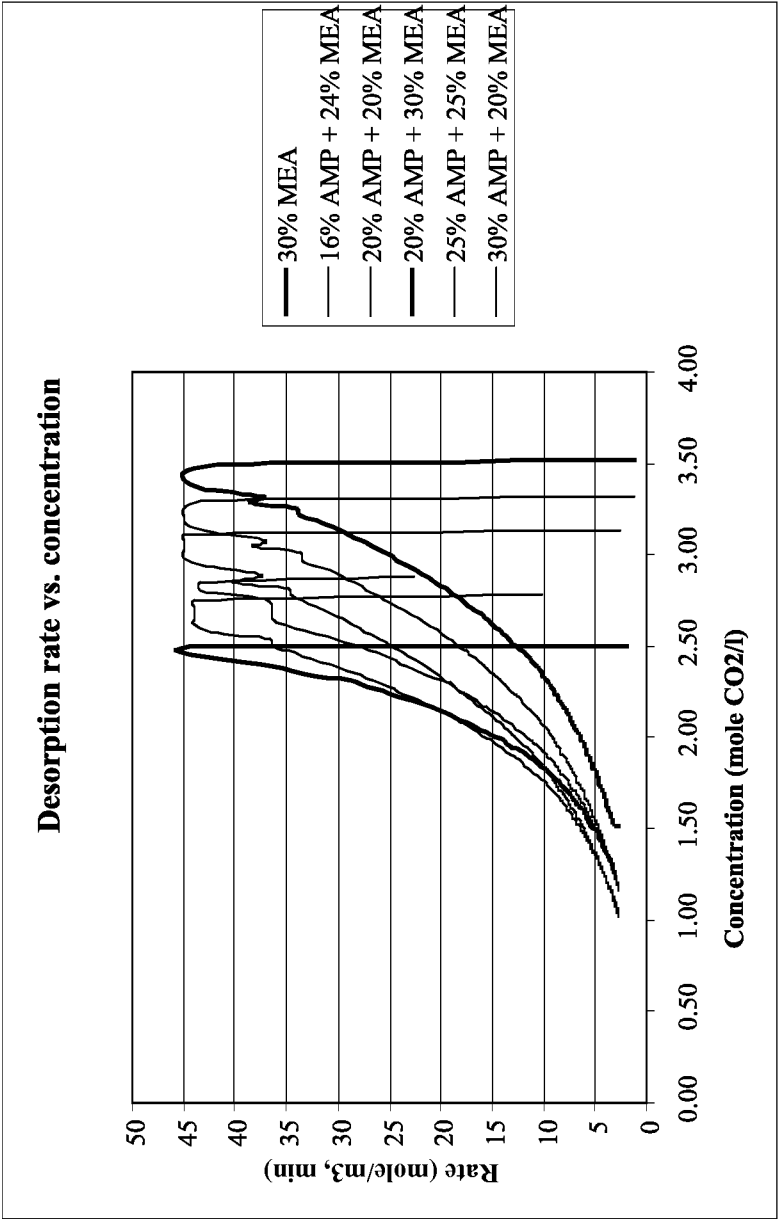
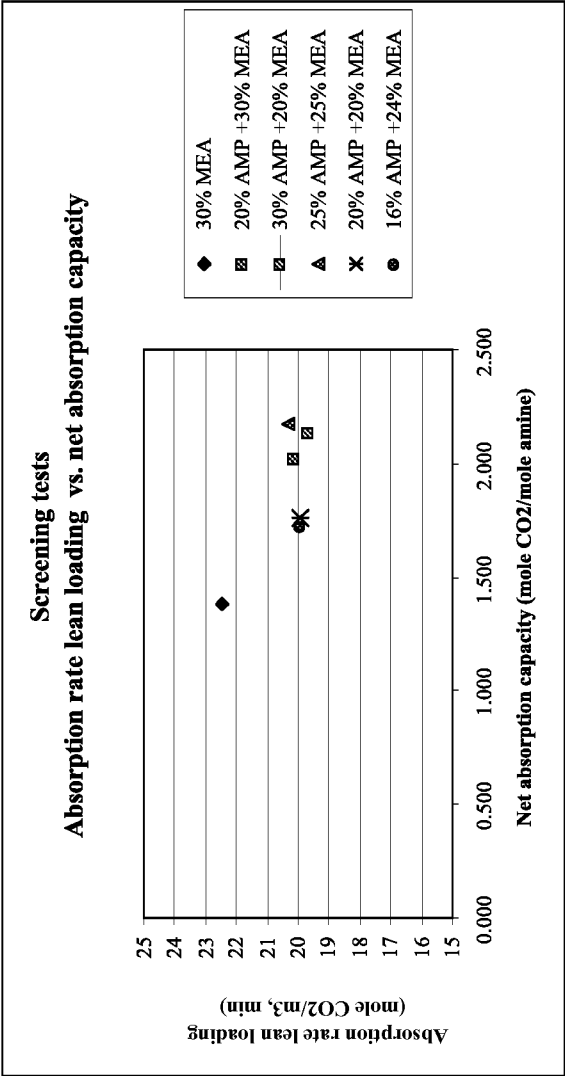
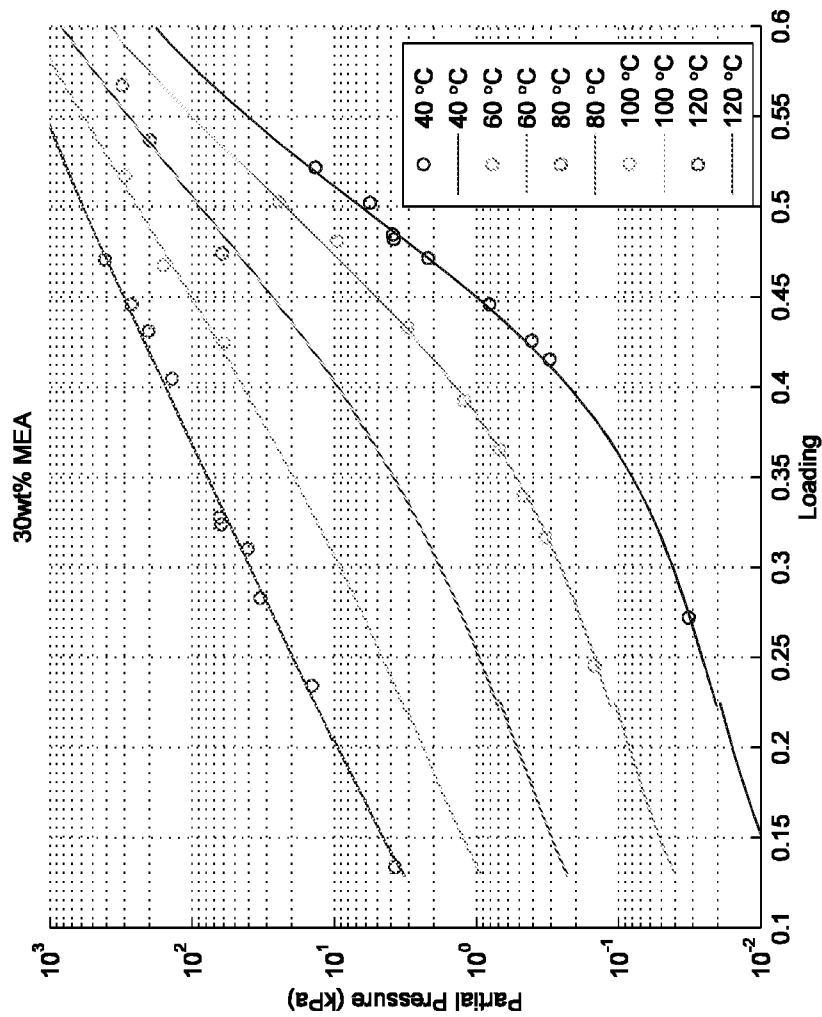


Fig. 4



Absorption rate in lean loading vs. net absorption capacity loading basis

Fig. 5



Equilibrium data (circle) and the fitted model (line) for 30wt% MEA
Temperatures from 40 °C (bottom line) to 120 °C (upper line).

Fig. 6

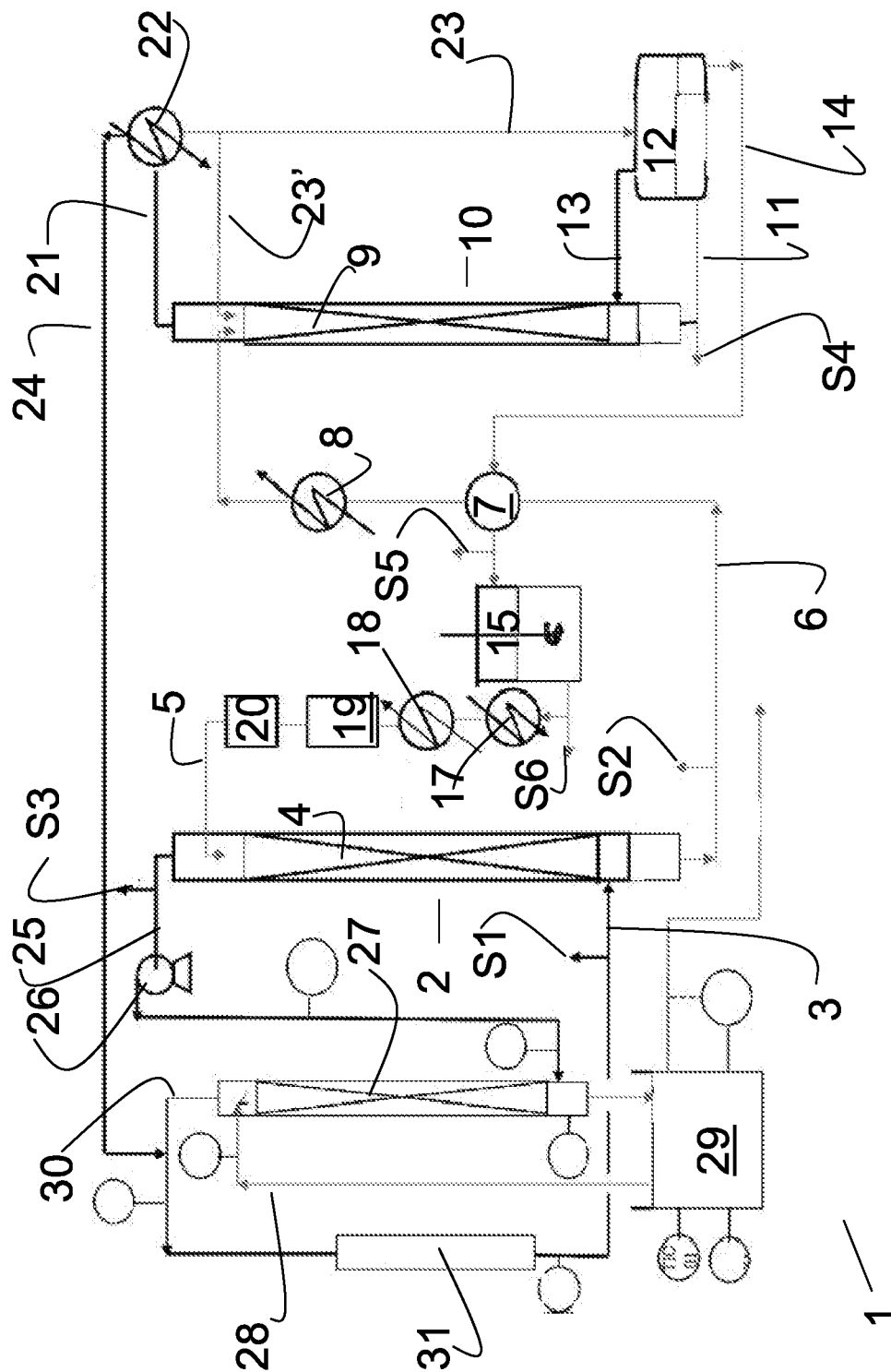


Fig. 7

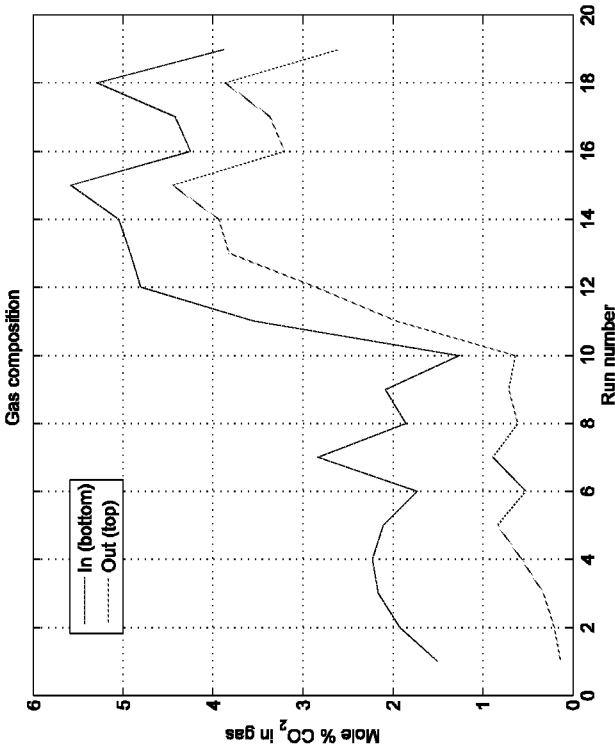


Fig. 8b

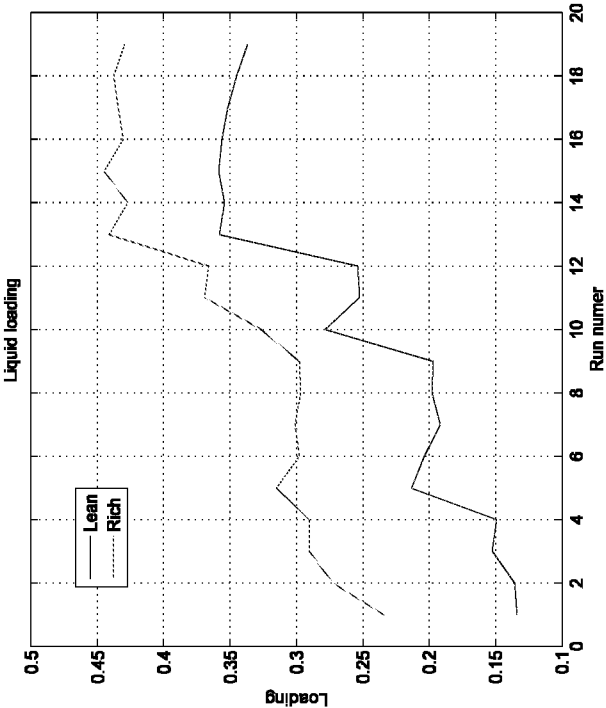


Fig. 8a

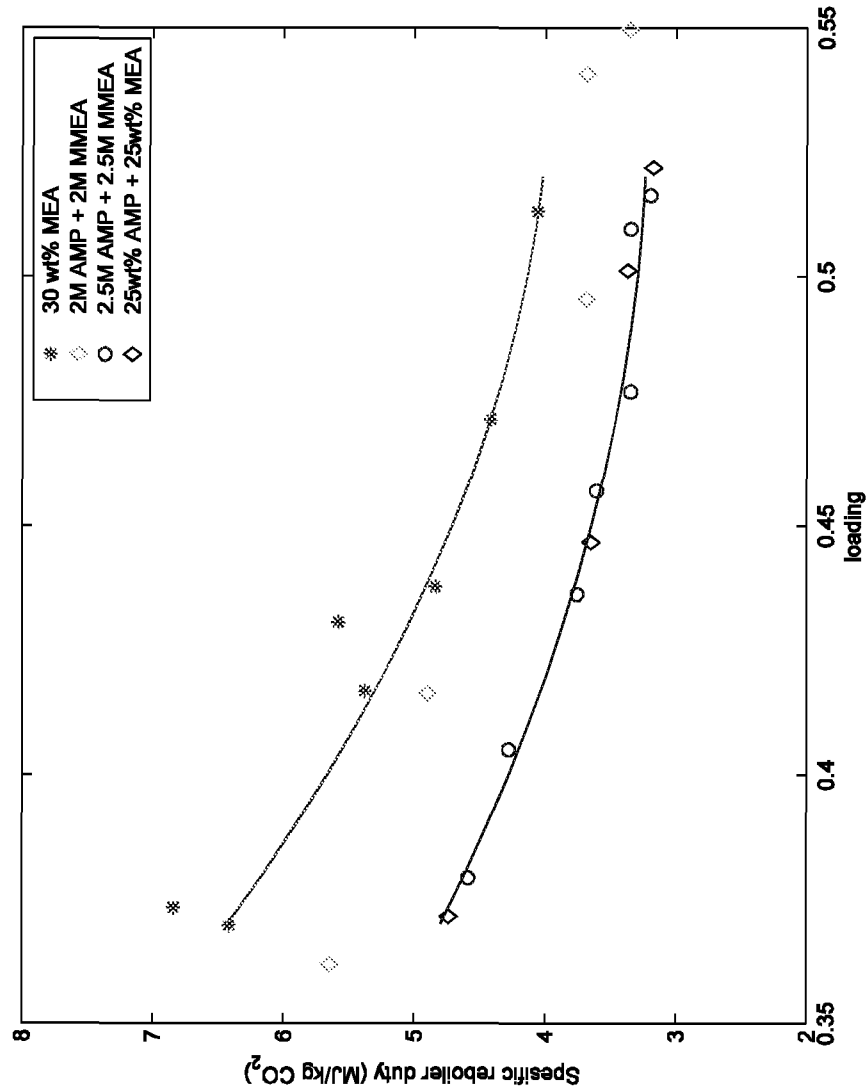


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2009/062776

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01D53/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ANINDO DEY ET AL: "Carbon Dioxide Absorption Characteristics of Blended Monoethanolamine and 2-Amino-2-methyl-1-propanol" EIC CLIMATE CHANGE TECHNOLOGY, 2006 IEEE, IEEE, PI, 1 May 2006 (2006-05-01), pages 1-5, XP031005176 ISBN: 978-1-4244-0218-2 page 2, column 1, paragraph 2 page 2, column 2, paragraph 1; figures 1-7 ----- -/--	1-8

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

15 December 2009

Date of mailing of the international search report

05/01/2010

Name and mailing address of the ISA/

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Persichini, Carlo

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2009/062776

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SAKWATTANAPONG ET AL: "Behaviour of reboiler heat duty for CO2 capture plants using regenerable single and blended alkanolamines" INDUSTRIAL AND ENGINEERING CHEMISTRY RESEARCH, vol. 44, no. 12, 8 June 2005 (2005-06-08), pages 4465-4473, XP002560572 American Chemical Society US abstract; figures 1,11,13	1-8
X	JP 06 343858 A (MITSUBISHI HEAVY IND LTD) 20 December 1994 (1994-12-20) abstract	1-8
A	EP 0 558 019 A (KANSAI ELECTRIC POWER CO [JP]; MITSUBISHI HEAVY IND LTD [JP] KANSAI EL) 1 September 1993 (1993-09-01) cited in the application the whole document	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2009/062776

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
JP 6343858	A	20-12-1994	NONE	
EP 0558019	A	01-09-1993	DE 69306829 D1	06-02-1997
			DE 69306829 T2	15-05-1997
			DK 0558019 T3	14-04-1997