



“Gheorghe Asachi” Technical University of Iasi, Romania



PACKED COLUMN SIMULATION FOR CO₂ CHEMISORPTION IN ACTIVATED SOLUTIONS

Elisabeta Droniuc Hultuana¹, Lidia Favier², Lacramioara Rusu³,
Igor Cretescu^{4*}, Gabriela Ciobanu¹, Maria Harja^{1*}

¹“Gheorghe Asachi” Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Chemical Engineering Department, 73 Prof.dr.doc. Dimitrie Mangeron Blvd., 700050 Iasi, Romania

²University Rennes, Ecole Nationale Supérieure de Chimie de Rennes, CNRS, ISCR – UMR6226, F-35000 Rennes, France

³“Vasile Alecsandri” University of Bacau, Faculty of Engineering, 157 Mărășești Blvd., 600115, Bacau, Romania

⁴“Gheorghe Asachi” Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Department of Environmental Engineering and Management, 73 Prof.dr.doc. Dimitrie Mangeron Blvd., 700050 Iasi, Romania

Abstract

Apart of new equipment's development such as absorption columns with higher efficiency, for chemical industry, there is a strong need for greenhouse gases reduction in order to assure the environmental protection and, consequently, many studies regarding the purification methods of exhausted gases have been performed. There are several types of reactors used for gases purification, such as: bubbling jet reactor, combined packed and spray tower absorber, cable wet scrubber and packed column. Among these, chemisorption in packed column was considered and analysed in this paper because of its increased absorption rate achieved by adding of activators and providing a good contact between liquid and gas phases.

Using a validated model at industrial scale, the performance of a packed column under various conditions was assessed, aiming to establish the effects of several parameters as temperature, pressure, activator concentration, transformation degree, initial solution concentration, etc. on the purification process performance. Based on the obtained results, new reactors for purification of the exhausted gases generated from burning process of fossil fuels, can be designed.

Key words: activated solution, chemisorption, influence of parameters, packed column

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1. Introduction

Important chemical processes such as carbon dioxide (CO₂) capture, flue gas desulphurization, synthesis gas purification, sulphonation, carbonation, ammonization, nitric acid synthesis, chlorination, hydrogenation, etc. involve an absorption process when they are used either for treatment purposes or manufacture of new products. These processes are commonly applied in organic and inorganic industries, as well as in environmental protection but the reactor modeling still have to be extensively studied (Harja et al., 2019).

Carbon dioxide (CO₂) is considered an important greenhouse gas that influences the climate change. The global warming caused by increasing emission of carbon dioxide is one of the most serious environmental problems (Berechet et al., 2019; Cai et al., 2019; Chisalita et al., 2019; Rotaru et al., 2019). Carbon dioxide constitutes the largest segment of the greenhouse gases that contribute to global warming and climate change. CO₂ is usually used as a reference for global warming potential (Aaron and Tsouris 2005; Năstase and Șerban, 2019).

Emissions of CO₂ result from waste incinerations, burning fossil fuel and wood, industrial

* Author to whom all correspondence should be addressed: e-mail: icre@tuiasi.ro; mharja@tuiasi.ro

processes such as cement, brick and glass manufacture, metallurgical plant, human activities etc. (EPA, 2019). Global emissions of carbon dioxide increased with an average of 2.0% per year. Based on estimation done by International Energy Agency (IEA), the global CO₂ emission has increased from approximately 21,000 Mt in 1990 to 28,000 Mt in 2006 (IEA, 2019). The CO₂ emission rate resulting from only fuel combustion was 32,000 Mt in 2014 and is predicted that this amount will be double in the next 50 years). Carbon dioxide resulted through burning of fossil fuel in thermoelectric plant, constitutes nearly 80% of the amount of all CO₂ discharged. This is the reason why the environmental effects of carbon dioxide are of great concern worldwide. The global warming caused by increasing emission of carbon dioxide is one of the most serious environmental problems. In the last years, researchers tried hard to control and reduce the CO₂ emissions into the atmosphere. Removal of carbon dioxide from flue gases is a key measure for reducing the CO₂ emission (Aroonwilas et al., 2003; Dincă and Badea, 2019; Zeng et al., 2013).

There are different industrial processes for gas treatment including the absorption into a physical or chemical liquid phase, absorption into ionic liquids; adsorption onto solids (zeolites, molecular sieves, activated carbon); membranes separation; cryogenic separation; biological fixation; chemical conversion in other compounds, etc. (Akinola et al., 2019a; Cowan et al., 2011; Harja, 1999; Yildirim et al., 2012). Among them, the absorption is the process recommended for removal of acidic contaminants, especially for removal of CO₂ from flue gases as a result of the fact that the solution can be regenerated with recovery of CO₂, or capitalization of final compounds as new products.

The absorption accompanied by chemical reaction (chemisorption) can be considered as a viable method for reducing CO₂ emission from exhaust gases. Chemically reactive solvents have to exhibit higher absorption capacity and higher mass transfer rates (Devries, 2014).

The possibilities to recover the reaction products, the financial investments (solvent, activators and equipment cost), CO₂ capitalization in other industrial area, energy requirements for regeneration process are the most important factors, decisive in selecting process (Fărnuș and Harja, 2017). The most widely used chemical solvents employed for removal of acid gases (CO₂, H₂S and COS) are:

- potassium carbonate solution with addition of amines (Hagiu and Harja, 1997; Harja et al., 2018; Hultuana et al., 2018; Ramazani et al., 2016),
- aqueous solution of amines such as: monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), monoethylenediamine (MDEA), piperazine (PZ), diisopropanolamine (DIPA) etc. (Akinola et al., 2019b; Das et al., 2017; Ma'mun and Svendsen, 2018),
- ammonia solution with different additives (Zeng et al., 2013).

The potassium carbonate solutions promoted by amines was investigated by several research groups for implementation of new amines as additives for CO₂ absorption (Hu et al., 2017; Khan et al., 2017; Sivtsova et al., 2017). The promoted potassium carbonate solution at a temperature of 70-80°C has several advantage over an aqueous solution of amines consisting in lower cost, better suitability for regeneration process, no toxicity, noncorrosive behavior etc. (Behr et al., 2011; Harja and Siminiceanu, 2000; Qin et al., 2016). On the other hand, it presents also disadvantages, such as: low CO₂ loading capacity, high equipment corrosion, degradation of amines by SO₂, NO₂, HCl and O₂ from the flue gas, high energy consumption for regeneration, toxicity, negative impact over environment etc. (Tay et al., 2017).

The ammonia solution can be an alternative absorbent for removing CO₂ from flue gas, because it has high absorption capacity and fast absorption rate. Moreover, the salts formed from reaction with CO₂ can be used as liquid fertilizer. Aqueous ammonia is not easy to be degraded and the solution does not have a corrosion related problem. However, the process has disadvantages considering that the: temperature in absorber must be lower than 60°C in order to prevent decomposition of ammonium bicarbonate, fact that involves a supplementary cooling process. Other disadvantages are the high volatility and ammonia presence into the outlet gas (Tan et al., 2012).

There are several types of reactors for flue gas treatment as: bubbling jet, spray tower, cable bundle wet scrubber, packed column, perforated plates etc. (Altway et al., 2015; Petrescu and Harja, 2006; Xu et al., 2000; Yasari, 2017). Packed column is taken for analysis within this work, due to its increased absorption rate, as well as to the fact that it provides a good contact with liquid and gas phases.

In this paper the performance of a packed column (reactor) was assessed experimentally under various conditions aiming at finding the effects of process parameters, including temperature, pressure, activator concentration, decarbonation degree, concentration of potassium carbonate on the absorption efficiency for CO₂ capture. The data obtained can be used successfully for the design of industrial CO₂ capture reactors when low temperature and pressure conditions are used in order to ensure energy savings.

2. Data for simulation

The simulation is performed in order to determine the operating conditions of the column that would result in high productivity at low prices. For this purpose, the influence of the main parameters of the process was studied, including: temperature, pressure, amine concentration, initial solution concentration, degree of regeneration, etc. The absorption is carried out in a solution of K₂CO₃ and KHCO₃. The initial solution used within the studied process, has the following composition: 25-28%

K₂CO₃, 4-7% K KHCO₃, 1.9% DEA and 0.4% V₂O₅ at the inlet of the column, the combustion gases contain 20% CO₂ (Harja and Siminceanu, 2000).

The quantitative criterion considered was the CO₂ fraction at the outlet of the absorption column. A low CO₂ content at the column outlet involves an advanced purification of the combustion gases. Also extreme cases, impossible to be carried out in practice have been considered for the process simulation, including the use of all possible compositions for the regenerated solution, absorption in totally regenerated solutions etc. (Harja, 1999; Harja et al., 2019; Koronaki et al., 2015).

The mathematical model of the packed column consists of Eqs. (1 - 7) and was broadly described and validated in a previous work (Harja et al., 2019).

The data required for the simulation were obtained for an industrial column used in the ammonia industry (Bui et al., 2014; Choi et al., 2017; Harja et al., 2019; Wang et al., 2005). The simulation of the column aims at identifying the parameters that influence the process.

$$\frac{dy_{CO_2}}{dz} = -\frac{1}{n_A} v_{CO_2} AS_v \quad (1)$$

$$\frac{dy_{H_2O}}{dz} = -\frac{1}{n_A} (\pm N_{H_2O}) AS_v \quad (2)$$

$$\frac{d\dot{n}_g}{dz} = n_A \left(\frac{dy_{CO_2}}{dz} + \frac{dy_{H_2O}}{dz} \right) \quad (3)$$

$$\frac{d\dot{n}_L}{dz} = \frac{M_L}{M_g} \left(\frac{d\dot{n}_g}{dz} \right) \quad (4)$$

$$\frac{dC_{Cb}}{dz} = \frac{\rho_L}{M_L \dot{n}_L} \left(-\frac{M_L}{\rho_L} C_{Cb} \frac{d\dot{n}_L}{dz} + v_{CO_2} AS_v \right) \quad (5)$$

$$\frac{dC_{Bc}}{dz} = \frac{\rho_L}{M_L \dot{n}_L} \left(-\frac{M_L}{\rho_L} C_{Cb} \frac{d\dot{n}_L}{dz} + 2v_{CO_2} AS_v \right) \quad (6)$$

$$M_g = \frac{8.6 + 44 \cdot y_{CO_2} + 18 \cdot y_{H_2O}}{1 + y_{CO_2} + y_{H_2O}} \quad (7)$$

The data required for the simulation were obtained for an industrial column used in the ammonia industry (Bui et al., 2014; Choi et al., 2017; Harja et al., 2019; Wang et al., 2005). The simulation of the column aims at identifying the parameters that influence the process.

3. Results and discussions

The mathematical model of the packed column with counter flow phase circulation under isobar-

isothermal conditions, with a 4% error, has been considered for the simulation of the process (Harja et al., 2019; Harja et al., 2008; Petrescu et al., 1998).

3.1. Influence of temperature

Temperature is an important parameter in the CO₂ absorption process. The parameters used in process modeling, whose values vary with the temperature are: potassium bicarbonate solubility, Henry's constant, interface concentration, hydroxyl ion content, reaction rate constants, CO₂ diffusion coefficient through liquid phase, transfer mass partial coefficients, density and viscosity of the liquid phase (Harja et al., 2008; Todinca et al., 2007). Considering that the temperature has an important effect upon the process, the influence of the temperature on the absorption rate of carbon dioxide in water, in potassium carbonate-bicarbonate solutions as well as in potassium carbonate-bicarbonate solutions activated with DEA has been investigated first. The temperature range studied was 273-373 K.

Fig. 1 shows the variation of the carbon dioxide absorption rate with temperature.

The temperature exponentially influences the rate of carbon dioxide absorption, as shown in Fig. 1. At the same time, it is obviously that the rate is strongly enhanced by adding the activator. Curves 1 and 2 of Fig. 1 correspond to an initial solution with the following composition: $C_{K_2CO_3} = 2.50$ mol/L and $C_{KHCO_3} = 1.38$ mol/L. The absorption rate at 350 K is nearly 10 folds higher in activated carbonate solutions compared to inactivated ones.

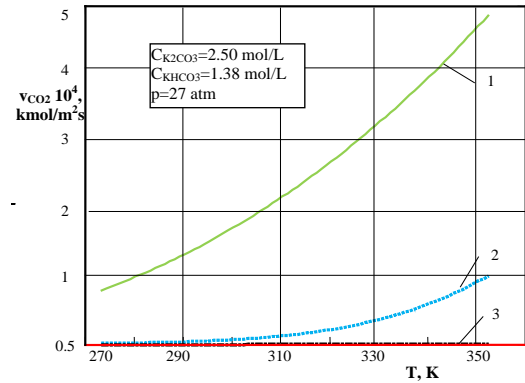


Fig. 1. The influence of temperature on CO₂ absorption rate: 1- $C_{DEA}=0.01818$ mol/L; 2 - $C_{DEA}=0$ mol/L; 3 - distilled water

In Fig. 2, the variation of the carbon dioxide fraction in gas, as function of the temperature is presented

For simulation, three temperatures, ranged between 353 and 373 K, were considered. The calculation was performed for the composition corresponding to the semi-generated solution. By increasing the temperature from 368 K to 378 K, the CO₂ fraction of 0.0084 in the gas phase at the column outlet, was obtained for a packing material height of

16 m. For these reasons, it is advisable to work at temperatures above 370 K avoiding thus, an advanced evaporation of the solvent. This is an advantage of the method since the combustion gas exhibits temperatures above 373 K after the economizer, thus saving energy also in the removal stage.

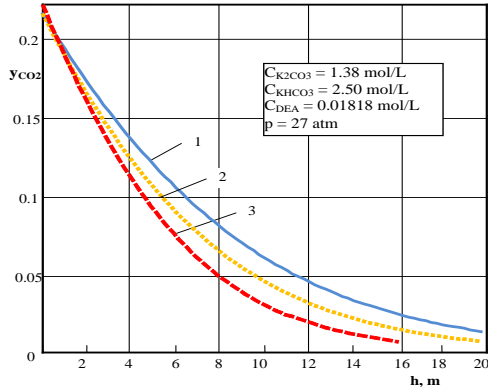


Fig. 2. The influence of temperature on CO₂, fraction profile: 1- 353 K, 2 - 368 K, 3 - 378 K

3.2. Influence of pressure

The pressure directly influences the absorption process rate. Increasing the pressure leads to an increase in the driving force of the process. The pressure values studied were ranged between 15 and 80 atm (Isa et al., 2016). According to Fig. 3, increase of absorption process rate with the pressure is higher at increased temperatures.

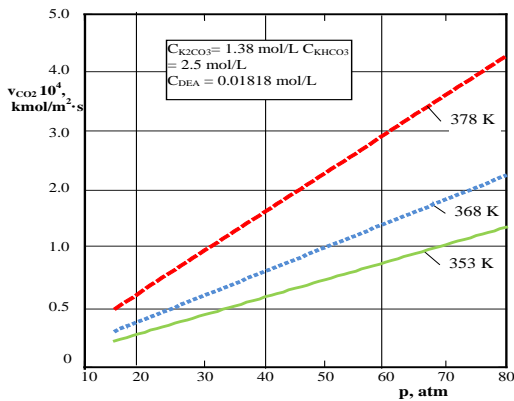


Fig. 3. The influence of pressure on the CO₂ absorption rate

By increasing the pressure from 20 atm to 80 atm, at a temperature of 378 K, the absorption process rate increases more than eight fold. The fact that the pressure has a strong positive influence on the absorption process suggests the necessity to increase the working pressure. However, the increasing of pressure lead to additional costs for process operation, and therefore an optimum should be established in order to assure a medium rate of the absorption process, corresponding to a reasonable operation costs. Fig. 4 depicts the variation of the CO₂ fraction from the gas phase with the pressure. The analysis was

performed for pressures ranged between 15 atm and 40 atm.

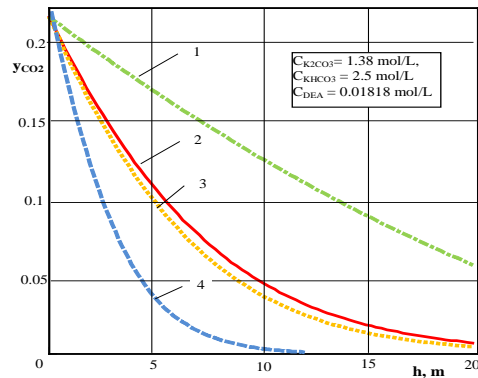


Fig. 4. The variation in y_{CO2} with the pressure: 1 - 15 atm, 2 - 27 atm, 3 - 30 atm, 4 - 40 atm

It has been found that, when pressure increases, the concentration of carbon dioxide in the column gas phase decreases more rapidly, as shown in Fig. 4, so that the volume of packing material required for reaching the same final concentration is much lower. By increasing the pressure from 30 atm to 40 atm, the height of the packing material necessary to achieve the same quality of the gas phase is lower. Although the increase in pressure results in a positive influence, there is no question of increasing the pressure over the value of the boiler, due to economic and safety related reasons. Working at constant pressure leads to energetic and financial savings.

3.3. Influence of amine concentration

As shown in Fig. 1, by adding the activator, the reaction rate increases with a factor depending on the amount of activator. Simulations for amine concentrations (DEA) ranging from 0.01818 mol/L to 0.025 mol/L were performed. In Fig. 5, the variation in the absorption rate with the amine concentration at different temperatures is described. Fig. 5 shows that at 360 K, the absorption rate is 1.5 10⁻⁴ kmol/m²s K within the inactivated solution, whereas for the composition corresponding to the semi-generated solution with 0.01818 mol/L DEA, the absorption rate is 4.7 10⁻⁴ kmol/m²s, hence, three fold higher.

Fig. 6 shows the variation in the CO₂ absorption rate with amine concentration, at 355 and 367 K. The amine concentration was considered in the range 0.01-0.18 mol/L, while the composition for which the calculations were performed is that of the semi-generated solution. From Fig. 6, one may see that at an amine concentration of 0.02 mol/L, the absorption rate has a value of 5.8, 10⁻⁴ kmol/m²s, and the increase of the amine concentration to 0.1 mol/L results in an absorption rate of 12.1 10⁻⁴ kmol/m²s. Consequently, a five-fold increase in the amine concentration results in the twofold increase in the absorption rate. Since, by increasing the amine concentration above a certain limit, the absorption rate increases insignificantly, it is not feasible from

economic point of view to work with concentrations higher than 5 %.

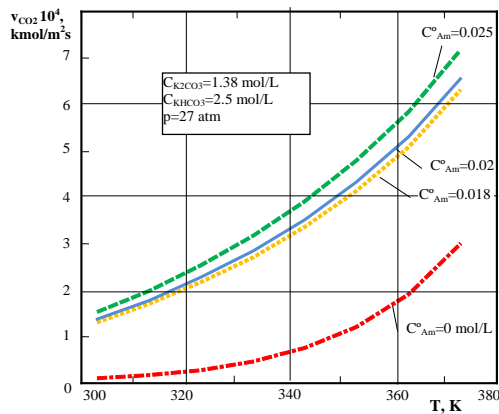


Fig. 5. Influence of amine concentration on CO₂ absorption rate

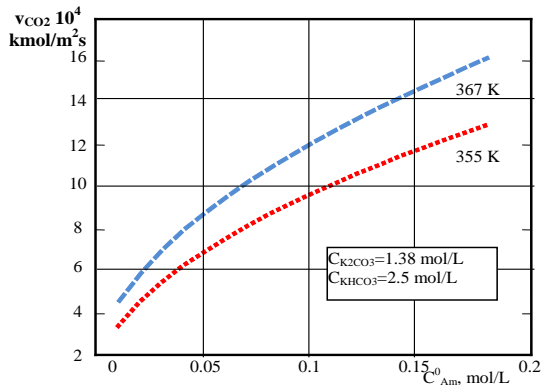


Fig. 6. The variation in CO₂ absorption rate with DEA concentration

In Fig. 7, the variation of the carbon dioxide fraction depending on the activator profile is presented. In order to describe these dependencies, amine (DEA) concentrations ranging from 1.9% to 6% (0.018-0.05 mol/L) were used for calculation.

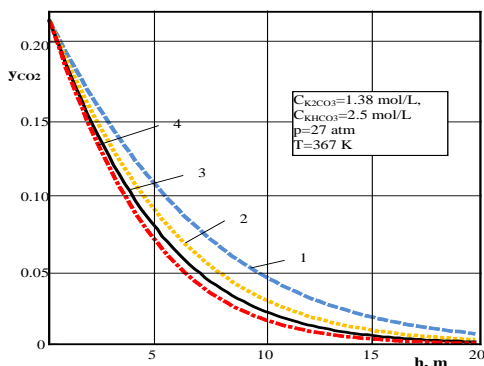


Fig. 7. Influence of amine concentration on CO₂ fraction: 1 – 0.018 mol/L; 2 – 0.03 mol/L; 3 – 0.04 mol/L; 4 – 0.05 mol/L

Increasing the concentration of the activator leads to a faster decrease of the carbon dioxide fraction

in the gas phase. However, by increasing the amine concentration from 0.04 mol/L to 0.05 mol/L, the decrease in carbon dioxide content in the gas phase is not significant. Due to this, as well as to high price and toxicity, it is not justified to increase the amine concentration above a certain limit.

The data presented in Fig. 6 and Fig. 7 leads to the conclusion that an optimal compromise is achieved by using an amine concentration of 0.05 mol/L

3.4. Influence of initial solution composition

If an increase in temperature requires high energy consumption and the pressure cannot be changed within very large limits, the composition of the liquid phase should be modified in order to obtain higher possible absorption rates (Wu et al., 2017). The composition of the initial solution has a significant influence on the CO₂ fraction in the gas phase. Fig. 8 shows the data obtained by simulating the column.

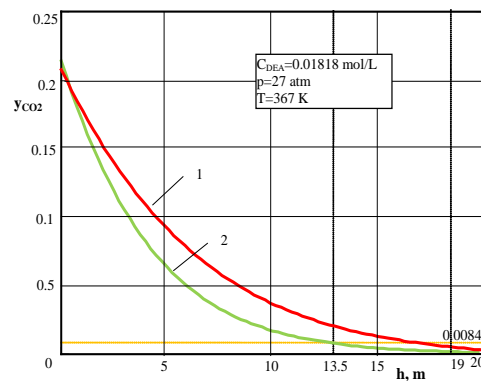


Fig. 8. The CO₂ fraction profile as function of initial solution concentration: 1 – C_{K2CO3}=1.7156, C_{KHCO3}=3.438; 2 – C_{K2CO3}=2.678, C_{KHCO3}=1.512 mol/L

Analyzing the data in Fig. 8 one may notice that, by regenerating the spent solution at the established value, the y_{CO2} fraction has the value of 0.0084 at a height of packing material equal to 5 m. The same value of the fraction, considering the actual composition, was obtained at a height of packing material of 19 m.

Since a significant influence of the initial solution composition on the carbon dioxide fraction was observed, the simulation of the packed column was performed under the conditions of several established initial solution compositions.

3.4.1. Absorption in potassium carbonate solutions

At the moment the plant started to work, the absorption column was fed with a potassium carbonate solution containing the activator in the established amount.

It has been analyzed the way how the potassium carbonate concentration in the initial solution influences the carbon dioxide fraction profile. It was considered that the initial solution had a content of 20, 25, 30, 35, and 40% K₂CO₃, whereas the content in KHCO₃ was that corresponding to

hydrolysis. The results achieved by simulation are shown in Fig. 9. Fig. 9 reveals that the increase in the potassium carbonate concentration into the initial solution does not involve the increasing in the degree of purity of the gas at the column outlet.

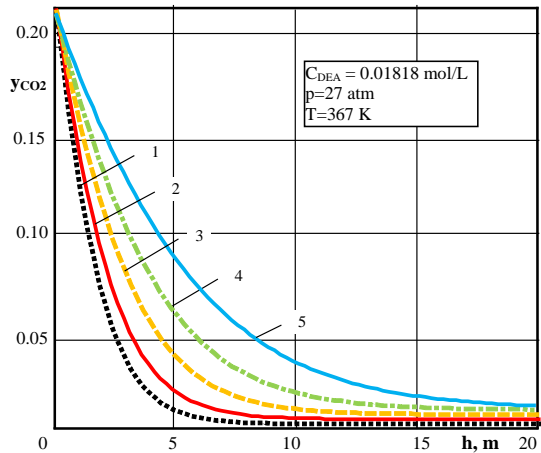


Fig. 9. The influence of potassium carbonate concentration in initial solution: 1 – 20% K_2CO_3 ; 2 – 25% K_2CO_3 ; 3 – 30% K_2CO_3 ; 4 – 35% K_2CO_3 ; 5 – 40% K_2CO_3

This can be explained by the fact that in diluted potassium carbonate solutions, the salting-out effect of potassium bicarbonate resulting from the chemical reaction does not appear very strongly. Increasing the potassium carbonate concentration in the solution has a significant influence on the Henry's constant. When working with 25% solutions at high temperatures, the negative influence of the potassium bicarbonate salting-out is avoided. Balance data analysis indicates a potassium carbonate concentration ranged between 2.3 and 2.5 mol/L. The results obtained by simulation are consistent with the equilibrium data.

3.4.2. Variable carbonate and constant bicarbonate contents

The solution used for absorption, will also contain potassium bicarbonate in amounts depending on the degree of regeneration of the spent solution, due to its recirculation. It was considered the case where the spent solution was regenerated to a potassium bicarbonate content equal to 0.64 mol/L. The concentration of potassium carbonate in the initial solution was assumed to be in the range 1.8-2.6 mol/L, while the potassium bicarbonate content was equal to 0.64 mol/L.

The variation of the carbon dioxide fraction from the gas phase along the first part of the column is shown in Fig. 10. Increasing the potassium carbonate content in the liquid phase, due to the occurrence of the salting-out, does not increase the absorption performance, as shown in Fig. 10. When the bicarbonate content was considered to be 2 mol/L, the CO_2 absorption rate was influenced by the potassium carbonate content according to the dependencies depicted in Fig. 11. The highest absorption rate was obtained for the lowest concentration in potassium

carbonate due to the above-mentioned salting-out effect. Fig. 12 shows the y_{CO_2} profile in the gas phase for the concentration of 2 mol/L $KHCO_3$.

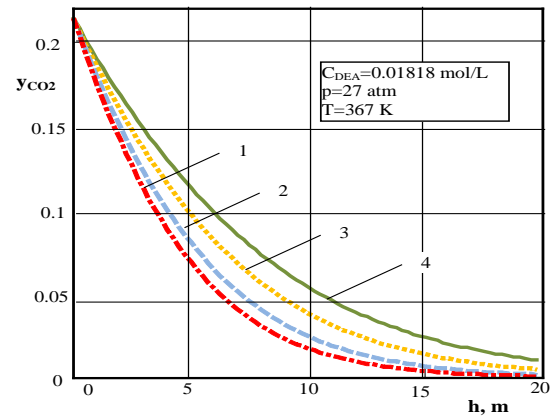


Fig. 10. The CO_2 fraction profile: 1 – 1.8 mol/L K_2CO_3 , 2 – 2.0 mol/L K_2CO_3 , 3 – 2.3 mol/L K_2CO_3 , 4 – 2.6 mol/L K_2CO_3

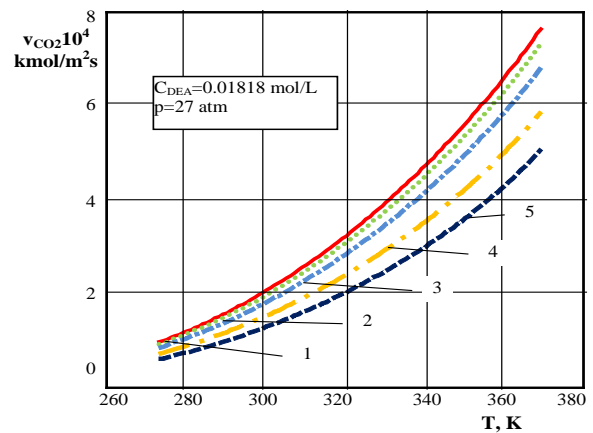


Fig. 11. The variation in the absorption rate with the initial solution concentration: 1 – 1.31 mol/L K_2CO_3 , 2 – 1.38 mol/L K_2CO_3 , 3 – 1.50 mol/L K_2CO_3 , 4 – 1.75 mol/L K_2CO_3 , 5 – 2 mol/L K_2CO_3

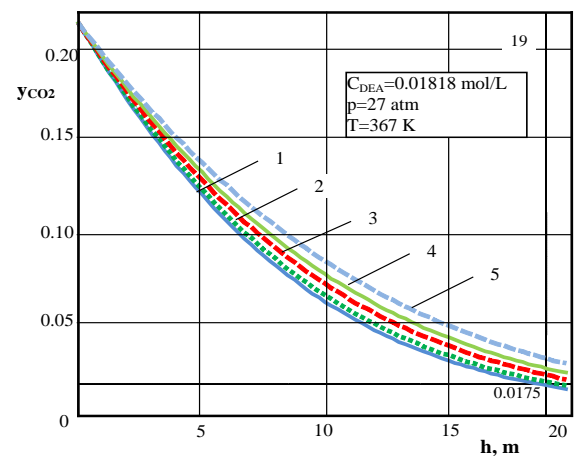


Fig. 12. The variation in CO_2 fraction for 2 mol/L $KHCO_3$ solution: 1 – 1.31 mol/L K_2CO_3 , 2 – 1.38 mol/L K_2CO_3 , 3 – 1.50 mol/L K_2CO_3 , 4 – 1.75 mol/L K_2CO_3 , 5 – 2 mol/L K_2CO_3

From Fig. 12 it is found that the carbon dioxide fraction in the gas phase is not positively influenced by the increase of the carbonate concentration in the liquid phase. Given that the potassium bicarbonate content in the liquid phase was 2 mol/L, it was observed that the gas phase at the reactor outlet, at 19 m height, had a fraction of $y_{CO_2} = 0.0175$. The calculated CO₂ fraction has a double value compared to the value of 0.0084, obtained in the previous cases.

3.4.3. Constant carbonate and variable bicarbonate contents

For potassium bicarbonate content in the range 0.18-2.5 mol/L and carbonation degrees in the range 27.2-37.5%, the potassium carbonate concentration was set to a value of 1.5 mol/L (Table 1). The y_{CO_2} variation was shown in Fig. 13.

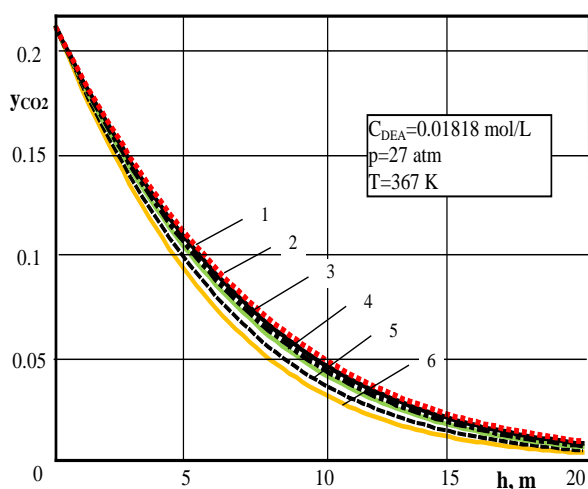


Fig. 13. The CO₂ fraction profile for K₂CO₃ constant concentrations

At the same potassium carbonate content, the increase in potassium bicarbonate concentration results in decreasing the absorption capacity of the solution. Fig.13 reveals that for a composition of $C_{K_2CO_3} = 1.5$ mol/L and $C_{KHCO_3} = 1.8$ mol/L solution, a molar fraction of carbon dioxide in the gas phase of 0.0084 was obtained at a reactor height of 18 m. If the initial solution of potassium carbonate used for the absorption exhibits a concentration of 25% (2.31 mol/L), a regeneration up to 1.5 mol / L K₂CO₃ leads to good absorption results.

The data obtained from the mathematical model of the column show that the solution should exhibit a KHCO₃ content ranged between 1.5-1.75 mol/L (max. 2 mol/L). By using these concentrations for the feed solutions, a carbon dioxide content of the gas phase at the column outlet below 0.1% is ensured.

Table 1. The corresponding concentration of absorption solutions used in different experimental conditions

	1	2	3	4	5	6
$C_{K_2CO_3}$	1.5	1.5	1.5	1.5	1.5	1.5
C_{KHCO_3}	2.5	2.4	2.3	2.2	2	1.8

4. Conclusions

The simulation presented in this paper aimed at establishing the operating conditions of a packed column. In this respect, the influence of the main parameters of the process was studied. Particular attention was paid to the establishment of concentrations in potassium carbonate, potassium bicarbonate and DEA that would lead to achieving of the desired quality for the gas phase. The influence of temperature, pressure and amine content on the CO₂ absorption rate was investigated. Given that high working pressures are not highly recommended for economic reasons, the possibilities to improve the process are related in particular to changing the temperature and composition of the initial liquid phase.

Temperature has a complex influence on absorption. At low temperatures, the solubility of potassium bicarbonate is low, fact that would lead to its crystallization. The rate of CO₂ absorption at 350 K is almost 10 times higher in activated solutions compared to inactivated ones.

Increasing pressure will increase the driving force of the process. Thus, at 378 K by increasing the pressure from 20 atm to 80 atm, an eight-fold increase in the absorption rate is observed.

By adding DEA as an activator, the reaction rate increases function of the amount added. The five-fold increase in amine concentration results in twofold increase in the rate of CO₂ absorption. Concentrations of around 5% are recommended in order to achieve the beneficial effect of increasing DEA concentration without affecting the economic aspects.

The composition of the initial solution has a significant influence on the CO₂ fraction profile in the final gas phase. The increase in the potassium carbonate concentration in the initial solution does not involve the increase in the degree of purity of the gas at the column outlet. This owe to fact that in the potassium carbonate diluted solutions, the KHCO₃ salting-out is not very strong. In order to avoid the occurrence of solid phase, 25% potassium carbonate solutions are recommended.

The analysis of the equilibrium data indicates a liquid phase composition in potassium carbonate within the range of 2.3-2.5 mol/L, according to the results obtained by simulation; The absorption process is not improved by the increase in potassium carbonate content in the liquid phase as a result of the appearance of the salting-out effect. At the same content in K₂CO₃, the increase in concentration of the solution in KHCO₃ causes the decrease in the absorption capacity. Increasing the carbonate level of the initial solution adversely affects the CO₂ fraction in the gas phase.

The data obtained leads to the conclusion that a total regeneration of the depleted/spent solution results in an advanced purity of the gas, but this also results into high costs in the desorption process. A compromise solution is recommended in the sense of partial regeneration of the solution supplied to the

column. According to the obtained results, the semi-generated solution must have a KHCO_3 content within 1.5-1.75 mol/L (maximum 2 mol/L). The proposed column can be successfully used to absorb CO_2 from combustion gases.

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