OPTIMIZAREA UTILIZĂRII MATERIALELOR ABSORBANTE ÎN TEHNOLOGIA DE CAPTARE A CO₂ POST-COMBUSTIE AFERENTE DIFERITELOR PROCESE TEHNOLOGICE (CIMENT, STICLĂ)
OPTIMISATION OF UTILISATION OF ABSORBENT MATERIALS FOR CO₂ POST-COMBUSTION CAPTURE TECHNOLOGY FOR DIFFERENT INDUSTRIAL PROCESSES (CEMENT, GLASS)

MIHAELA NORIŞOR, EDUARD MINCIUC, ROXANA PĂTRAŞCU*, GEORGE DARIE, DIANA TUTICĂ
Universitatea POLITEHNICA Bucureşti, Splaiul Independenţei nr. 313, sector 6, Bucureşti,România

The aim of the paper consists in optimising the integration of CO₂ post-combustion capture technology using chemical absorption within the fluidised circulating coal combustion (FCCC) with direct application in glass and cement industries. The authors have performed some comparison of the effects of using primary amines (MEA) and tertiary amines (TEA) in order to reduce energy consumption of regeneration process, and, at the same time, keeping the efficiency of CO₂ capture over 85 %. The paper presents results of an experimental study using laboratory equipment for fluidised circulating coal combustion, and also simulation results of CO₂ post-combustion capture using specialised software HYSYS 3.2.

Obiectivul lucrării constă în optimizarea integrării proceselor de captare a CO₂ post-combustie prin absorbţie chimică în cadrul tehnologiei de ardere a cărbunelui în strat fluidizat circulant (ASFC) cu aplicare directă în industriile sticlei şi cimentului. Se compară efectele utilizării aminelor primare (MEA) şi terţiare (TEA), pentru reducerea consumului energetic aferent procesului de regenerare, menţinând o eficienţă de peste 85% a procesului de captare a CO₂. Lucrarea se bazează atât pe realizarea unui studiu experimental utilizând instalaţia de ardere în strat fluidizat circulant cât şi pe rezultatele obţinute în urma simulării procesului de captare a CO₂ post-combustie utilizând programul HYSYS 3.2.

Keywords: solid electrolytes, LSGM, microwave technique, IT-SOFC.

1. Introducere

Cement industry is responsible for about 5 % of total global CO_2 emissions resulted from production activities and for about 3 % of global emissions generated by human activities. The cement production process leads to generating about 0.73-0.99 kg CO_2 per kg of produced cement. CO_2 emissions of cement industry come from: fabrication process (40 %), transport (5 %) and combustion of fossil fuels for electricity used within the process (5 %). The rest of emissions (about 50 %) come from decarbonation of limestone [1 - 2].

In perspective, up to 2020 there is intended to reduce CO_2 emissions per tonne of cement with about 30 %, as shown in Table 1.

Another industrial process directly responsible for great quantities of CO_2 emissions is glass manufacture. The greatest air pollutant is represented by the melting phase of raw and auxiliary materials in glass furnaces. The pollutant emissions, generally, appear due to the following

processes: a. combustion of fossil fuels in furnaces; b. melting phase of raw and auxiliary materials in glass furnaces.

The phenomena directly responsible for CO_2 generation during the melting phase include decomposition of carbonates, such as soda and limestone [3 - 4].

From data presented in Table 2 there can be shown the importance of CO_2 emissions resulted from the combustion process used within production of two types of glass [5].

Nowadays, there are three types of solutions for reducing emissions of carbon dioxide, thus reducing Green House Gasses (GHC): partial and progressive replacement of fossil fuels with renewable energy sources and raw materials, partially or totally, with some with low or zero greenhouse gas ; increasing the efficiency of utilisation of energy resources; integration of carbon capture, transport and storage technologies within energy processes. Unfortunately, none of these solutions can entirely solve the problem of

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Tabelul 1

Technical potential for CO$_2$ emissions reduction per tonne of cement up to 2020 [2]
Potenţialul tehnic de reducere a emisiilor de CO$_2$ pe tona de ciment, până în anul 2020 [2]

Area / Domeniul îmbunătăţirii	Measure / Denumire măsura	Weight Pondere
Process emissions / Emisii de proces	Adding cements / Cimenturi cu adaos	7%
Emissions from fossil fuels combustion Emisii rezultate din arderea combustibilului	Efficiency of combustion Changing the fuel type *Eficienţa arderii Schimbarea tipului de combustibil*	11% 3%
Transport /Transport	Transport efficiency and transport using biomass *Eficienţa transportului şi transport cu biomasă*	sub 1% *under*
Power generation *Generare de electricitate*	Energy efficiency and power generation with low carbon emissions *Eficienţă energetică şi generarea de energie electrică cu emisii scăzute de carbon*	sub 1% *under*
Other / Alte reduceri	Alternative fuels / Combustibili alternativi	12%
Total	All measures / Toate măsurile	cca 30% *about*

Tabelul 2

CO$_2$ emissions for glass production / *Emisii CO$_2$ la fabricarea sticlei*

CO$_2$ emission type *Tip emisie CO$_2$*	Quantity (kg/t glass) / *Cantitate (kg/t sticlă)*	
	Household glass *Sticlă de menaj*	Optical glass *Sticlă optică*
Process emissions/ *Emisii de proces*	140	87
Combustion emissions/ *Emisii de ardere*	590	8276.6
Total emissions / *Emisii totale*	730	8363.6

reducing CO$_2$ emissions, and, thus, allowing further use fossil fuels within the sustainable development.

In both industrial process (cement and glass production) a significant quantity CO$_2$ emissions come from fossil fuel combustion used within technological processes.

In the present paper the authors have concentrated upon CO$_2$ separation stage from flue gasses resulted from coal combustion. The main objective of the paper consists in reducing energy consumption needed for regeneration process of different types of primary and tertiary amines solvents, keeping at the same time high level of efficiency of CO$_2$ capture. The energy demand of regeneration process of solvent is influenced by three factors, each of them corresponding to an endothermic process: heat demand for increasing the temperature of solvent in the desorption unit, heat demand for breaking the link between CO$_2$ and nitrogenous compounds and heat demand for water vaporisation [6].

Carbon capture and storage, (CCS) technology includes the following stages: CO$_2$ separation from flue gasses evacuated from combustion equipment and further capturing in a tank; compressing CO$_2$ up to supercritical stage so it can be transported to the storage site; and finally, CO$_2$ storage in different sites (depleted hydrocarbon deposits, artificial deposits, etc.).

It is well known that the major technical disadvantage of CO$_2$ separation process is due to high energy demand, as shown in literature references [7-10]. A feasible solution to solve this problem represents utilisation of solvents with high capacity of CO$_2$ retention from flue gasses and with low energy consumption for regeneration process;

such experiments have been successfully performed in different countries [11-13].

In [14-16] there have been shown that use of primary, secondary and tertiary amine solvents leads to significant decrease of energy consumption for regeneration process; the results of studies show that for efficiencies of CO$_2$ capture process of 80 %, 85 %, 90 % and 95 % the minimum energy consumption for regeneration process is obtained for equal mixture of methyl diethanolamine (20% MDEA) and diethanolamine (20% DEA) and water (60% H$_2$O), these being 2.3, 2.4, 2.7; and respectively 2.95 GJ/tone CO$_2$ [17 - 18].

Establishment of optimal conditions for CO$_2$ capture using chemical absorption with amines consists in mixture process and in choosing the right proportion for combining different types of amines. Thus, the optimal proportions for the maximal absorber efficiency for MDEA and DEA are: 40% MDEA with 10% DEA, 30% MDEA with 10% DEA and 40% MDEA with 5% DEA; this has also been studied in [19].

The results presented by authors have been obtained through an experimental study within fluidised circulating coal combustion (FCCC) equipment and also through a simulation study using specialised software Hysys 3.2. Utilisation of specialised simulation software has the advantage of analysing different cases that can be hardly reproduced in experimental study, as have been shown in papers, ASPEN Plus [20-22], Aspen HYSYS [23 - 24] Hysys [25], UniSim Design Suite of Honeywell [26], HYSYS 7.1 [27], ProTrea (Optimized Gas Treating) [16].
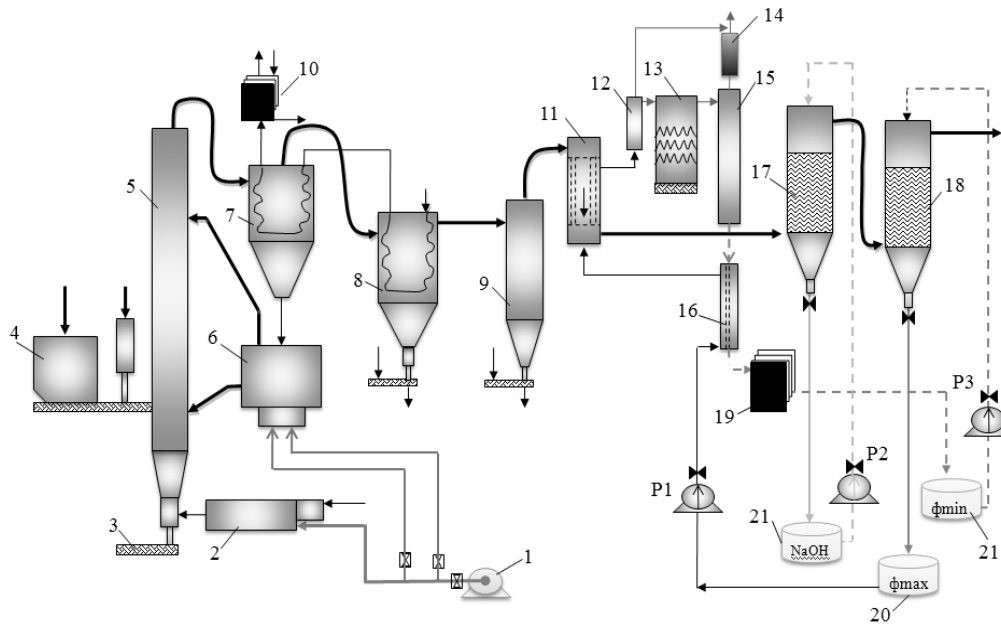
Fig.1 - Scheme of the fluidised circulating combustion unit / *Schema instalaţiei de ardere în strat fluidizat circulant*
1. Blower; 2. Pre-firing using natural gas; 3. Ash evacuation screw conveyor; 4. Fuel feeding system; 5. Combustion chamber;
6. Recirculation system; 7. Cyclone; 8. Convective heat exchanger; 9. Cyclone; 10. Heat exchanger; 11. Flue gases –MEA heat
exchanger; 12. CO_2 expansion tank; 13.Reboiler; 14. Condenser; 15. Desorption column; 16. Economisers; 17. Desulphurization unit; 18.
Absorbing column; 19. H_2O-MEA heat exchanger; 20. Rich MEA solution tank; 21. NaOH solution tank; 22. Lean MEA solution tank;
P1.Pump ф max; P2.Circulation pump NaOH &H_2O; P3.Pump ф min.
1.Ventilator; 2.Antefocar; 3.Şnec evacuare cenuşă; 4.Buncăr cărbune/biomasă; 5.Focar; 6.Dispozitiv recirculare cenuşă;
7.Ciclon recirculare cenuşă; 8.Corp convectiv; 9.Ciclon; 10.Schimbător de căldură; 11.Schimbător de căldură MEA-gaze de ardere;
12.CO₂ Vas de detentă; 13.Reboiler; 14.Condensator; 15.Coloana desorbţie; 16.Economizor; 17.Coloană desulfurare gaze; 18.Coloană
de absorbţie; 19.Răcitor; 20.Rezervor soluţie MEA bogată; 21.Rezervor NaOH;22.Rezervor soluţie MEA regenerată; P1.Pompă ф max;
P2.Pompă circulaţie NaOH &H₂O; P3.Pompă ф min .
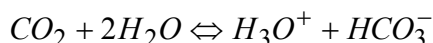
2. Description of the experimental unit

Figure 1 shows the experimental unit for fluidised circulating coal combustion (FCCC) used for the study. The experimental unit installed at the laboratory of Renewable Energy Sources at the Power Engineering Faculty of University Politehnica of Bucharest allows performing experiments for fossil fuel combustion, renewable fuels combustion and co-combustion.

The experimental unit is equipped with a de-sulphuring equipment (12) used for reducing the concentration of sulphur oxides in flue gasses before entering the absorption equipment (13). Solution with lean CO_2 (15 – MEA, lean) is introduced in the absorption unit at upper part using a pump in a counter-current allowing complete CO_2 separation from flue gasses corresponding to chemical reactions of equilibrium CO_2-MEA-H_2O:
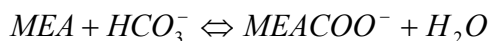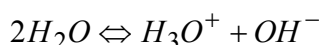
Dissociation of MEA:

$$MEA + H_3O^+ \Leftrightarrow MEA^+ + H_2O$$

Bi-carbonate formation:

$$CO_2 + 2H_2O \Leftrightarrow H_3O^+ + HCO_3^-$$

Carbamate formation:

$$MEA + HCO_3^- \Leftrightarrow MEACOO^- + H_2O$$

Water hydrolysis:

$$2H_2O \Leftrightarrow H_3O^+ + OH^-$$

3. Methodology used within the experimental and simulation study

There has been used local lignite for experimental study having the following characteristics, shown in Table 3.

Table 3

Fossil fuel characteristics
Compoziţia combustibilului folosit

Lignite flow / *Debit Lignit*	10 kg/h
Lignite composition / *Compoziţia lignitului*	
Hydrogen / *Hidrogen*	1.25%
Humidity / *Umiditate*	36%
Sulphur / *Sulf*	1%
Nitrogen / *Azot*	0.65%
Oxygen / *Oxigen*	2.55%
Carbon / *Carbon*	21.55%
Lower calorific value *Puterea calorifică inferioară*	7543 kJ/kg

Tabelul 4

Flue gasses composition
Compoziţia gazelor de ardere rezultate în urma arderii combustibilului

CO_2	11%
N_2	72%
O_2	7%
H_2O.	10%

There have been used two gas analysers TESTO 350 XL for determining flue gasses composition.

Regeneration of solution using amines has been performed in two stages: in the first stage there have been used flue gasses from the lignite combustion process for partial regeneration of the solvent through increasing the temperature of the solvent; in the second stage there have been used electric resistances for supplementary heating of amine solution up to the temperature corresponding to total regeneration.

Even though that it is known that primary amines, monoethanolamine (MEA) react very well with acid gasses and offer a very good CO_2 separation from flue gasses they have a limited capacity of absorption: for absorption of 1 mole of CO_2 there is needed two moles of amines, and they also have a high energy demand for regeneration between 3 and 5 GJ/tCO_2 [23]. Due to amine's high corrosive nature they are used in different mixtures with secondary and tertiary amines.

The utilisation of tri-ethanolamine for the absorption process has the advantage that regenerates very easy in proportion of 95 %, having also low energy consumption for regeneration. But, it is well known that this type of amine reacts with more difficulty with CO_2 needing different activators to mixture with such as primary amines, monoethanolamine and diglycolamine (MES, DGA) or piperazine (PZ) in order to increase speed reaction. Taking into consideration these characteristics of primary and secondary amines they have been used in different proportion in the present experimental and simulation research looking at variation of the following parameters:

a) The effect of variation of regeneration energy as function of efficiency of CO_2 capture for different ratio of flows of liquid and flue gasses (L/G) ratio, [GJ/tCO_2].

b) The influence of concentration and type of amine on regeneration energy of the solvent.

c) Variation of regeneration energy of solution as function of efficiency of CO_2 capture process and lean CO_2 loading solvent, keeping constant concentration of TEA+MEA.

HYSYS 3.2 is a software application that allows simulation in dynamic regime and for equilibrium reactions of thermo-chemical processes. The software includes procedures for determination of chemical and physical properties of substances, elaboration of mass and energy balances, design of different equipment and optimisation of thermo-chemical processes.

For simulation with amines there have been chosen the Amine fluid package and Kent-Eisenberg, (non-ideal vapour phase), as a thermodynamic calculation model since they offer the best model accuracy. The software application requires a limited number of input values such as:

temperature, pressure and flow.

The efficiency of CO_2 capture process has been calculated as a ratio between the value of carbon dioxide from flue gasses at the input of the absorber and the value of the carbon dioxide from flue gasses at the output of the desorber.

$$\varepsilon CO_2 = \frac{CO_2^i(vol\%) - CO_2^e(vol\%)}{CO_2^i(vol\%)} \cdot 100 \ [\%](1)$$

Where: εCO_2 - efficiency of CO_2 capture process

CO_2^i - carbon dioxide from flue gasses at the input of the absorber

CO_2^e - carbon dioxide from flue gasses at the output of the desorber

Lean CO_2 loading solvent represents a very important parameter for the capture process that through determination of the optimal value helps to determination of the maximum regeneration degree with minimal heat consumption. In order to determine the optimal value of lean CO_2 loading solvent there have been varied the solvent flow, the efficiency of CO_2 capture process and the temperature in the desorber through change the energy demand of the desorber, other parameters (solvent concentration, pressure in absorber/desorber) being constant.

$$\gamma = \frac{mol \ CO_2}{mol MEA + mol TEA} \qquad (2)$$

Where: γ - Loading degree of lean/rich solution molCO_2/mol TEA+MEA

4. Results and discussions

4.1. Interpretation of experimental results

Figure 2 shows the variation of lean CO_2 loading solution having a mixture of tertiary and primary amines that had the role to increase the speed reaction. Adding the primary amine in proportion of 4 % MEA leads to increasing energy demand for regeneration of the solvent, since this type of amine needs more energy for regeneration process. For the case of efficiency of 85 % it has been observed that for a lean CO_2 loading solution with 0.16 molCO_2/mol TEA+MEA higher energy consumption with 46 % than for a concentration of 50 % TEA up to 2.15 GJ/tCO_2 [28].

Increasing the weight of MEA to 6 % in the solution mixture (30 %TEA+6 %MEA) led to increasing the energy demand for regeneration with 5.6 % compared to the previous case keeping the same value for lean CO_2 loading solution at 0.16 and for an efficiency of 85 %, (Figure 3). No matter the value of the efficiency of capture
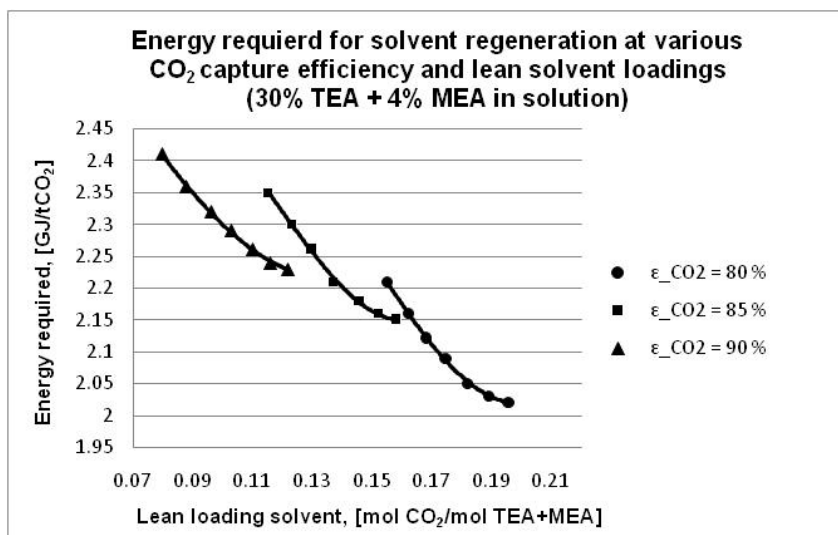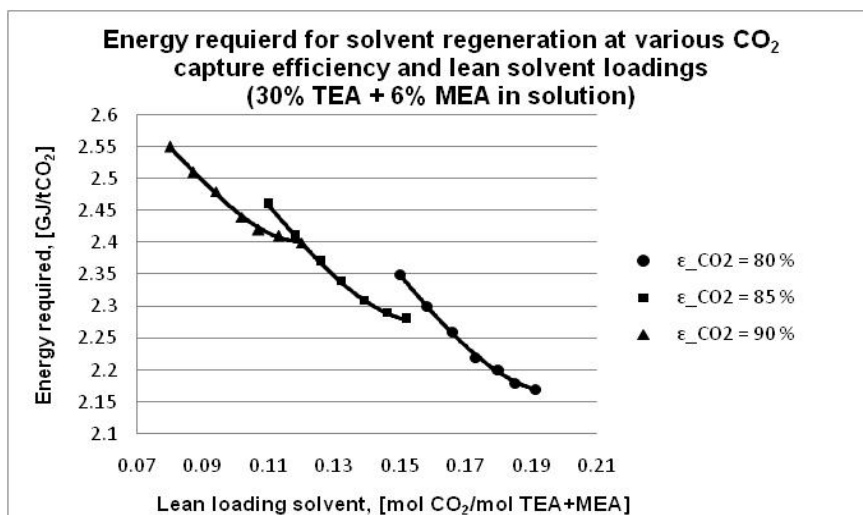
Fig.2 - Regenerative energy variation depending on efficiency CO_2 capture process and lean CO_2 loading solvent, keeping constant concentration of 30% TEA+4% MEA. / *Variaţia energiei de regenerare a soluţiei în funcţie de eficienţa procesului de captare a CO_2 şi de gradul de încărcare al soluţiei sărace în CO_2, menţinând constantă concentraţia de 30% TEA+4% MEA.*

Fig.3 - Regenerative energy variation depending on efficiency CO_2 capture process and lean CO_2 loading solvent, keeping constant concentration of 30% TEA+6% MEA./ *Variaţia energiei de regenerare a soluţiei în funcţie de eficienţa procesului de captare a CO_2 şi de gradul de încărcare al soluţiei sărace în CO_2, menţinând constantă concentraţia de 30% TEA+6% MEA .*
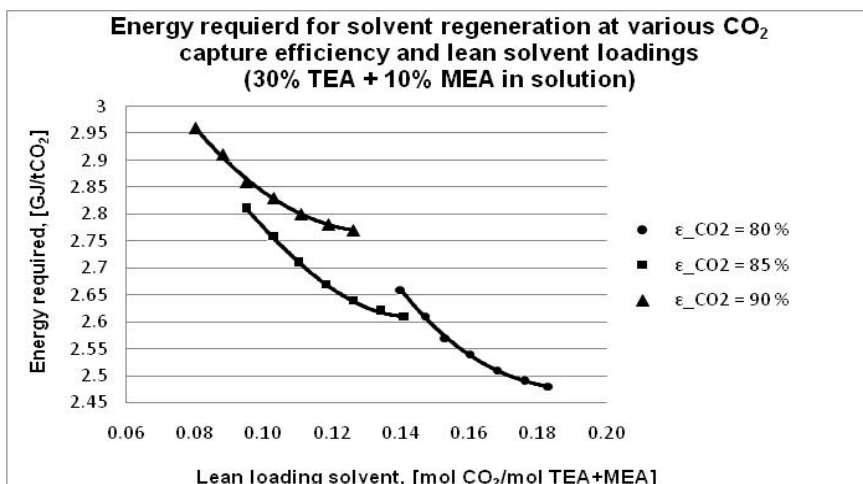

Fig.4 - Regenerative energy variation depending on efficiency CO_2 capture process and lean CO_2 loading solvent, keeping constant concentration of 30% TEA+10 % MEA / *Variaţia energiei de regenerare a soluţiei în funcţie de eficienţa procesului de captare a CO_2 şi de gradul de încărcare al soluţiei sărace în CO_2 menţinând constantă concentraţia de 30% TEA+10 % MEA .*

process for this case there can observed an increase of energy consumption for solvent regeneration having values between 5.6 and 6.8 % compared to the case of concentration of 30 % TEA+4 % MEA.

For the case of increasing the proportion up to 10 % MEA (Figure 4) in the solution mixture (30 %TEA+10 %MEA) in order to increase speed reaction there has been observed an increase with 13-15 % of energy demand for solvent regeneration, no matter the value of efficiency, for the same values of lean CO$_2$ loading solution compared to the previous case.
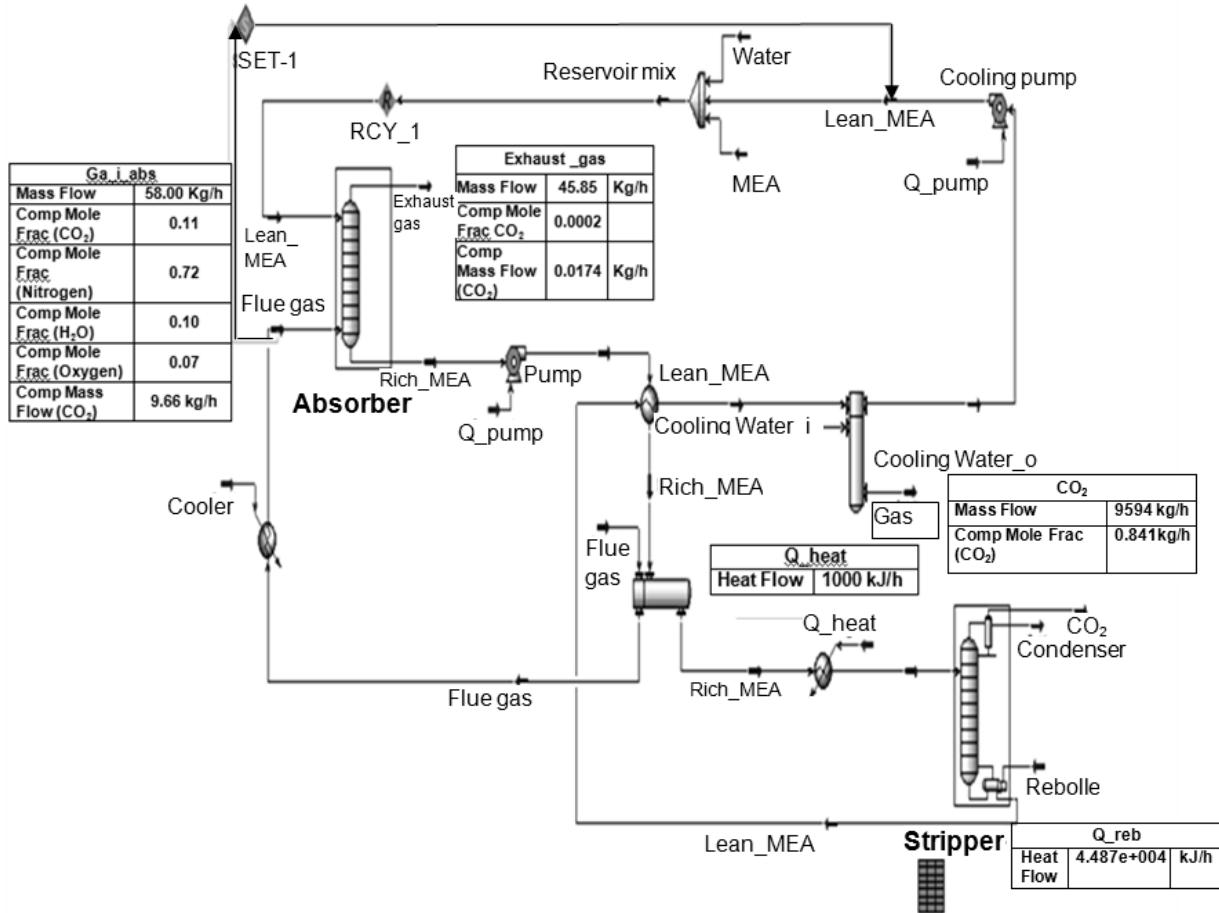

Fig.5 - Simplified scheme of CO$_2$ capture process elaborated in HYSYS 3.2./ *Schema procesului de captare a CO$_2$ realizată în HYSYS 3.2.*

Fig. 6 - Regenerative energy variation depending on efficiency of CO$_2$ capture for different L/G ratios and keeping constant concentration of TEA30%+MEA5%/ *Variaţia energiei de regenerare în funcţie de eficienţa de captare a CO$_2$ pentru diferite rapoarte L/G şi menţinând constant un amestec de TEA30%+MEA5% .*
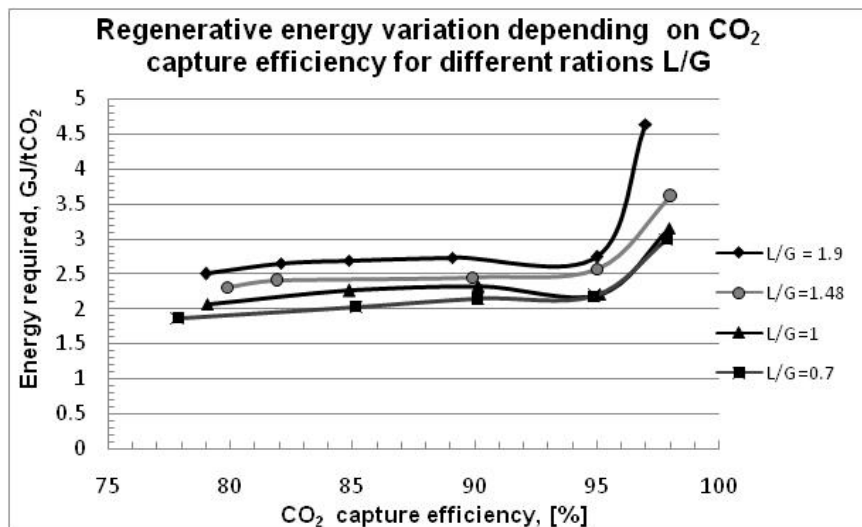
Fig.7 - *Regenerative energy variation depending on efficiency of CO_2 capture for different L/G ratios and keeping constant concentration of TEA30%+MEA10%. / Variaţia energiei de regenerare în funcţie de eficienţa de captare a CO_2 pentru diferite rapoarte L/G şi menţinând constant un amestec de TEA30%+MEA10% .*
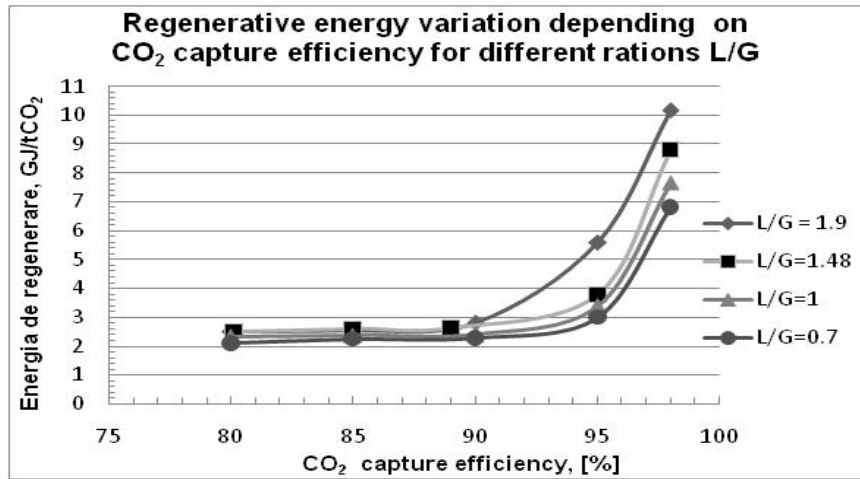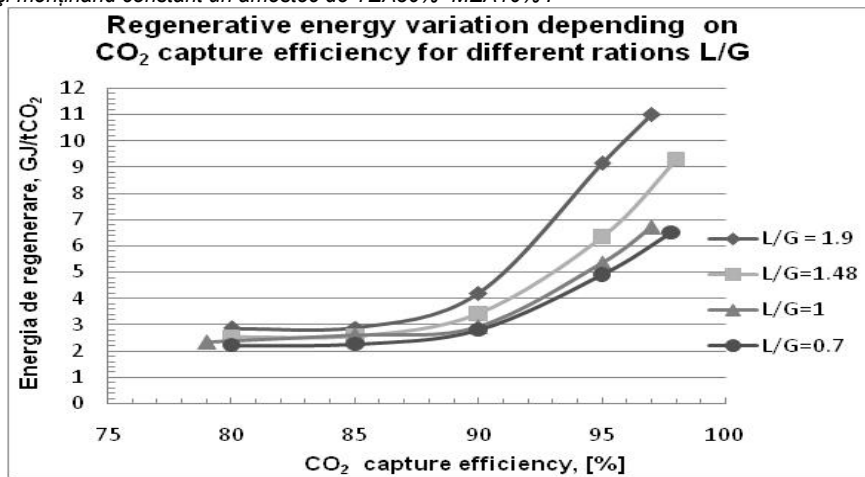

Fig.8 - Regenerative energy variation depending on efficiency of CO_2 capture for different L/G ratios and keeping constant concentration of TEA30%+MEA15% / *Variaţia energiei de regenerare în funcţie de eficienţa de captare a CO_2 pentru diferite rapoarte L/G şi menţinând constant un amestec de TEA30%+MEA15% .*
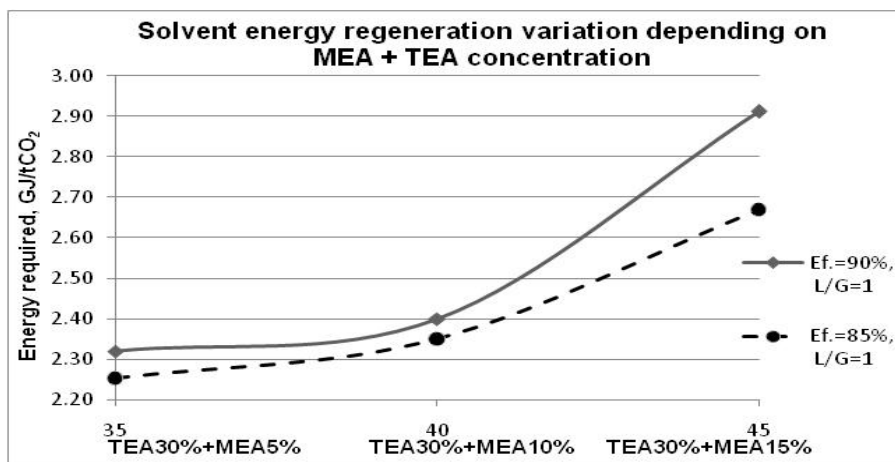

Fig.9 - Solvent energy regeneration variation depending on MEA+TEA concentration keeping constant L/G=1
     Variaţia necesarului de energie de regenerarea pentru diferite concentraţii de TEA+MEA, menţinând constant raportul L/G=1.

4.2 Interpretation of simulation results in HYSYS 3.2

The advantage of a simulation process is that it allows analysis of different cases difficult to obtain using experimental unit. The simulation of the entire CO$_2$ capture process has been performed through optimisation of absorption and desorption units modifying the number of stages and differential pressure. The elaborated scheme within the simulating software is presented in Figure 5.

For the case of mixture of 30 %TEA+5 % MEA, (Figure 6) there has been observed minimal energy consumption for a ratio L/G of 0.7 no matter the CO$_2$ capture process efficiency. For a capture efficiency of 85 % there has been observed minimal regeneration energy demand of 2 GJ/t CO$_2$ for the ratio L/G of 0.7. When increasing the ratio L/G to 1.9 it has been observed an increase of energy consumption for solvent regeneration with 40 % reaching 2.8 GJ/t CO$_2$.

For the case of increasing the weight of MEA 30 % TEA+10 % MEA (Figure 7) it has been observed a light tendency of increasing the energy demand for regeneration, thus the minimum energy demand for regeneration for the CO$_2$ capture process efficiency of 85 % is 2.3 GJ/t CO$_2$ for a ratio L/G of 0.7. For the case of efficiency higher than 93 % there has been observed a more significant increase of energy demand for regeneration.

Increasing the weight of MEA in the mixture 30 % TEA+15 % MEA (Figure 8) has shown a significant increase of energy demand for regeneration of solvent for efficiencies higher than 92 %. This tendency can be explained by high energy consumption for regeneration needed by MEA. L/G ratio for which energy demand for regeneration is minimal is between 0.7 and 1. In case of increasing CO$_2$ capture efficiency from 90 to 95 % the energy demand for regeneration increases with 66 % for the ration L/G of 1.

Figure 9 shows the influence of concentration and type of amine on the energy demand for regeneration of solvent, keeping constant L/G ratio to 1 and varying the efficiency of CO$_2$ capture process from 85 % to 90 %. As solvents there have been used mixtures of primary and tertiary amines (MEA+TEA).

There has been observed an increase of energy demand for regeneration with increasing the weight of primary amine in the mixture, which needs more energy for regeneration, with 5, 10 and 15 %. The increase of energy demand with 20% is observed for the case of CO$_2$ capture efficiency of 85 %, and with 25 % for the efficiency of 90 %, reaching energy consumption of 2.3 and respectively of 2.9 GJ/tCO$_2$. For the case of mixture 30 % TEA + 10 % MEA it has been observed an insignificant increase of energy demand for regeneration resulting the optimal solution.

5. Conclusions

The CO$_2$ post-combustion capture technology using chemical absorption based on solvents has as a main problem high energy demand for the regeneration process of solvents. Thus, the present paper tries to identify the optimal combination of two types of amine solvents, primary amines (MEA) and tertiary amines (TEA) in different proportions so the energy demand can be kept at minimal values and the efficiency of CO$_2$ capture process can be kept over 85 %.

For an efficiency of CO$_2$ capture process of 85 %, from the point of view of energy demand for regeneration, the optimal solution is a mixture of primary and tertiary amines 5 % MEA+30 % TEA, ratio L/G=0.75 [kg_l/kg_gas]. For this solution there has been obtained the minimal energy demand for regeneration of solvent of 2.15-2 GJ/tCO$_2$. The results have been obtained in the experimental study and simulation process using the software HYSYS 3.2.

Regarding the lean CO$_2$ loading solution, there can be said that more quantity of solution is loaded into the desorption unit helps to decreasing energy demand for regeneration through the supplementary heat generated due to water vaporisation from the solution, helping to breaking the bonds between CO$_2$ and amine. At the same time there should be mentioned that a greater quantity of solution needs greater energy quantity for heating up the solution. The experimental study led to the optimal value of lean CO2 loading solution of de 0.16 molCO$_2$/mol TEA+MEA, with a minimal energy consumption of 2.15 GJ/tCO$_2$ and an efficiency of 85 % of the CO$_2$ capture process.L/G ratio represents another very important parameter for analysing variation of energy demand for regeneration of CO$_2$ capture process. There has been determined the optimal value of this ratio for which the energy demand is minimal and efficiency of CO$_2$ capture is maximal. The variation of L/G ratio has been performed for constant flue gasses flow and modifying the flow of the solution, determining the optimal value for L/G ratio as function of the type and concentration of solvent used*.* The results show that the optimal value of L/G ratio for the minimal energy demand for regeneration (2 and 2.5 GJ/tCO$_2$) has been established between 0.7 and 1 [kg_l/kg_gas], keeping the efficiency of CO$_2$ capture process over 85 %.

As a general conclusion the mixture of primary and tertiary amines represents an advantageous solution that keeps the energy demand low for 30 % TEA+5 % MEA and the efficiency of CO$_2$ capture process can be increased up to 95 %.

The analysed process can be directly used in cement and glass industries, being an advanced measure of CO$_2$ management through efficient

capture and isolation of carbon. This method can be also used for large flows of flue gasses resulted from technological processes from cement and glass industries with condition to keep the L/G ratio within the recommended domain between 1 and 2.5 [kg_l/kg_gas]. Eventual restrictions regarding the flue gasses flow can be of economic nature due to the increase of costs of absorbant solution with increasing its quantity.

The described method, being a post-combustion CO_2 capture method, imposes a certain domain of temperature for flue gasses cooling (30 - 45°C), in order to achieve optimal efficiency of carbon absorption.

Heat from flue gasses, resulted at high temperatures (over 1000°C), from technological processes form glass and cement industries and also from other industries with combustion processes, can be recovered within the analysed contour,e.g. pre-heating combustion air, or using an external recuperation for heat generation. This can lead to increasing energy efficiency of the process through heat recuperation from flue gasses as secondary energy resources, which also leads to decreasing envrinomental impact, and flue gasses are cooled down to temperatures required by CO_2 capture technology [29].

In the cement industry, for substantial reduction of CO_2 emissions (about 30 % and even more), it is opportunistic to combine this technology with other measures such as: utilisation of different technologies for CO_2 capture at stages before combustion or during combustion process, cement production with low clincher contain, e.g. composite cement from fly ash or slag, intensive utilisation of alternative fuels (biofuels, with low carbon content, with reduced CO_2 emissions), increasing the energy efficiency of cement production processes through improving the equipment technology [30-34].

Increasing the efficiency of CO_2 capture by using the proposed method can lead to increasing the economic benefit of the cement, glass and other construction materials companies through commercialisation of CO_2 emissions.

Increasing the price of the carbon certificate can be a measure to support different CO_2 capture technologies. In 2012 the price for carbon certificate has varied between 4 and 12 Euro/tCO_2. Some studies anticipate an increase of price of carbon certificate up to 60 Euro/tCO_2 [35].

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