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Analysis of Absorber Packed Height for Power Plants with Post-Combustion CO_2 Capture

Miriam Navarrete Procopio *, Gustavo Urquiza and Laura Castro

Center for Research in Engineering and Applied Sciences, Universidad Autónoma del Estado de Morelos, Cuernavaca 62209, Mexico; lauracg@uaem.mx (L.C.)
* Correspondence: miriam.navarrete@uaem.mx

Abstract: The electricity generation process from fossil fuels is one of the sources of CO_2 emissions. The post-combustion CO_2 capture is an alternative to minimize emissions. The packed absorption column is the first unit of the CO_2 capture process. In this study, the values of the process parameters were established to reduce the absorber-packed height using a simulator developed in this work. The simulator was validated using measurements in a laboratory-scale absorption unit; simulations were carried out with the same operating conditions as measurements and two different fuels were treated; coal and natural gas. A combined-cycle power plant in Mexico was simulated, with the objective of evaluating the main parameters in the absorption process and required dimensions of the packed absorption column required to carry out the capture of CO_2 in the power plant. From the result of the simulations, three columns treatment with 3 m diameter and 7 m height were established to remove 99% of the CO_2 of the flue gases with 20 wt.% of MEA composition using Mellapak 500Y structured packaging.

Keywords: absorber packed height; absorption column; power plant; process system modelling

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1. Introduction

CO_2 is the greenhouse gas which makes the largest contribution to global warming. The second main source of CO_2 emissions in Mexico is the electricity generation process from fossil fuels [1,2].

Carbon capture and storage (CCS) represents an option for the mitigation of CO_2 caused by fossil fuel use. CCS consists of the separation of CO_2 from industrial sources, transportation of CO_2 to a storage location, and long-term isolation of CO_2 from the atmosphere. Three technological pathways can be used for CO_2 capture from coal-derived power generation: oxy-combustion, pre-combustion, and post-combustion capture [3,4].

From the available methods of CO_2 capture, post-combustion is the method that can be retrofitted to the power plants. In the post-combustion capture, the separation of CO_2 from flue gas derived from combustion fossil fuels is carried out using amine solvents then the absorbed CO_2 is liberated from the solvent and is compressed for transportation and storage [5–8].

The literature discusses two main paths; trying different solvents and optimization of the process configuration [9–11]. Solvents have been proposed for the chemical CO_2 absorption process, but these may not fulfill the expectations of the capture of CO_2 in a global scenario. Monoethanolamine (MEA) is the most used, industrially [12–14].

Simulators are important in industrial processes since they provide valuable information. These are friendly tools that perform all the relevant calculations with indispensable input data. Industries have to use them to improve the efficiency of their process by modifying the operating conditions [15–17].

The reduction of CO_2 emissions from thermoelectric power plants is of great importance. A recent study quantified the high amounts of CO_2 from power plants by building calculation models, analyzing the sensitivity of carbon emission parameters and suggesting support for proposing policies related to carbon emissions [18]. Post-combustion CO_2 capture work continues as it is one of the most efficient technologies in mitigating CO_2 emissions. Authors intend to integrate the technology to processes that have CO_2 emissions in their combustion gases, such as ship engines [19]. Other authors continue optimizing the energy consumption required for absorbent solution regeneration, evaluating the performance of new multi-amine solvents in CO_2 absorption processes using mathematical models and also developing optimization models [20,21]. Work based on the second law of thermodynamics reported the thermodynamic inefficiencies of post-combustion technology and evaluated them using exergy, exergoeconomic and exergoenvironmental analyses.The analysis tools for this study were optimization models and neural networks, the latter to generate the decision variables and the objective function [22,23].

In this work we developed a gas absorption-packed column simulator for the analysis of an absorber-packed height for power plants with post-combustion CO_2 capture. The model was validated with experimental data, where the following parameters were varied: The CO_2 content of the entering gas, the gas flow, the MEA weight percentage, and the solvent flow. In addition, a thermoelectric plant in Mexico was simulated to obtain the needed dimensions and operating conditions of the absorption column to capture its CO_2 emissions.

This work describes the development of the mathematical model (Section 3), the validation of the mathematical model (Section 4) and the simulation of a power plant (Section 5).

2. Energy Transition

2.1. CO_2 Emissions in Mexico

Greenhouse gases contribute to global warming and cause climate change. CO_2 is the greenhouse gas with the greatest impact since it remains in the atmosphere for many years, and its concentration is also related to anthropogenic activity. On 5 November 2016, an international treaty on climate change (the Paris Agreement) entered into force, which sought to intensify actions and investments to reduce GHG emissions worldwide. Mexico is one of the 20 countries with the highest greenhouse gas emissions, placing it in fifteenth place worldwide, emitting 407 $MtCO_2$. In Mexico, INECC (Instituto Nacional de Ecología y Cambio Climático) is a decentralized public entity that carries out the national inventory of greenhouse gas and compound emissions. The INECC categorizes, in its database, four sources of CO_2 emissions from fuel burning: Energy industries, manufacturing and construction industries, transportation, and other industries. The energy industry is responsible for emitting the largest amount of CO_2 into the atmosphere, with 45% of total emissions in Mexico. Figure 1 shows the percentage of each CO_2 emitting source and the sub-sources belonging to the energy industries. The production of electricity and heat emits 80% of CO_2 (147.50 $MtCO_2$) [24].

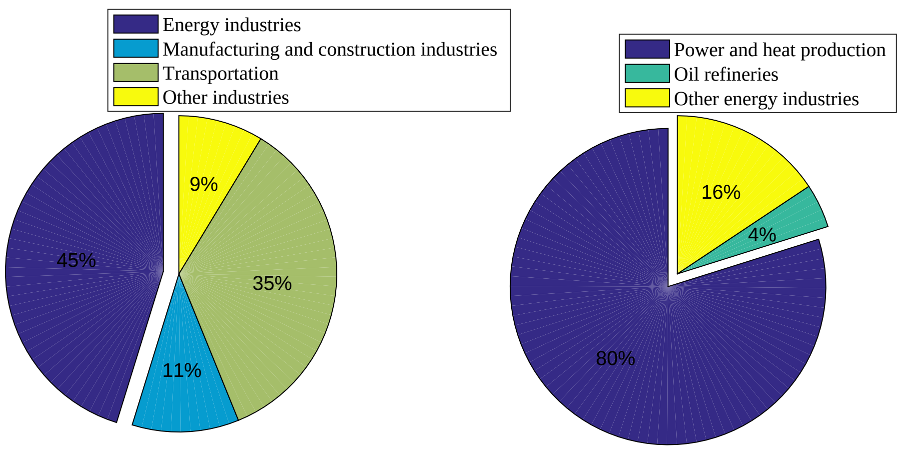

Figure 1. CO_2 contribution by emission source and sub-source.

2.2. Electricity Generation

The CFE (Comisión Federal de Electricidad) produces electricity in Mexico. The CFE reported in its 2021 annual report: 195 power plants with a total capacity of 59,561 MW. Of the total capacity, 25.78% corresponded to plants that generated energy with renewable sources such as water, wind, geothermal steam, sun, and nuclear energy, and 74.22% with hydrocarbons. Power plants used different primary sources for power generation. Table 1 shows the technologies for electricity generation and the energy sources for each one. Natural gas was the most widely used source of energy from fossil fuels. Unlike fuel oil, diesel, and coal, natural gas emits CO_2 in a lower concentration. However, it does not stop emitting a large amount of polluting gas [25].

Table 1. Technologies and energy sources in Mexico.

	Technology	Number of Power Plants	Power Generation (MW)	Power Source
Thermoelectric power plants	Coal fired	3	5463.45	coal
	Combined cycle	47	24,650.03	natural gas
	Conventional steam	21	10,047.60	natural gas/oil/diesel
	Internal combustion	5	5360.82	oil/diesel
	Turbogas	43	2836.43	natural gas/diesel
Renewable power plants	Geothermal	4	918.08	geothermal heat
	Hydroelectric	60	12,125.36	water in motion
	Wind power	9	698.55	wind
	Solar photovoltaic	2	6.00	solar radiation
	Nuclear power	1	1608.00	uranium

2.3. Electricity Consumption

In 2018, the global annual electricity consumption reached 24.7 million GWh; Mexico consumed 290,100 GWh, occupying the fourteenth position. It is important to ensure a sufficient and reliable electricity supply to boost the growth and economic development of the country. The government of Mexico forecasts the demand for electricity for planning and decision-making in the preparation of programs for the expansion and modernization of the National Electric Network. The demand and consumption of electrical energy are subject to various factors, the most determining of which are: Economic growth, population growth, climatic factors, fuel prices, and electromobility. Every company has the goal of achieving an increase in its income. If the economy of a region increases, then the demand for electricity also increases. Population growth is directly related to the construction of housing, public services, and commercial developments and consequently to more consumption of electricity. Extreme weather like heat waves, winter storms, and droughts increase electrical energy consumption. The price of energy products, especially those derived from hydrocarbons, affects the supply of electricity, and the power for electric vehicles also increases the demand for the country's electrical system [26].

2.4. Technological for Electricity Demand

In Mexico, the generation of energy with renewable sources include the use of water, wind, geothermal steam, and the sun. These are the cleanest types of energy generation so far and generate less than 25% of the total energy. Planning the construction of power plants with renewable sources has some general disadvantages, such as the need to have large spaces located in areas with natural resources and the building of high-voltage lines to distribute electrical energy from the power plants. Solar power plants have the disadvantage of depending on the climate and environmental pollution in the installation area. With cloudy weather, solar panels generate energy at 25% of their total capacity and they do not generate electricity at night. In the same way, wind energy has disadvantages, since it is dependent on the wind; this type of energy is intermittent and discontinuous. Wind turbines are designed to operate with limits on wind speed. If the wind speed is higher than the upper limit value, the blades can be damaged and energy production will decrease. In addition, the wind turbines represent a danger for migratory birds that collide with the blades. The construction of hydraulic power plants has the disadvantage of prioritizing the water source which must be allocated primarily to the population, livestock, and agriculture. Geothermal energy is limited; not all types of soil can install this technology. Installing this technology depends on the hardness of the soil and the temperature reached in the subsoil. In addition, with low probability, Geothermal plants may trigger earthquakes as it alters the Earth's structure by digging. Lastly, nuclear power plants do not release greenhouse gases and they have a low operating cost; power generation is available 24 h a day throughout the year. The main disadvantages of this technology are the generation and handling of radioactive waste and the potential risk of nuclear accidents. The nuclear energy source cannot be regenerated once consumed. Therefore, it is not renewable [27–30]. In Mexico, thermoelectric power plants generate the highest amount of electrical energy and are the ones that emit the highest concentrations of CO_2 into the environment. They contribute to global warming and climate change. Conventional technologies for power generation will continue to operate to supply the country's electricity needs. Therefore, it is important to develop technologies and strategies to mitigate CO_2 emissions from these sources. Current technologies to separate CO_2 from the mixture of gases from the burning of fossil fuels in power plants are classified into treatment technologies before combustion (pre-combustion), during combustion (oxy-combustion), and after combustion (post-combustion). Post-combustion technology is the one used for the elimination of CO_2 from the combustion gases in thermoelectric plants. This technology consists of CO_2 absorption with an amine absorbent solution. The main units of the post-combustion process are the packed absorption and desorption columns, the pumps, and the heat exchangers. The main advantage of post-combustion CO_2 capture is that it can be retrofitted to existing power plants without significant modifications. The main disadvantage of this technology is the high energy demand required for the regeneration of the absorbent solution. This paper presents a technological alternative to mitigate CO_2 emissions from combined cycle power plants, to later analyze one of the units of the process, the absorption column. Figure 2 shows the units that make up the post-combustion CO_2 capture process incorporated into a combined cycle power plant. The exhaust gases from the heat recovery of the combined cycle plant pass through a heat exchanger to lower their temperature and enter the CO_2 capture process. The cooled gases enter a packed absorption column from the bottom, having countercurrent contact with an absorbent solution that reacts chemically with CO_2. The treated gas exits at the top, and the absorbent solution with CO_2 is pumped into the packed stripping column, through a heat recovery that increases its temperature before the stripping process, using energy recovered from the regeneration of the absorbent solution. In the stripper, the CO_2-rich solution is brought into countercurrent contact with the steam generated in the reboiler. At the bottom of the packed stripping column, the regenerated absorbent solution with a minimal amount of CO_2 is obtained, which is pumped back to the absorber column through the heat recovery unit. At the top of the packed stripping column, the water vapor condenses and the CO_2 is compressed and cooled in liquid form.

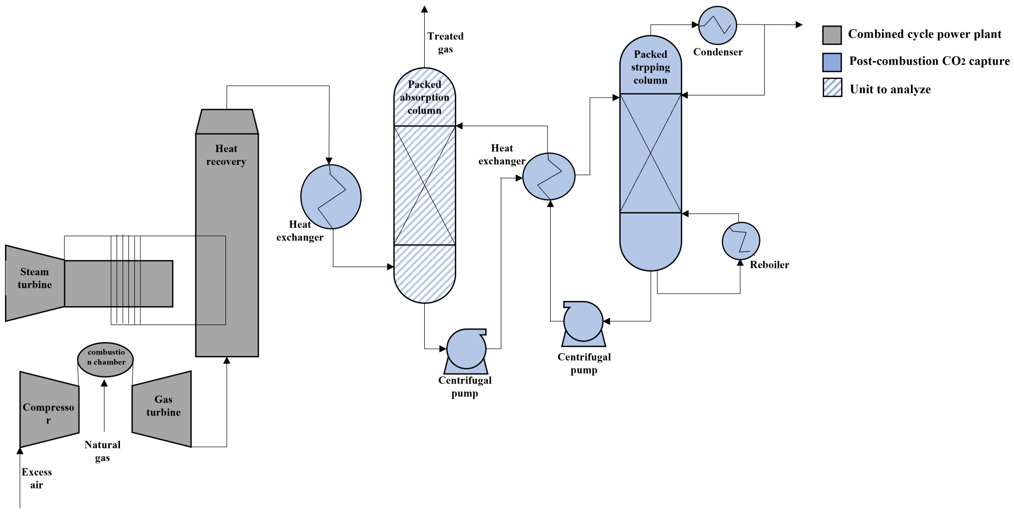

Figure 2. Post-combustion CO_2 capture for a combined cycle power plant.

3. Mathematical Model

3.1. Process Unit Description

For this work, an absorption packed column is used as the processing unit. It is equipped with a gas inlet at the bottom (G_1) and liquid inlet on the top (L_2); liquid flows downward using gravity and exits at bottom (L_1), while gas flows upward through the wetted packing, contacting the liquid and coming out at the top (G_2) (countercurrent flow). Figure 3 show the absorber unit for the model.

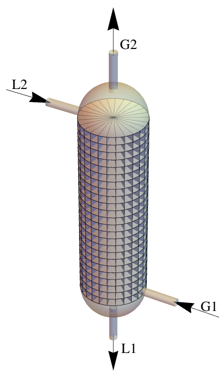

Figure 3. Packed column process unit.

The reaction between the amines and CO_2 is quite complex. However, the overall reactions can be represented as follows [31]:

$$\begin{array}{c} MEA + CO_2 \leftrightarrow MEACOO^- + H^+ \\ MEA + H^+ \leftrightarrow MEAH^+ \\ \hline 2MEA + CO_2 \leftrightarrow MEACOO^- + MEAH^+ \end{array}$$

Gas absorption is a mass-transfer operation through diffusion. The driving force for transfer is a concentration difference, where a solute in a gas mixture is absorbed with a solvent in the packing. The packing increases contact between the liquid and gas; random and structured are the principal types of packing. In this work, random ceramic packs were used for model validation (½-inch ceramic Berl saddle) and several structured metal packs were used for power plant simulations.

3.2. Equations of Balance and Design

The evaluation of an absorption column involves the determination of its dimensions. The diameter of an absorption column is the function of the flow of the gas to be treated and absorbent solvent. The total volume of packing determines the column size, which depends on the final concentration of solute and the overall mass transfer coefficient. In addition, equilibrium data and fluid properties are needed.

The main assumptions used to simplify the analysis are:

- The processes are in steady-state conditions.
- The absorption process is adiabatic.
- The species of gas in the gas mixture are ideal gases.
- Thermodynamic and transport properties were modelled using RefProp for CO_2, O_2, N_2 and H_2O
- The MEA properties were included of the base version Aspen Plus

The overall material balance for the column in the Figure 3 can be written as follows:

$$G_1 y_1 + L_2 x_2 = G_2 y_2 + L_1 x_1 \tag{1}$$

The relationship between x and y at any point in the column, obtained by rearranging Equation (1), is called the operating-line equation.

$$\left(\frac{y_2}{1-y_2}\right) = \frac{L_s}{G_s}\left(\frac{x_2}{1-x_2} - \frac{x_1}{1-x_1}\right) + \left(\frac{y_1}{1-y_1}\right) \tag{2}$$

where $\left(\frac{y_2}{1-y_2}\right)$ represent the molar ratio for gas and $\left(\frac{x_2}{1-x_2}\right)$ for the liquid.

Figure 4 shows the equilibrium curve of CO_2 in aqueous 30 wt.% MEA [32]. In the same figure the minimum and real operating line can be plotted; these have to be drawn above the equilibrium for the absorption process to take place, since this gives a positive driving force $y - y^*$ for absorption.

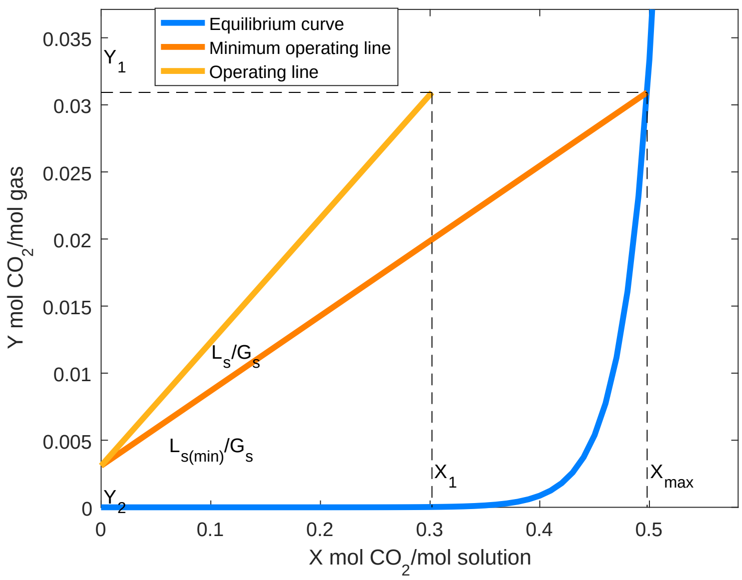

Figure 4. Construction of the operation line for the H_2O-MEA-CO_2 30% wt system.

The absorber packed height (Z_T) required for the relevant separation process can be obtained from this equation:

$$Z_T = \frac{G/A}{K_G a P} \int \frac{dy}{y - y^*} \tag{3}$$

The integral in Equation (3) is called the number of transfer units (NTU) based on the global driving force for the gas phase. The simulator solves NTU for diluted and concentrated conditions. The other side of Equation (3) has the units of length and is called the height of a transfer unit (HTU). It is calculated from the mass transfer correlations.

The overall mass transfer coefficient of liquid and gas have been predicted with different correlations. The correlation to calculate mass transfer coefficients is the Onda model for random packaging and the SRP (Separations Research Program) model for structured packaging [33–35].

In chemical process engineering, absorption unit design requires the absorber packed height as a function of system equilibrium and mass transfer. The mass transfer coefficient is a function that depends on the type of packing, the flow rates, and the fluid properties of chemical compositions in the liquid and gas stream. The equilibrium depends on the composition and the temperature of the absorbent solution. In mathematical modeling, it is essential to ensure that the necessary number of variables are specified to define the problem correctly using degrees of freedom analysis. For the analysis in the absorption column, the independent variables and equations are specified, and the input variables to run the model are established. The input variables of the power plant are established, such as flow rate, temperature, and composition of the flue gas. The process variables that can be parameterized are the removal percentage, the temperature, flow, and composition of the solution, and the type of packaging.

The algorithm was programmed at GUIDE MATLAB version R2018a. Figure 5 shows the programming algorithm, and Figure 6 shows The simulator's main screen.

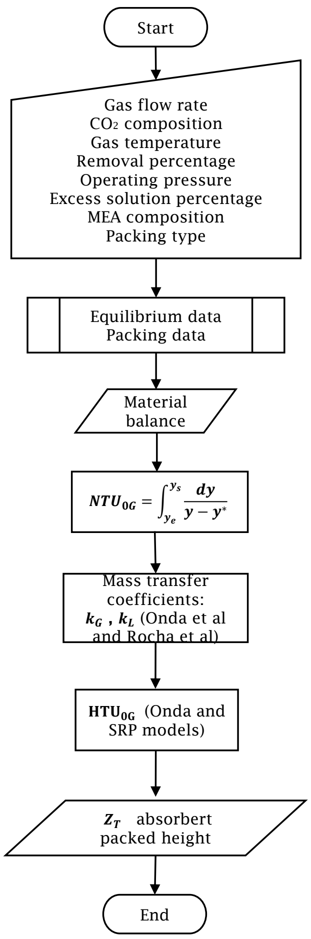

Figure 5. Programming algorithm.

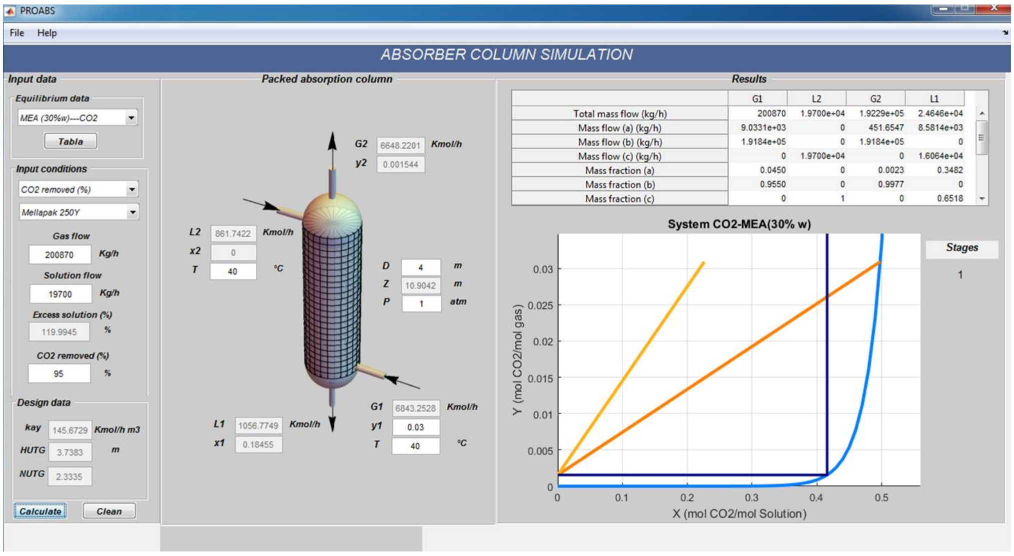

Figure 6. Simulator main screen.

4. Model Validation

The model validation was performed with experiments in a laboratory-scale absorption unit at the Universidad Autónoma del Estado de Morelos (UAEM). The absorption column is a cylindrical device made of acrylic supported on a metallic structure.

Experimental Section

The diagram of the absorption system is presented in Figure 7. The system consists of a column packed with ½-inch ceramic Berl saddle (PT-101). Tank 1 (TK-101) contains the CO_2 that mixes with the airflow supplied by the piston compressor (C-101). Tank 2 (TK-102) contains the MEA solution that feeds the absorption column from the top (stream 1) through a peristaltic pump (P-101). The concentration of CO_2 in the gas stream is controlled with the rotameters (R-101, R-102). The gas mixture is fed at the bottom of the column (stream 4). The purified gas is vented to the atmosphere from the top of the absorption column through a gas analyzer to determine the CO_2 concentration (stream 5). Tank 3 (TK-103) contains the MEA solution saturated with CO_2 that exits from the bottom of the absorption column (stream 6). The system has four type T thermocouples located in the 1, 4, 5, and 6 streams.

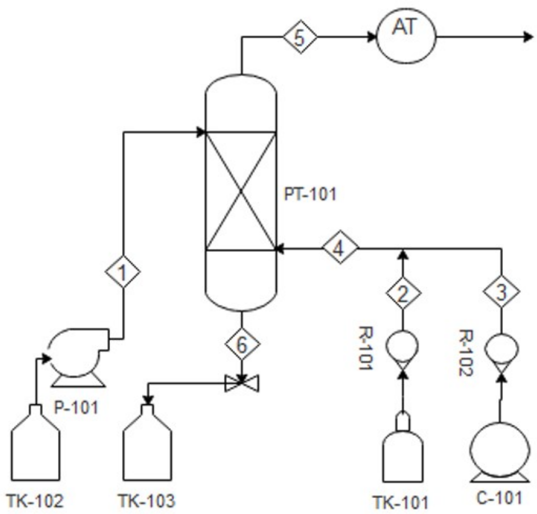

Figure 7. Schematic flow diagram-Experimental process.

Table 2 shows the operation parameters in the experiment, and the specifications of random packing used in the experiments and in the model validation are shown in Table 3.

Table 2. Experimental operation parameters.

Parameters	Data
Packing type	½-inch ceramic Berl saddle
Absorber packed height (m)	0.70
Absorber diameter (m)	0.08
Gas flow rate (L/min)	16 and 15.5
CO_2 composition (vol.%)	12.5 and 3.2
MEA composition (wt.%)	20, 25 and 30
Operating pressure (kPa)	80

Table 3. Specifications of packing.

Type	Material	Size (mm)	Area per Unit Packed Volume (m^2/m^3)	Void Fraction m^3/m^3
Berl Saddle	Ceramic	13	545	0.65

Table 4 shows the parameters used during experiments and later in simulations for model validation and shows the absorber packed height for simulation results with its percentage accuracy.

They were conducted using two different gas mass flow rate, 35 g/s m^2 with 3.20 vol.% CO_2 concentration and 54 g/s m^2 with 12.50 vol.% CO_2 concentration, tests for CO_2 composition of a combined cycle and a coal power plant, respectively; besides three different MEA composition 20, 25 and 30 wt.%, the flow rates of MEA solution were varied for each MEA composition.

Table 4. Experiment configurations and simulation results.

Case	Gas Mass Flow Rate (g/s m^2)	CO_2 Composition (vol%)	Solution Mass Flow Rate (g/s m^2)	MEA Composition (wt%)	Z_T (m)	Percentage Accuracy (%)
1	35	3.20	130	20	0.70	0
2	35	3.20	110	25	0.75	6.66
3	35	3.20	90	30	0.79	11.39
4	54	12.50	130	20	0.69	1.45
5	54	12.50	110	25	0.74	5.40
6	54	12.50	90	30	0.78	10.26

The absorber-packed heights (Z_T) for each simulation with the developed model are include in the Table 4. These results can be compared with the real absorber-packed height to the laboratory-scale absorption unit. Several studies that proposec models for the capture of CO_2 using absorption columns have reported results with higher relative errors than this work [36,37].

5. Power Plant Simulation

The reference plant was a natural gas-fired combined cycle with 244 MW power. It is located in the center region of Mexico. Table 5 shows the power plant key data.

Table 5. Base case power plant summary.

Process Variable	Value
Power (MW)	244
Natural gas consumption (kg/s)	4.62
Flow of gases to be treated (kg/s)	279
Exhaust gas pressure (kPa)	101.32
Exhaust gas temperature (°C)	146

To know the composition of the exhaust gases to be treated in the combined cycle plant, stoichiometric calculations of the methane combustion reaction were made, taking as input data, the flow of fuel and exhaust gases. The Equation (4) establishes the combustion reaction of methane, the major component of natural gas.

$$CH_4 + a[O_2 + 3.76N_2] \rightarrow iCO_2 + jH_2O + eN_2 + gO_2 \tag{4}$$

The molar composition of the exhaust gases are: 3% CO_2, 15% O_2, 5% H_2O, 77% N_2 with 124 kg/MW h to CO_2 emission rate.

This work analyzes the absorber packed height as a function of different operating variables such as flows, compositions, temperatures, absorber diameter, and packing type. Table 6 shows the baseline values of these variables for the sensitivity analyses. The total flow of gases to be treated was divided into three treatment trains. The flow for each treatment train was 93 kg/s with 3 vol.% CO_2. Studies showed that concentrations higher than 30 wt. % lead to corrosion problems.

A high removal percentage was established to absorb the greatest amount of CO_2 found in the gas flow to be treated. An amount of solution was lost in the regeneration process in a post-combustion CO_2 capture; it has to be fed with an excess percentage, in this study, a minimum excess solution percentage was established as a baseline.

Table 6. Baseline case.

Parameter	Value
Operating pressure (kPa)	101.32
Temperature (°C)	40
Inlet flue gas flow-rate (kg/s)	93
CO_2 composition (vol.%)	3
MEA composition (wt.%)	30
Removal percentage (%)	99
Excess solution percentage (%)	10
Column diameter (m)	1

6. Results and Discussion

This study established the operating conditions to reduce the absorber packed height using the simulator developed in this work. A sensitivity analysis was made with the data established in Table 6 and the different structured packages present in the literature. Table 7 shows the characteristics of the packages that were entered as a database in the mathematical model. The characteristics were the surface area per unit packed volume (ap), void fraction, corrugation angle, and channel dimensions (base, height, and side). The structured packages analyzed below apply to the SRP model for the systems of the absorption and distillation processes [38].

Figure 8 shows the absorber packed heights with different structured packaging. As can be seen, the packings with a corrugation angle of 60° cause a greater height packed section than the packings with a corrugation angle of 45° under the same channels dimensions. The structured packing with greater surface area per unit packed volume (ap) have lower packaged section heights, such as Mellapak 500 Y, Sulzer BX, Flexipac 1.Y. In this study, Mellapak 500 Y structured packing were established for sensitivity analysis of the process parameters.

Table 7. Characteristics of the structured packing.

Packing	ap (m^2/m^3)	Void Fraction	Corrugation Angle	Base (m)	Height (m)	Side (m)
Montz B1-250	244	0.98	45	0.0225	0.012	0.01645
Montz B1-250.60	245	0.978	60	0.0223	0.012	0.01645
Montz B1-400	394	0.96	45	0.014	0.0074	0.01033
Montz B1-400.60	390	0.96	60	0.0143	0.0074	0.01029
Montz BSH-400	378	0.97	45	0.0151	0.0074	0.01058
Montz BSH-400.60	382	0.97	60	0.0148	0.0074	0.01047
Mellapak 250.X	250	0.98	60	0.0241	0.017	0.0119
Flexipac 1.Y	453	0.91	45	0.0127	0.0064	0.009
Mellapak 250.Y	250	0.95	45	0.0241	0.0119	0.017
Mellapak 350.Y	350	0.93	45	0.0153	0.0089	0.0119
Mellapak 500.Y	500	0.91	45	0.0096	0.00653	0.0081
Sulzer BX	492	0.90	60	0.0241	0.0119	0.017

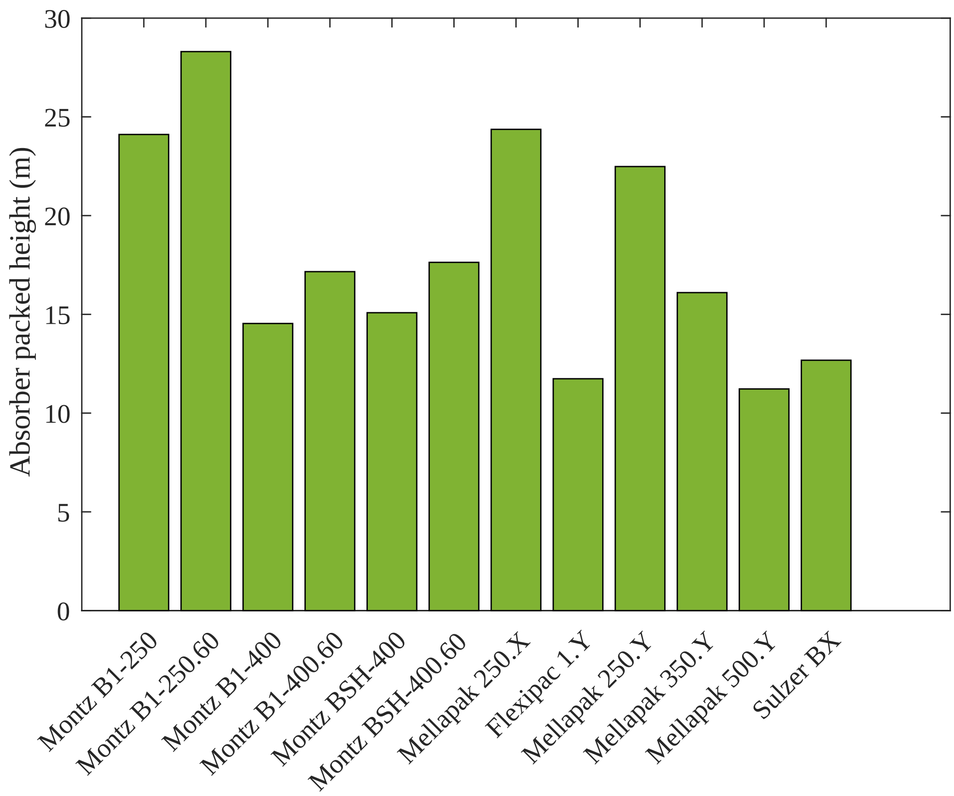

Figure 8. The absorber packed heights with different structured packaging.

Mellapak 500Y is a type of commercial structured packing manufactured by Sulzer Chemtech. it is fine packing with a channel inclination angle of 45° and a specific area of 500 m^2/m^3. The structured packing consists of corrugated sheets; Mellapak 500Y has the largest geometric area within structured packaging. In this study for the MEA-H_2O-CO_2 system, Mellapak 500Y was the package with the lowest absorber-packed height compared to the results of the other packages. However, mathematical modeling studies [39] and numerical simulations in CFD report a higher effective area for this type of packaging [40,41].

The process parameters were varied in the post-combustion CO_2 capture process. The values are shown in Table 8. The range for temperature and MEA composition was limited to the equilibrium database.

Table 8. Value range for process parameters.

Parameter	Value
Gas and solution temperature (°C)	40–55
Excess solution percentage (%)	10–100
MEA composition (w%)	15–30
Removal percentage (%)	90–99
Column diameter (m)	1–5

The most sensitive process parameters to absorber-packed height were the column diameter and the removal percentage, with up to almost four meters in height between the lower and upper values of these process parameters. The absorber-packed height was increased with a higher removal percentage and was decreased with a higher diameter. Moreover, solution temperature and MEA composition were sensitive to the absorber-packed height. With high values of these process parameters, the packed height was decreased, but increasing these process parameters led to a greater corrosion rate [42]. The less sensitive process parameters to absorber-packed height were the gas temperature and the excess solution percentage, as can be seen in Figure 9.

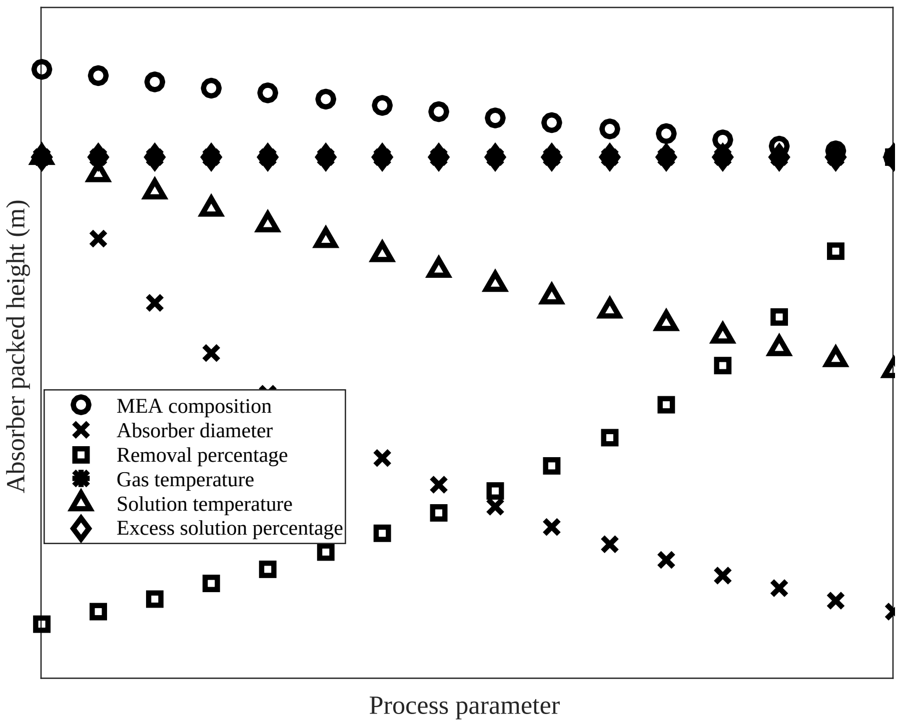

Figure 9. Process parameters sensitivity to absorber packed height.

The process parameter values of the absorption column were established through sensitivity analysis. First, the most sensitive parameters to the absorber packed height were analyzed, and their operating values were established (removal percentage and column diameter), then the following two sensitive variables were analyzed, and their operating values were established (solution temperature and MEA composition). The less sensitive parameters were established without analysis. The gas temperature was 40 °C, and the excess solution percentage was 10%.

NTU is directly proportional to the absorber-packed height. It calculates solving the material balance in the absorption column with the removal percentage and equilibrium data. The area under the equilibrium curve and the operating line increases as the CO_2 concentration gradient in the gaseous streams increases, therefore the height of the absorber-packed height increases. However, keeping the highest removal percentage in the absorption column improved the efficiency of the post-combustion CO_2 capture process. In this analysis, a removal percentage of 99% was established.

The HTU calculation requires solving the mass transfer coefficients and superficial velocities. The absorber diameter was required for the calculation. Considering structured packing size costs, it was not feasible to choose the largest diameter, nor the smallest diameter, since it increased the cost of the column size.

In this study, a column diameter of 3 m was established. It was the point where the behavior of the absorber-packed height as a function of column diameter was no longer exponential, and the changes in height were less (Figure 10).

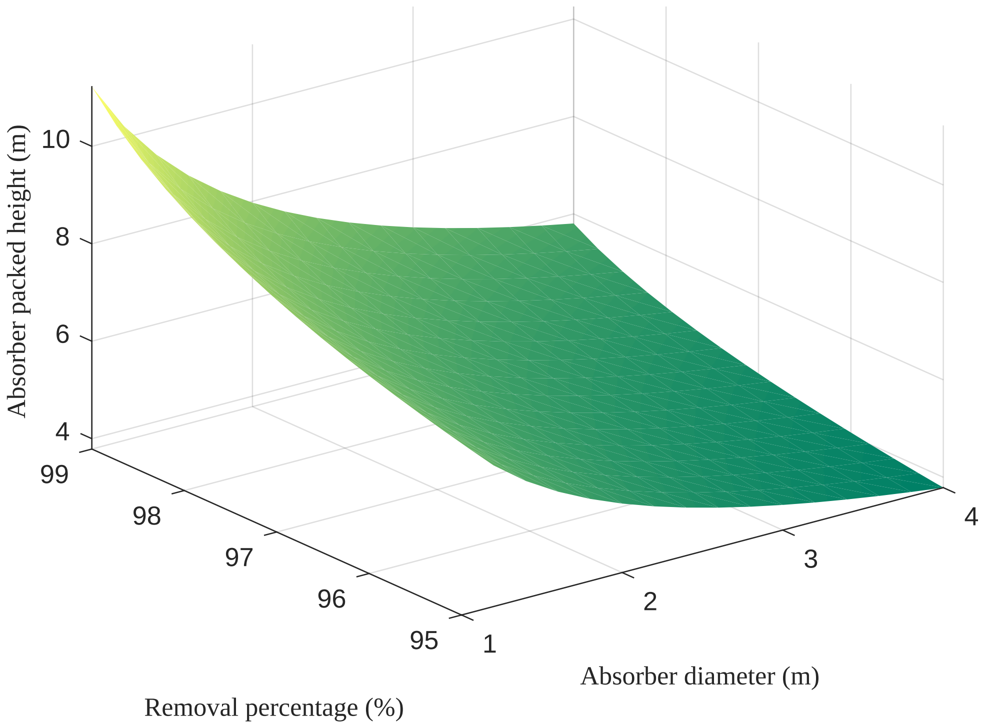

Figure 10. The absorber-packed height as a function to the removal percentage and column diameter.

The use of a higher MEA composition caused corrosion to the equipment, and the amine loss due to the degradation and evaporation with high solution temperatures generates pollutants to the environment [43]. The solution temperature was established at 40 °C with 20 wt.% MEA composition. Figure 11 shows the variation of the absorber-packed height at 40 °C for the different MEA compositions. A packed column height of 7 m was established.

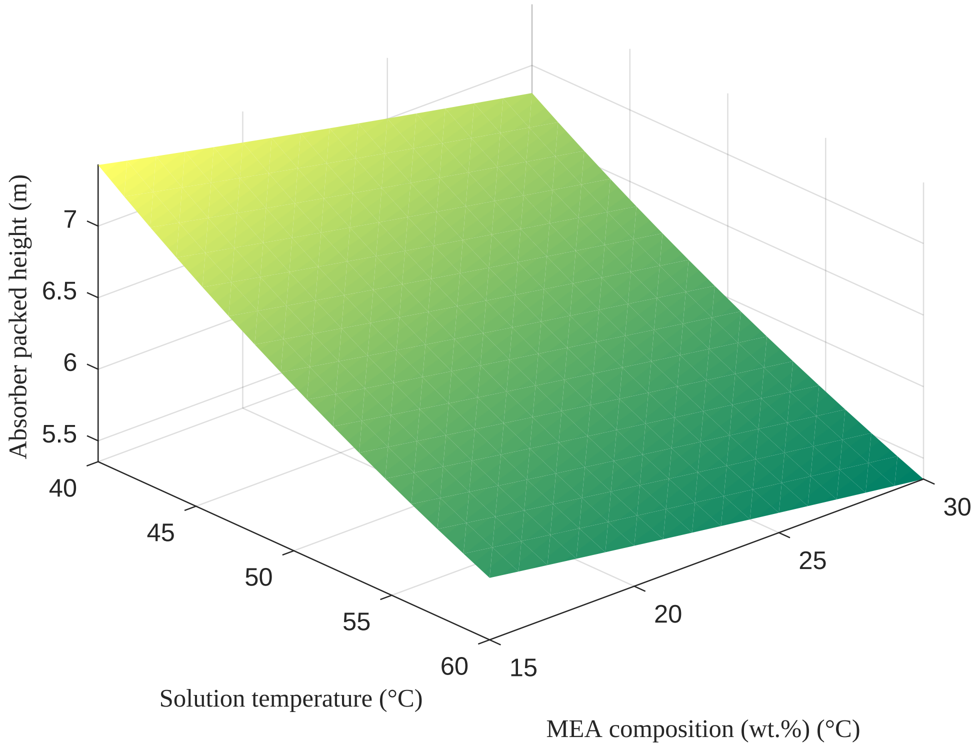

Figure 11. The absorber packed height as a function to the MEA composition and solution temperature.

In this study, absorption columns to remove CO_2 were used. Three columns were required to treat 279 kg/s of the exhaust from the combined cycle power plant. It will absorb 0.37 $MtCO_2$/year, having a favorable environmental impact. Table 9 shows the overall results for column absorption.

Table 9. Results of the baseline case.

Parameter	Value
Flue gas components	CO_2, O_2, N_2, H_2O
Operating pressure (kPa)	1.0
Temperature (°C)	40
Inlet flue gas flow-rate (t/h)	93
CO_2 (vol%)	3
Packing type	Mellapak 500 Y
MEA composition (wt.%)	20
Removal percentage (%)	99
Column diameter (m)	3
Absorber packed height (m)	7
Excess solution percentage (%)	10

Mexico reported that in 2020 it emitted 409 $MtCO_2$ into the atmosphere at the report of INEGyCEI (Inventario nacional de emisiones de gases y compuestos de efecto invernadero), 36% of CO_2 emissions correspond to the generation of electricity. In particular, combined cycle power plants emitted 36.18 Mt of CO_2, which is equivalent to 9% of total emissions. According to the results of this work, if post-combustion CO_2 capture technologies are implemented in combined cycle thermoelectric power plants, total CO_2 emissions would decrease by 8% of total emissions. Mexico will continue to generate 24,650.03 MW of power with almost zero CO_2 emissions through this technology. Starting the energy transition is a priority for all countries. This document has given the option of a technology that supports the high demand for electrical energy and is friendly to the environment.

7. Conclusions

The first cause of CO_2 emissions in Mexico is electricity generation from thermoelectric power plants. This paper describes a technological proposal to reduce CO_2 emissions in the combined cycle power plant and produce electricity in a sustainable way. Post-combustion CO_2 capture technology can be integrated into thermoelectric plants without modifying the power plant design. Instead, the combustion gases are transported to the absorption column through a heat exchanger. With this technology, 8% of total CO_2 emissions from combined cycle thermoelectric power plants can be reduced.

Post-combustion technology includes several process units. The packed absorption column was analyzed to establish the operating conditions for a height section packed, programming a mathematical modeling. The developed model solves the dimensions of the absorption column for treating concentrated and diluted gas flows, creating an analogue of a natural gas combined-cycle power plant or a coal–electric power plant, respectively. Unlike commercial software for simulating processes, the simulator developed in this work is user-friendly, and the flowsheet is easy for balance results checking.

The mathematical model was validated with data from a laboratory-scale absorption unit. The absorber-packed height was predicted by the simulator and developed with a deviation of 0–8% .

A combined cycle-electric power station was simulated to determine the dimensions of the absorption column necessary to remove the CO_2 contained in its exhaust gases. With several parametrizations, it was found that three columns treatment of a 3 m in diameter and 7 m in height removed 99% of the CO_2 contained in the flue gases with 20 wt.% of MEA composition using Mellapak 500Y structured packaging.

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Abbreviations

The following abbreviations are used in this manuscript:

NTU	number of overall transfer units
HTU	overall height of a mass transfer unit
MEA	monoethanolamine
CO_2	carbon dioxide

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