15° ENCONTRO BRASILEIRO SOBRE ADSORÇÃO
15th Brazilian Meeting about Adsorption

Moving bed temperature swing adsorption in pilot scale using zeolite 13X for post combustion CO_2 capture

Flavio Michels Bianchi[a], Pedro Rodrigo Silva Moura[a], Thiago Fernandes de Aquino[a], George Clark Bleyer[a], Rodrigo Almeida Silva da Costa[b]

[a] *Beneficent Association of the Santa Catarina Coal Industry (SATC), Pascoal Meller St. 73, Criciuma, SC - 88805-380, Brazil*
[b] *Eneva S.A., Botafogo Beach 501, Rio de Janeiro, RJ - 22250-040, Brazil*

Abstract

CO_2 emissions in the most diverse industrial segments have driven the search for technological alternatives for CO_2 capture worldwide. Properly technical solutions, such as the chemical absorption process, are available. However, the costs associated with these technologies are still high considering the energy penalty that current abatement systems bring to the final product. In this scenario, adsorption processes are one of the most promising alternatives to gas separation, since absorption requires a lot of energy to regenerate the involved solvents. The fossil-based thermoelectric generation sector is one of the most notable in the volume of greenhouse gas emissions. The US Department of Energy has made substantial progress in an attempt to reduce the costs of CO_2 capture. A process that can contribute to this reduction is temperature swing adsorption. In this context, the work aims to present the project of a pilot CO_2 capture plant that operates with a moving bed of 13X zeolites for temperature swing adsorption (TSA). The pilot plant is designed to capture 2 tons of CO_2 per day using a typical composition from natural gas and coal power plant. The system is being tested in two phases where in the first phase, average CO_2 removal from 25 to 54% was achieved with specific peaks of 84% capture. For phase two with mechanical modifications to the system, initial results pointed to an average reduction of approximately 60% with the expectation of reaching 90% at the end of the tests with improvements to the equipment. For the economic analysis of the process industrial application, the zeolite replacement was preponderant for the economics applicability of the project.

Keywords: Temperature Swing Adsorption; CO_2 Capture; Zeolite; Power Generation.

1. Introduction

Although accompanied by the growth of the shares related to renewable fuels, CO_2 emissions increased by 1.1% in 2023 compared to emissions in 2022, where emission levels once again exceeded pre-COVID-19 pandemic values [1].

While emissions from all fuels rose, the power sector accounted for nearly two-thirds of the emissions growth. This release of CO_2 into the atmosphere causes climate change, which requires urgent reduction in greenhouse gas emissions. Reducing the emission of this gas into the environment represents a challenge and an opportunity for technological development.

Coal used in thermoelectric plants carries the stigma of being a polluting fossil fuel due, among other reasons, to high CO_2 emissions. Beyond that, even with lower CO_2 concentration (around 4%), the emissions from natural gas power plants also need to be reduced to achieve the GHG-reducing compromise from different sectors. Therefore, many efforts have been made to develop technologies capable of sequestering CO_2 in fossil fuel conversion processes. Currently, the carbon dioxide capture from the combustion gases of power plants is one of the most critical issues in trying to solve the problem of global warming. However, carbon capture and storage (CCS) is a viable possibility to reduce emissions and then climate change. One of the big draws of CCS is that it could allow fossil fuels without contributing to global warming [2].

In this context, this work aims to present the project of a CO_2 capture plant on a pilot scale installed at the of Beneficent Association of Santa Catarina Coal Industry (SATC) that operates as a moving bed temperature swing adsorption with 13X zeolites for CO_2 separation.

This plant was planned to capture two tons of CO_2 per day and is currently in the second phase of tests for optimization.

2. Materials and methods

The concept used in the process of capturing CO_2 through temperature fluctuations in post-combustion coal-fired thermal plants is directly linked to the use of surplus heat from the plant. In this case, as shown in Figure 1, a conventional thermoelectric generation system based on a Rankine cycle does not undergo major process modifications since the capture system is coupled at the end of the process (chimney).

If the plant has cold gas cleaning systems such as bag filters, gas scrubbers, and even cold side electrostatic precipitator must be replaced with a hot side electrostatic precipitator since this type of device the particulate matter is removed without the need for temperature reduction, keeping hot gases in usable condition in the CO_2 temperature swing capture system. For the application of the MBTSA in a natural gas combined cycle power plant, part of heat to regenerate the zeolites can come from the flues gas and the another from the steam. In this case the power penalties need to be quantified case to case and an external heat generation can be pointed.

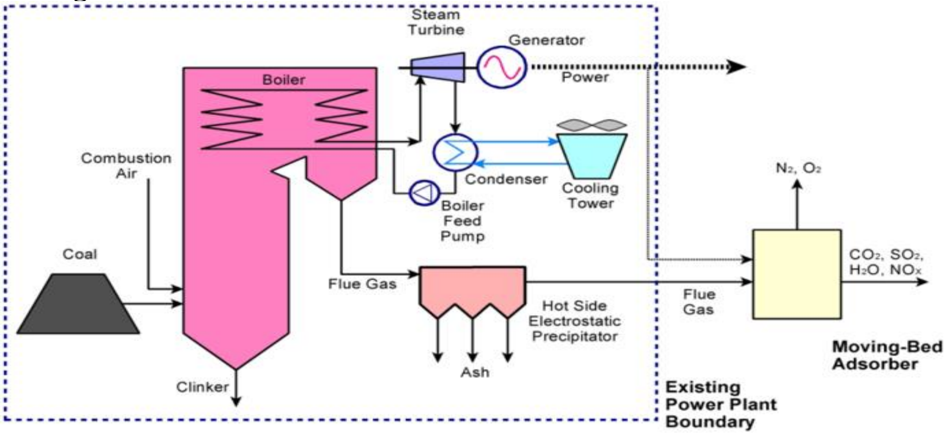

Fig. 1 MBTSA layout at power plant

The concept of adsorption by moving bed temperature fluctuation is based on a traditional adsorption process, typically carried out in batches, but in this case occurs continuously. A schematic configuration of the moving bed temperature swing adsorption process (MBTSA) is illustrated in Figure 2. The system is divided into four sections: adsorption section, preheating section, regeneration section, and heat recovery section.

The system continuously applies an average zeolite recirculation rate of 25 to 75 kg/min. The zeolite particles used in the system are spherical with an average size of 2.1 mm and are fed at the top of the column, that is, at the entrance to the adsorption section.

This zone is made up of perforated plates that aim to increase the contact time between the zeolites and the combustion gas that enters the countercurrent at the bottom of the zone.

Looking at the process through the zeolite path, it is inserted at the top of the column where at low temperatures (less than 50 °C) it is placed in direct contact with the cooled exhaust gas where CO_2 is captured.

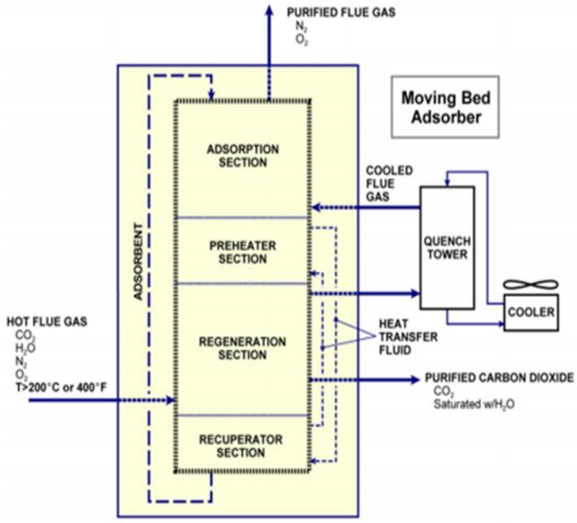

Fig 2 MBTSA simplified scheme [3]

After adsorption, the material begins to move slowly through the movement of a moving bed where the purpose is to gain temperature until regeneration.

In the regeneration zone, the zeolites reach the temperature for regeneration to take place and then a slight vacuum is applied to the column that removes a stream rich in CO_2 from the system.

After regeneration, a plate exchanger is located in the heat recovery zone, where the zeolite is finally cooled until it reaches temperatures suitable for adsorption again. Then is carried by a bucket elevator to the top of the column.

To generate flue gas, around 2 to 7 m^3/h of liquefied petroleum gas (LPG) are burned, obtaining a CO_2 concentration that can vary from 3 to 12% when the system reaches a stable operating condition. New CO_2 concentrations can be modulated from the recirculation of purified gas (rich in nitrogen) or diluted with air. More concentrated CO_2 gas can be done using recirculation of the CO_2 rich stream that was captured, thus allowing a wide range of tests from the variation in gas composition.

The test planning was split into two phases, with eight main tests being carried out in the first phase, where the solid, gas flow rates and gas inlet temperature were changed. Table 1 presents the test planning for phase 1.

Phase 2 is in progress, and only initial tests were carried out using the same test matrix as phase 1, but with many modifications and improvements necessary for the original project to work better.

Table 1. Phase 1 adsorption test planning

Run	Solid rate [kg/min]	Gas Inlet [°C]	Gas rate [m³/h]
1	37	500	100
2	25	500	100
3	25	300	250
4	37	300	100
5	37	300	250
6	49	300	250
7	37	300	100
8	49	300	50

3. Results

To carry out phase 1 tests, the equipment was previously heated by burning LPG and, based on temperatures considered suitable for the start of thermal exchange, the movement of the zeolite inventory through the system began.

The originally designed system did not perform as expected, requiring changes, mainly the installation of a quench tower to cool the exhaust gases before direct contact with the zeolites to activate the adsorption zone. After this installation, the inlet gas reached temperatures of around 20°C, making it possible to obtain CO_2 capture data.

Preliminary tests indicated the need of improvements in the heat recovery section to cool the zeolites before returning to the adsorption zone. Therefore, the tests carried out in phase 1 did not reach prolonged durations, since, as the test progressed the zeolites did not reach the necessary cooling to return regenerated to the adsorption zone, thus reducing the capture efficiency in this zone.

Table 2 summarizes the main results of the phase 1 test schedule.

After carrying out tests in the adsorption condition, the best tests showed an average removal of CO_2 between 25.71% and 54.71%, with a levelized cost of around US$ 70 per ton of CO_2 captured. These values should be largely reduced after system optimization in phase 2.

Table 2. Phase 1 adsorption test results

Run	Max. CO_2 Removal	Avg. CO_2 Removal
1	48.28%	43.51%
2	47.72%	37.16%
3	9.27%	6.53%
4	44.00%	32.71%
5	32.00%	25.71%
6	15.91%	10.00%
7	42.00%	24.00%
8	84.18%	54.71%

There is a work in progress at phase 2 of this project, then the preliminary results with no all modifications done show us better operation than phase 1. The first results point to more stability of the system and minor powder formation by zeolite wear.

In addition, the preliminary test results suggest removal percentages of around 60% of capture as shown in Figure 3.

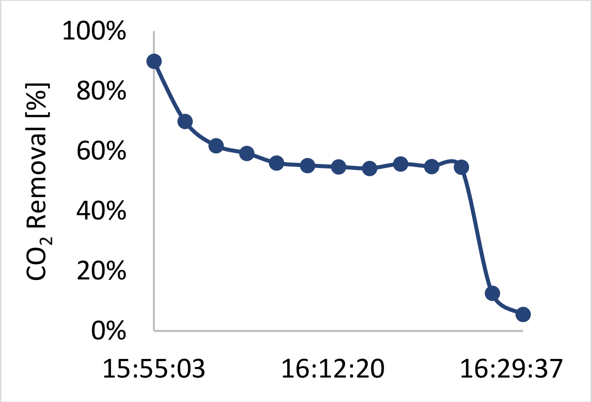

Fig 3 - Preliminary phase 2 CO_2 removal results

For the economic viability of the process, a base case was simulated for capturing CO_2 in a plant with 360 MW of net power, indicating a levelized costs below US$ 50 per ton of CO_2, with possibility of reduction with technological learning and process improvements.

The most significant cost component is variable O&M. The largest portion is associated with the cost of replacing zeolites in the process, depending on the defined make-up rate. By varying this rate, it was found that there is a great sensitivity of costs regarded to this parameter.

4. Conclusion

The designed system did not perform as expected, requiring changes to do better operation. The installation of a quench tower to cool the exhaust gases before direct contact with the zeolites was necessary to activate the adsorption zone. After installation, the inlet gas reached temperatures of around 20°C, making it possible to obtain CO_2 capture data.

Preliminary tests indicated the need for improvements in the heat recovery section to cool the zeolites before returning to the adsorption zone.

After tests in the adsorption condition, the best results showed an average removal of CO_2 between 25.71% and 54.71%, with a levelized cost of around US$ 70 per ton of CO_2 captured. These values should be largely reduced after system optimization in phase 2.

For phase two with mechanical modifications to the system, initial results pointed to an average reduction of approximately 60% with the expectation of reaching 90% at the end of the tests with improvements to the equipment.

Acknowledgements

The authors would like to thank ENEVA S.A. for supporting this research in accordance with the regulations of the Research, Development, and Innovation Program (PD&I) of the National Electric Energy Agency (ANEEL).

References

[1] International Energy Agency (IEA). CO_2 emissions in 2023. IEA, Paris https://www.iea.org/reports/co2-emissions-in-2023. 2024.
[2] Silva FTF da, Szklo A, Schaeffer R, Rochedo P. Carbon retrieving: Missing opportunities for a just transition in the Coal Industry. Energy and Climate Change. 2024.
[3] Knaebel K. Temperature swing adsorption system. Dublin, Ohio, USA, 2009.