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Designing and Demonstrating a Master Student Project To Explore Carbon Dioxide Capture Technology

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Supporting Information

ABSTRACT: The rise in carbon dioxide (CO_2) concentration in the Earth's atmosphere, and the associated strengthening of the greenhouse effect, requires the development of low carbon technologies. New carbon capture processes are being developed to remove CO_2 that would otherwise be emitted from industrial processes and fossil fuel power stations. Given the increasing importance of this technology, we report on a new educational project, which is aimed to instill greater awareness of the role of CO_2 in climate change while stimulating student interest in science, technology, engineering, and the environment. The project was carried out by master students, that is, $Cool_LCap$ team, who contributed to the design and manufacture of a pilot plant that demonstrates the basic operation of an amine scrubbing plant. The main goal of the project was to develop educational material and presentations for a range of audiences, from primary school to university students and academics. In this article, we present the project team's approach to design, commission, and deliver the pilot plant and educational material as well as the feedback received from 267 students from a primary school and a university. We provide additional information to enable other educators to recreate our pilot plant design.

KEYWORDS: *General Public, Elementary/Middle School Science, High School/Introductory Chemistry, Chemical Engineering, Environmental Chemistry, Public Understanding/Outreach, Communication/Writing, Laboratory Equipment/Apparatus*

■ INTRODUCTION

The increase of the greenhouse effect is known as a worldwide issue partly due to human activities.[1−4] Global warming, sustainable development, and greenhouse effect are taught at primary school or university. To reduce the consequences of human activities on the climate, it is not only essential to develop new technologies, but also to raise awareness among the young generation and the nonscientific community.[5] At our department, we have reached to the conclusion that it could be an excellent challenge for master students to carry out such project.

The Coo_LCap project, which is a kind of acronym for CO_2 capture in liquid phase, was created. This project was carried out by successively two groups of eight master students of the engineering school INSA Rouen (France). The ambition of this project was to introduce carbon capture technologies to different audiences by having an interactive dialogue. This project had three main objectives:

(1) To experience a team project for master students involving client relationship.
(2) To build transportable lab-scale pilot based on chemical absorption and desorption of CO_2 (Figure 1).
(3) To demonstrate and explain the technologies[6] to broad audiences with a pedagogical strategy.

For the sake of clarity, the master students who have organized the project are named Coo_LCap team in the manuscript. Several events were organized by the Coo_LCap team to meet groups of students, from primary school to university, to present and show the pilot. The purpose of the demonstrations included developing children's interest in science by showing them that chemistry can be used to reduce the greenhouse effect. Moreover, the instrumentation used to make the pilot work was presented.

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Figure 1. Carbon dioxide capture pilot plant designed and manufactured by the student project team.

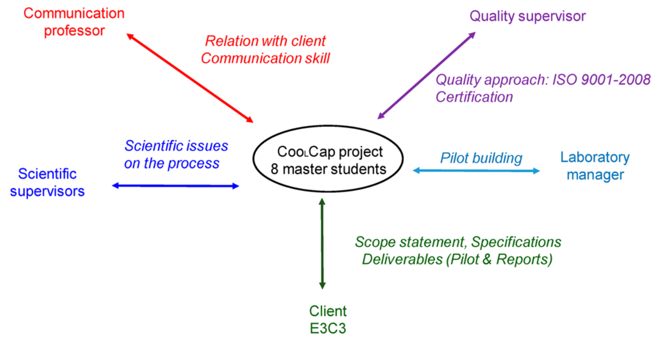

Figure 2. Different actors participating in the Cool$_L$Cap project.

The goal of this article is mainly to present the carbon capture technologies and the pilot. The work team experience of the Coo$_L$Cap project is briefly discussed.

TEAM PROJECT

This chapter introduces the Coo$_L$Cap project framework. At our university, master students should perform a project, named PIC project, which is a certified INSA. The team project is composed of eight students from the master of industrial and environmental risks management. The project is one academic year, and two workdays per week are dedicated to realize the PIC project. The PIC project should follow a quality approach, that is, ISO 9001−2008. The PIC students are supervised by a quality supervisor during their project to obtain the certification at the end. A teaching staff member (scientific supervisor) supervises the team project to ensure extensive theoretical basis. A contract is signed with an industrial or academic client to define the different products to deliver. The evaluation of the PIC project is done four times per year. For the Coo$_L$Cap project, the client was a European program, named E3C3. One of the goals of E3C3 was to promote sustainable development and, more precisely, to improve knowledge and create tools to carry out clean combustion and biomass combustion. The Coo$_L$Cap team was also mentored by a communication teacher to improve the communication skills of the team. It included interpersonal communication in the team and with the client. Also, the communication teacher helped the team to carry out presentations about the progress of the project. In the case of the Coo$_L$Cap project, the laboratory manager has helped the student for the pilot building. Figure 2 illustrates the interaction between the different actors of the Coo$_L$Cap project.

DEVELOPMENT OF A PILOT FOR CARBON CAPTURE

Carbon capture is a decarbonization technology (also known as decarburization technology) that has been designed to capture carbon dioxide generated by combustion reactions in industrial applications.[6] Therefore, this technology abates CO_2 emissions into the atmosphere. In 2011, there were 89 CO_2 capture and storage (CCS) demonstration projects or pilots in the United States.[7] For example, a CCS technology has been in place since 1996 on the Sleipner offshore gas field (Norway) located in the central North Sea. On this field, CO_2 is both captured and stored into a dedicated well.[8] More recently, a carbon capture power plant was launched in 2014 at Boundary Dam Power Station in Saskatchewan (Canada), and its goal is to capture 1 million tons of CO_2 every year to reduce CO_2 emissions by 90%.[8] In 2011, the Laboratory of Chemical Process Safety (Laboratoire de Sécurité des Procédés Chimiques LSPC, INSA Rouen - Université Rouen) has contributed to the scale up of a large-scale pilot, in association with Veolia Environment, for a waste incinerator in Normandy (France).[9,10]

Different chemical processes can be used to capture and regenerate pure CO_2. A suitable solution to integrate carbon capture into an existing combustion process is to modify the postcombustion unit (Figure 3). It is also known as the downstream modification of the existing CO_2 emitting process. The postcombustion carbon capture is based on absorption and desorption phenomena. Those chemical principles are used to absorb CO_2 and separate it from other gases resulting from a combustion reaction. The flue gas is first absorbed into a solvent, for example, monoethanolamine (MEA), and CO_2 can then be regenerated by altering the thermodynamic conditions of the CO_2-loaded solvent (e.g., by increasing its temperature).[11]

Design and Operation of the Carbon Capture and Storage Pilot Plant

The pilot plant performed the carbon dioxide capture process through absorption using a chemical solvent. An amine-based solvent was selected to absorb CO_2 due to the strong chemical affinity between the two compounds. There are different types of amine that allow CO_2 capture. Most of the commercial plants use monoethanolamine (MEA). This aqueous primary amine is commonly used for postcombustion separation processes,[12,13] as it is highly reactive with CO_2, inexpensive, and readily available.[14] The absorption occurs in accordance with the following reaction equation:

$$2(C_2H_4OH)NH_2 + CO_2 \rightleftarrows (C_2H_4OH)NH_3^+ + (C_2H_4OH)NHCOO^-$$

The CO_2 present in the flue gases is normally pumped into the carbon dioxide scrubber and then cooled down by a heat exchanger. The cooled effluent gas is then fed into the bottom of an absorption column and propagates up through packing material. A counter flow of MEA is produced by nozzles located at the top of the absorption column and propagates down, contacting with the gases through the packing material. The

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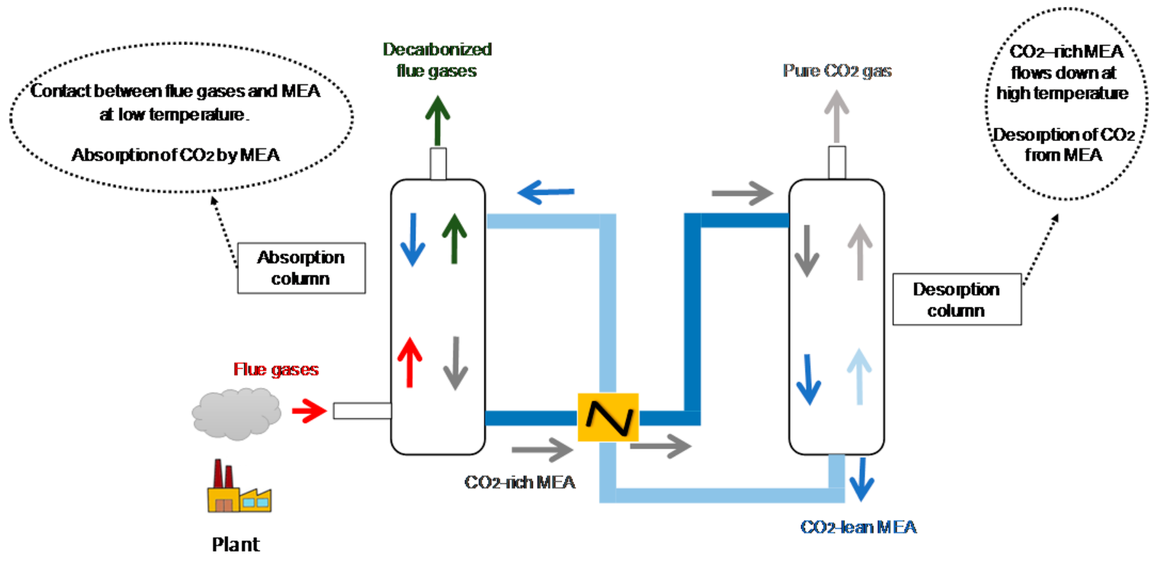

Figure 3. Schematic of the carbon capture chemical process.

packing material improves contact between the gas and the liquid phases, thus increasing the absorption rate of the CO_2. The CO_2-loaded MEA flows down to the bottom of the column, while the decarbonized effluent gas rises up to the top of the column and can be released from the scrubber. The absorption generally occurs at atmospheric pressure and at temperature of approximately 50 °C.

The loaded MEA is then pumped and heated up to 70 °C before being introduced at the top of an air stripper. The liquid in the column is heated to 100 °C, and the pressure remains at 1 bar. The increased temperature activates the desorption of CO_2 from the MEA, which remains in the liquid state. Once released, the gaseous CO_2 can be extracted from the top of the desorption column. The extracted gas is then cooled down with a water heat exchanger to condensate the water and solvent steam and to obtain pure CO_2 gas. The CO_2-lean MEA that remains in the desorption column is pumped out of the column and cooled down through a heat exchanger using the water and CO_2-rich MEA flows. MEA is then regenerated and returned to the absorption column to be reused in a closed-loop cycle (Figure 3).[9−11,13−15]

Adapting the Pilot Plant for Educational Outreach Purposes

The lab-scale pilot plant described above, and shown in Figure 1, was commissioned by the Coo_LCap team as a visual aid to demonstrate concretely the theoretical and operating principles of carbon capture to a broad audience. The pilot was placed in a mobile cabinet (1.2 m long, 1.8 m high, 0.6 m deep) fitted with casters to facilitate transportation.

The design and pilot appearance were specifically customized like a pilot plant to make it more informative to young audiences. Industrial activity was illustrated with a miniature factory made of steel. An alcohol lamp burned to represent industrial combustion and created some effluent gas, which was then aspirated into the pilot and to the absorption column.

The MEA can also be dyed yellow to improve the visualization of its circulation through the pilot plant by the addition of a small amount of fluorescein (a few milligrams).

At the end of the desorption process, experiments were used to demonstrate that the gas extracted from the desorption column contains mostly CO_2. For example, limewater was used in a laboratory flask and connected to the end of the process. Limewater becomes cloudy when exposed to CO_2 because of the formation of a precipitate, thus demonstrating the presence of CO_2 in the gas extracted from the desorption column.

Moreover, to illustrate the geological storage of CO_2, the outlet of the desorption column was connected to a vase full of sand, representing geological layers. A vacuum was generated in the center of the vase to draw the gas through the vase. This is the technology of CCS. The transformation or valorization of CO_2 to chemicals, fuels, or its use as a solvent was also discussed. This is the technology of carbon capture and utilization (CCU).

■ EDUCATIONAL APPROACH

The demonstration had a number of education objectives:

(1) To raise awareness of the greenhouse effect among children.
(2) To present a new technology that can help to reduce CO_2 emissions.
(3) To show that chemistry can be useful to find concrete solutions to problems such as global warming.
(4) To share information about chemical principles: absorption and desorption phenomena between CO_2 and an amine-based solvent.
(5) To promote science and chemistry to children.

The demonstrations were tailored to the age of the audience but always based on the same framework. The greenhouse effect and global warming were explained or reminded as an introduction, and then the carbon capture technology was presented using the pilot plant and some interactive chemical experiments. The ways in which we adapted our pedagogical approach for primary school, high school, and university students were based on effective communication strategies and recommended good practices[16,17] and described in the next sections.

Presentation Carried Out

The Coo_LCap team carried out presentations to several groups in schools and universities:

(1) Four groups of 10−30 high school students.
(2) Two groups of 10 and 17 masters students.

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(3) Three groups of 15−30 bachelor students.
(4) Eight groups of 30 primary school students.

The project team took part in the French national science festival "Fête de la Science" for 3 days in October 2014. This included presentations and demonstrations to several-hundred students from primary school to university levels. In the following sections, we present our approach to tailoring the learning experience to audiences from a primary school and a high school.

Primary School

The Coo_LCap team carried out presentations and interactive demonstrations at a British primary school, with students from 7−12 years of age. They were grouped into classes of 30 students of similar ages. The aim was to make the presentation as interactive as possible and to have a series of discussions with the children. To maintain the younger audience's attention, the demonstrations lasted no more than 30 min. Prior to these presentations, the learning objectives and lesson plans were presented to the class teachers so they could introduce the topic to provide complementary information about chemistry fundamentals including chemical reactions or basic thermodynamics.

The first part of the demonstration reviewed concepts of the greenhouse effect and global warming to make the children aware of these environmental issues and to explain the need for CO_2 capture technologies. First, the project team asked what they already knew about the greenhouse effect and global warming. The majority of students already had notions about climate change. The purpose was to add scientific notions about solar radiation, greenhouse gases, and the global increase in the Earth's surface temperature. This discussion was supported by a model (Figure 4), which facilitated the step-by-step demonstration of the propagation and reflection of the Sun's rays through the atmosphere. Different solutions to reduce CO_2 emissions were discussed with the children, the CCS and CCU technologies were then presented as a possible solution to diminish the release of industrially generated CO_2 into the atmosphere.

Figure 4. Model used to explain the greenhouse effect.

In the second part of the demonstration, the operating principle of carbon capture was explained and demonstrated using the pilot plant. This helped the children better understand the various steps of the process and how the absorption and desorption phenomena occur in such plants. From a chemical point of view, only the absorption and desorption phenomena were described through the chemical reaction and the affinity between MEA and CO_2. Images were used to support the explanation of this chemical principle. One example we used was to compare the solvent to a train, which collected CO_2 "passengers" inside the absorption column and dropped them off in the desorption column. Another way to explain this process was to suggest that MEA swallows CO_2 molecules in the absorption column and releases them in the desorption column. After the chemical process was explained, CO_2 storage was then explained with the visual support from a vase full of colored sands representing the sedimentary layers and the well used to store the extracted carbon dioxide.

The third part of the presentation consisted of carrying out two experiments to highlight the phenomena of absorption and desorption. Those simple experiments helped the public engage with the presentation and participate in the demonstration.

Experiment To Show the Absorption Phenomenon. The first experiment highlighted the phenomenon of absorption of carbon dioxide by MEA in the absorption column. For this purpose, we used 20 mL of a sodium hydroxide solution at a concentration of 2 mol L^{-1}. Since NaOH is a base, it has similar properties to MEA regarding the absorption of CO_2,[18] but it has the advantage of being less corrosive and toxic than MEA. Thus, the experiments can be carried out more safely than with MEA.

The experiment required two empty plastic bottles of 0.5 L and one volumetric pipet. One of the plastic bottles was filled with CO_2 in advance, while the second bottle was full of air. By using the pipet, 10 mL of the sodium hydroxide solution was then inserted in both bottles, and the bottles were sealed. Two students were asked to volunteer to shake the bottles for few seconds. Then the audience could compare the two bottles: one bottle had contracted and became warmer, while the other one had remained unchanged (Figure 5). The NaOH solution absorbs CO_2 but not air, hence only the bottle that contained CO_2 had contracted. This interactive demonstration helped support the explanation that liquid solvents can absorb gaseous CO_2. This simple experiment provided a visual support for explaining that the bottle full of CO_2 had contracted due to the CO_2 molecules being absorbed by the NaOH solution. Since this is an exothermic reaction, it generated heat and warmed the

Figure 5. Plastic bottles filled with sodium hydroxide solution and CO_2 (left), and filled with sodium hydroxide solution and air (right). The NaOH solution absorbs CO_2 but not air, hence only the bottle that contains CO_2 has contracted. This interactive demonstration helped support the explanation that liquid solvents could absorb gaseous CO_2.

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bottle up. This phenomenon was described with an increasing level of detail to high school and university students who have prior knowledge of chemical reactions.

Experiment To Show the Desorption Phenomenon. The second experiment demonstrated the phenomenon of CO_2 desorption. As mentioned previously, CO_2 can transfer into the gas phase by increasing the temperature of the solvent. To demonstrate this process, a beaker was filled with cold water (approximately 5 °C), while another one was filled with hot water (approximately 40 °C). Then two test tubes were filled with a soft drink (carbonated beverage) and partially closed with a pierced lid. These two test tubes were turned upside down, blocking the pierced lid with the thumb, and plunged into the two water beakers. The experimenter could then release the pierced lids and let the desorption phenomenon occur. After a few minutes, it could be observed that the level of soft drink in the test tube plunged in the hot water beaker decreased, while the level of soft drink in the cold test tube remained constant (Figure 6).

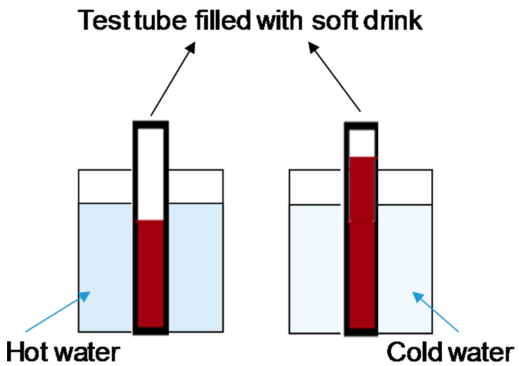

Figure 6. Schematic representation of the desorption experiment with a warm water beaker (left) and a cold water beaker (right). This demonstrated the influence of temperature on the solubility of carbon dioxide in a liquid solvent and that the added heat enabled the desorption of CO_2.

This experiment demonstrated to the children the influence of temperature on the solubility of carbon dioxide in a liquid solvent and that the heat enabled the desorption of CO_2. As a result of this desorption, the pressure above the soft drink increased, and the level of liquid in the test tube reduced.

High School

The primary school presentation was adapted for older students from high schools and universities. The demonstrations lasted between 45 min and 1 h, including more technically and scientifically detailed explanations. Since the students already have prior knowledge of the greenhouse effect, the project team presented facts and data about the international context of climate change, and the United Nations' agreements to develop new technologies for the reduction of anthropogenic production of CO_2. The CCS and CCU technologies were presented as one of the potential solutions. The three carbon capture methods were introduced: the oxyfuel-combustion, precombustion, and postcombustion capture. Details were given about the combustion reaction, about the differences between the methods, and how they were used in industrial processes. The postcombustion capture was used for the pilot plant. Hence, this process was explained in more details, and supported by the pilot plant, with a view of the way the exhaust gases and the solvent propagate through the absorption column, the heat exchangers, and the air stripper. The chemical reactions and the thermodynamic conditions, such as molecule groups, temperature, and pressure, were more detailed than for the younger audience. The topic was also discussed with the students' teachers to extend the learning beyond our interactive demonstration and to cover some of the fundamental principles linked to these chemical processes. Storage and transformation of carbon dioxide were then presented, including the different geological layers that can be used for storage, and the industrial sectors that can reuse carbon dioxide. We observed that the students were particularly interested in the industrial aspects of the technology such as how to incorporate the system in global industrial processes. They were also interested in the technical details of the carbon capture process.

■ STUDENT FEEDBACK

To evaluate the delivery of our demonstrations and the interest of the students, we gave questionnaires to the audience after our presentations. Two types of feedback forms were prepared: one for students under the age of 11, and one for older students. For the presentation at the primary school, 90% of the 240 students were satisfied with the presentation and enjoyed the experiments. From the survey, 81% understood very much the greenhouse effect, 16% understood a little, and 3% answered they did not understand it. From the survey, 77% understood very much the CO_2 capture, and 23% understood a little (see Figure 2, Supporting Information).

The feedback for the older audience asked more specific questions including their level of satisfaction with the presentation: the visual aids, the duration, the exchanges with the team, and the level of technical detail. They were also asked if the presentation was adapted to their prior knowledge and if they understood the different elements. To give an example, for 27 master students in mechanical engineering, 96% were satisfied by the presentation, with 52% totally satisfied, 44% very much satisfied, and 4% a little. The talk was globally understood by 96% of the students, 41% understood completely, 52% very much, and 7% a little. The analysis of the feedback forms indicates that the demonstrations were generally appreciated and well understood (see Figure 3, Supporting Information).

■ CONCLUSIONS

We presented a new and innovative approach to demonstrate carbon capture technology while supporting the learning of chemical processes to a wide range of audiences. The challenges of presenting a complex technology, and the chemical reaction between a liquid solvent and gaseous CO_2, to primary school students were overcome through visually simple and hands-on experiments supported by a purpose-built pilot plant. The educational pilot plant we designed and built can be replicated to demonstrate chemistry notions in a novel and interactive way. The feedback we received from 267 primary school students and master students suggests that the educational approach we have described in this article stimulated student interest in science and technology while improving their awareness of the challenges posed by the strengthening of the greenhouse effect and the impact on climate change.

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00073.

> Construction of carbon dioxide capture pilot plant; equipment for the pilot plant; pilot plant startup procedure; pilot plant shutdown procedure; process flow diagram of the carbon dioxide capture pilot plant; feedback results from masters students in mechanical engineering from the University of Brighton (Brighton, U.K.); feedback results from the students of the Glebe Primary School (Southwick, U.K.) (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) NASA. *Climate Change: How do we know?*. http://climate.nasa.gov/evidence (accessed December 2014).

(2) Intergovernmental Panel on Climate Change (IPCC). Chapter 8 Anthropogenic and Natural Radiative Forcing. In *Climate Change 2013: The Physical Science Basis*. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf (accessed December 2014).

(3) American Association for Advancement of Science. *AAAS Board Releases New Statement on Climate Change*. http://www.aaas.org/news/aaas-board-releases-new-statement-climate-change (accessed December 2014).

(4) United Nations Framework Convention on Climate Change. *Kyoto Protocol*. http://unfccc.int/kyoto_protocol/items/2830.php (accessed January 2015).

(5) Flener-Lovitt, C. Using the Socioscientific Context of Climate Change to Teach Chemical Content and the Nature of Science. *J. Chem. Educ.* **2014**, *91* (10), 1587−1593.

(6) Al-Fattah, S. M.; Barghouty, M. F.; Dabbousi, B. O. King Abdullah Petroleum Studies, Chapter 1: CCS in a Global Context. In *Carbon Capture and Storage: Technologies, Policies, Economics, and Implementation Strategies*; CRC Press/Balkema: Boca Raton, FL, 2011; pp 3−10.

(7) Zhao, R.; Deng, S.; Zhao, L.; Liu, Y.; Tan, Y. Energy-saving Pathway Exploration of CCS Integrated with Solar Energy: Literature Research and Comparative Analysis. *Energy Convers. Manage.* **2015**, *102*, 66−80.

(8) Mumford, K. A.; Wu, Y.; Smith, K. H.; Stevens, G. W. Review of Solvent based Carbon-dioxide Capture Technologies. *Front. Chem. Sci. Eng.* **2015**, *9* (2), 125−141.

(9) Aouini, I.; Ledoux, A.; Estel, L.; Mary, S. Pilot Plant Studies for CO_2 Capture from Waste Incinerator Flue Gas Using MEA Based Solvent. *Oil Gas Sci. Technol.* **2014**, *69* (6), 1091−1104.

(10) Aouini I. *Captage du dioxyde de carbone en postcombustion - Application à un incinérateur de déchets industriels*. PhD Thesis, LSPC INSA, Rouen, 2012.

(11) Al-Fattah, Saud M.; Barghouty, M. F.; Dabbousi, B. O. King Abdullah Petroleum Studies, Chapter 3: CO_2 Capture and Separation. In *Carbon Capture and Storage: Technologies, Policies, Economics, and Implementation Strategies*; CRC Press/Balkema: Boca Raton, FL, 2011; pp 119−124.

(12) Nuchitprasittichai, A.; Cremaschi, S. Sensitivity of Amine-based CO_2 Capture Cost: The Influences of CO_2 Concentration in Flue Gas and Utility Cost Fluctuations. *Int. J. Greenhouse Gas Control* **2013**, *13*, 34−43.

(13) Han, C.; Graves, K.; Neathery, J.; Liu, K. Simulation of the Energy Consumption of CO_2 Capture by Aqueous Monoethanolamine in Pilot Plant. *Energy and Environment Research* **2011**, *1* (1), 67−80.

(14) Yang, Qi; James, S.; Ballard, M.; Bown, M.; Attalla, M. Chapter 2: Influence of Amine Chemical Structures to Amine Capacities in CO_2 Capture. In *Recent Advances in Post-Combustion CO_2 Capture Chemistry*; American Chemical Society: Washington, DC, 2012; pp 29−42.

(15) Yeh, J. T.; Pennline, H. W.; Resnik, K. P. Study of CO_2 Absorption and Desorption in a Packed Column. *Energy Fuels* **2001**, *15* (2), 274−278.

(16) Schwan, S.; Grajal, A.; Lewalter, D. Understanding and Engagement in Places of Science Experience: Science Museums, Science Centers, Zoos, and Aquariums. *Educational Psychologist* **2014**, *49* (2), 70−85.

(17) Sinatra, G. M.; Kienhues, D.; Hofer, B. K. Addressing Challenges to Public Understanding of Science: Epistemic Cognition, Motivated Reasoning, and Conceptual Change. *Educational Psychologist* **2014**, *49* (2), 123−138.

(18) Mahmoudkhani, M.; Keith, D. W. Low-energy Sodium Hydroxide Recovery for CO_2 Capture from Atmospheric Air—Thermodynamic Analysis. *Int. J. Greenhouse Gas Control* **2009**, *3* (4), 376−384.