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CARBON DIOXIDE CAPTURE: THERMOPHYSICAL PROPERTIES AND PROCESS DESIGN (THE TAIWAN EXPERIENCE)

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Abstract

The paper, in general, discusses carbon dioxide capture research and in particular, the involvement of thermophysical properties characterization and process design simulation using the author's personal research experience in Taiwan.

Keywords: Absorption, carbon dioxide capture, process simulation, thermophysical properties

Objectives of CO_2 Capture

Capture and sequestration of CO_2 initially started as an economic issue before 1980 before it was considered as a moral issue in the early 90's. Before, they capture CO_2 for the sole aim of gas sweetening (purification) to reduce the capital cost incurred by the production of acids, which corrode the pipelines and equipment. The issue elevate to a moral responsibility when the global warming phenomenon was discovered. It was the effort of Ex-Vice President Al Gore of USA and the Intergovernmental Panel on Climate Change (IPCC) that awakens the public about the potential hazards of increasing CO_2 emissions. With their efforts, they were given the Nobel Peace Prize in 2007 for disseminating information on global warming.

CO_2 Emissions in Taiwan and the World

An exponential increase in the population and the dramatic growth in the energy consumption of most nations were seen during the 20^{th} century. Today, as the developing countries with high populations become more industrialized, the demand for energy consumption increased significantly (Gielen and Podkanski 2004). Despite the fact that numerous nations have promoted the involvement of different energy incomes (solar energy, wind energy, geothermal energy, etc.), still 95% of their energy sources are generated by coal-fired power plants and fossil fuels (Yang et al. 2008; Li et al. 2011). These power plants are the main generators of energy for transportation purposes and for the production of electricity, cement, and steel. However, these industries are also responsible for 50% of the total CO_2 emissions worldwide due to the combustion process needed for coal and fossil fuels to produce energy (Carapellucci and Milazzo 2003). Due to these anthropogenic activities, excessive amounts of CO_2 are emitted into the atmosphere that trapped disproportionate heat and pave the way for the phenomena of global warming and climate change (Preston et al. 2006; Yamasaki 2003).

Greenhouses gases such as CO_2, CH_4, NO_2, HFCs, PFCs, and SF_6 are the culprits for the global warming and climate change. Of these, CO_2 contributes the most (more than 60%). Before the industrial revolution (end of 18th century), the CO_2 level is around 280 ppm but the rate increase in concentration moves up rapidly in the last decades: 315 ppm in 1950 and 381 ppm in 2006. The concentration was predicted to increase to 550 ppm in 2030 and probably shoots up to 970 ppm by 2100 if the current rate continues.

Tables 1 and 2 presented the world ranking (top 10) on the total CO_2 discharge and average personal CO_2 discharge, respectively. Taiwan's total CO_2 discharge and personal CO_2 discharge are 264 Mtons/yr and 12 tons/person, respectively. Taiwan is not included in the list because it is not recognized as a country. From 1990 to 2004, CO_2 discharge in Taiwan increased by 110% (4 times of increase, in the world; personal discharge of 12 tons/person is 3 times, in the world). In Kaohsiung, Taiwan, the average personal discharge is 34.7 tons/year (8 times of the world average, thus, Kaohsiung has the highest CO_2 discharge).

Table 1. World ranking on total CO_2 discharge

Rank	Country	Quantity (million tons per year)
1	America	2,790
2	China	2,680
3	Russia	661
4	India	583
5	Japan	400
6	Germany	356
7	Australia	226
8	Africa	222
9	England	212
10	S. Korea	185

Table 2. World ranking on average personal CO_2 discharge

Rank	Country	Quantity (tons per person)
1	Australia	10.7
2	America	9.3
3	S. Africa	4.6
3	Russia	4.6
5	Germany	4.3
5	Poland	4.3
5	Canada	4.3
8	S. Korea	3.8
9	Spain	3.7
10	England	3.5

If no actions are taken to limit global warming, there would be severe consequences including more extreme weather conditions, rising of sea levels, reduction of drinking water sources, spreading of diseases, and extinction of endangered species. Figure 1 shows some of the evidences that possibly support the global warming effect such as increase in global average temperature and global average sea level and decrease in the northern hemisphere snow covers.

Climate change in Taiwan is of high risk. Its average temperature increase is 1.3 °C (Taipei 2 °C) in recent year (the rate of increase is doubled compared to the world). If the warming continues, on year 2100, there is only Show Shan Mountain in Kaohsiung. Disasters like flood, drought, acidic rain, and intense summer heat is most likely to occur frequently. The price for life could become higher and dengue fever will likely move up North.

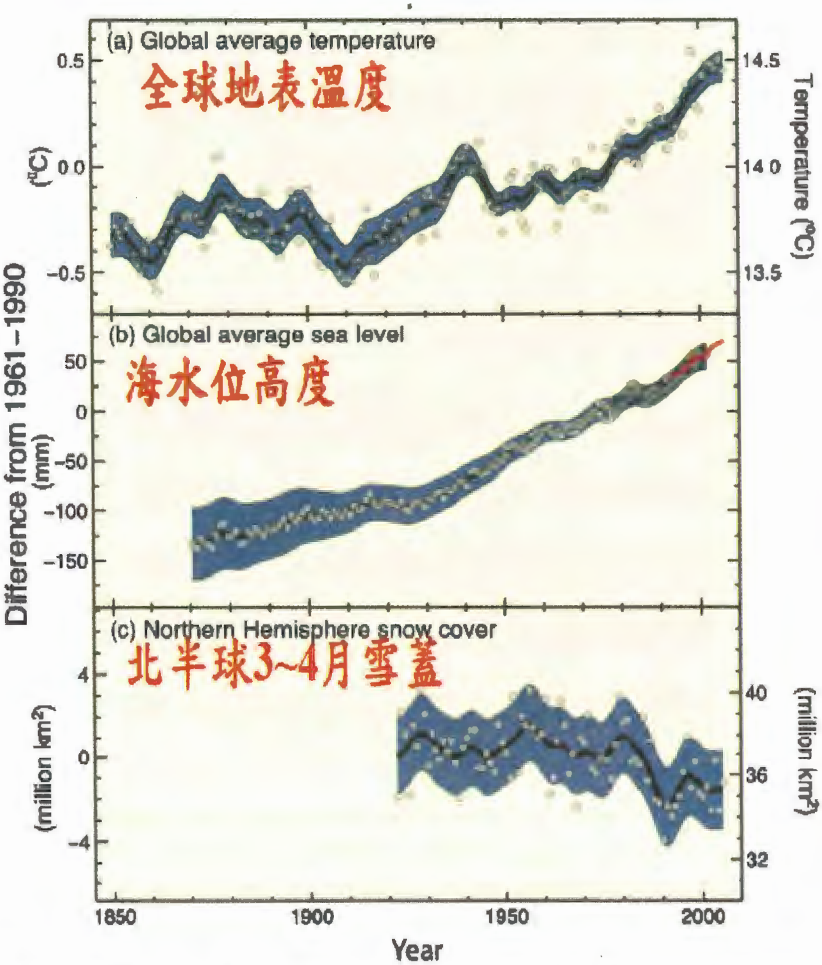

Figure 1. Changes in temperature, sea level, and northern hemisphere snow cover (UN-IPCC, Climate change report, 2007)

Reduction of CO_2 Emissions

As stated by Aaron and Tsouris (2005), reduction of CO_2 emissions could be done in three basic terms: short, medium, and long term. Short term is considered the most challenging steps since it requires not just technological push but also a strong political will. Sequestration and separation process are considered as short term solutions. Medium term target includes finding a better way to improve fuel efficiency and re-using the captured CO_2. Long-term plan is to develop alternative energy sources such as renewable energy like solar, wind, etc.

In Taiwan, the government encourages the use of low carbon energy resources such as sustainable energy, fuel cell, and biofuel. Likewise, the usage of natural gas, the efficiency of the power plants, and electricity bill must be increase to help reduce CO_2 emissions. Taiwanese are also encourage to ride bicycles more often to limit the use of motorcycles and automobiles, to eat local foods and vegetables, to stop smoking, and to file formal suits for the violators.

CO_2 Capture, Separation, and Reuse

By capturing CO_2 from the flue gases of coal-fired power plants and fossil fuel plants, and by effective implementation of carbon tax, the total greenhouse gas emission will be reduced significantly. CO_2 capture and storage is currently being viewed as a technology of last resort that is needed to mitigate climate change and global warming (Bhargava et al. 2011). Nevertheless, CO_2 capture and storage technology is not only propelled by the desire of reducing the CO_2 emissions, but the application of stored pure CO_2 to food industries (carbonated beverages, brewing, and flash drying), enhanced oil recovery, welding, firefighting, and solvent extraction (Chapel et al. 1999). Figure 2 shows the possible fate of the captured CO_2. Via membrane separation, flue gases could be processed to produce purified CO_2 gas, via chemical conversion it could be used to produce methanol and urea, and via fossil conversion it could be stored as $MgCO_3$ and $CaCO_3$. Re-using CO_2 as a raw material to other chemical process is considered as short-term goal and its storage is a possible long-term solution for reducing CO_2 emissions.

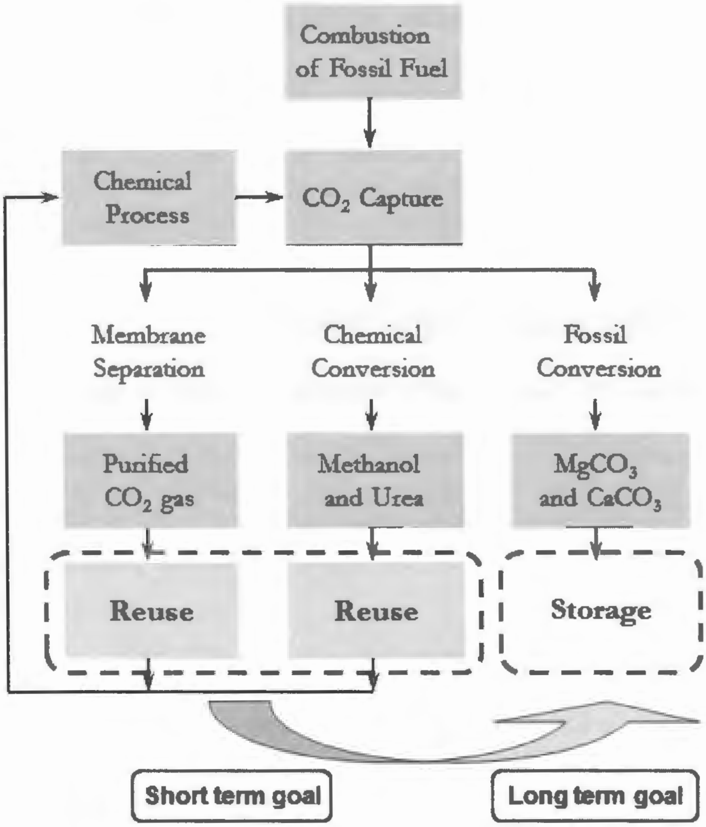

Figure 2. Fossil fuel combustion's post-combustion CO_2 capture and sequestration

Feasible Process for CO_2 Reduction

Four processes are now being deemed as industrially feasible in reducing CO_2. These are absorption, adsorption, cryogenic, and membrane separation. According to Aaron and Tsouris (2005), absorption process is still considered as the most economically feasible technique to capture CO_2 in terms of the cost of separation in flue gases. A report published by Figueroa et al. (2008) shows that in the next 50 years, absorption using solvent systems is still considered as the most viable option in capturing CO_2. Figure 3 shows the other possible innovation advances in CO_2 capture technology.

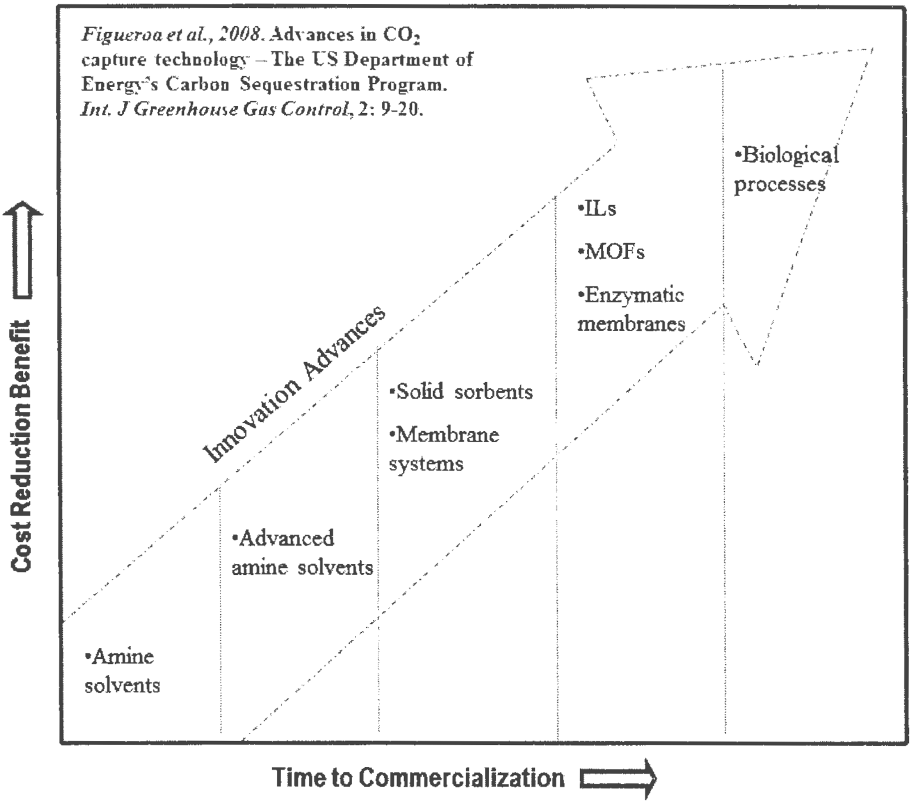

Figure 3. Cost reduction benefit versus time to commercialization (Figueroa et al. 2008)

Absorption for CO_2 Capture

Combustion of fossil fuels is still considered as the biggest contributors of CO_2, which could be sequestered and captured on a large scale. Power plants emit large amount of flue gases. In Taiwan alone, it accounts to 141 Mton/yr in 2006. The CO_2 concentration in the flue gas stream accounts to 12–15vol% total. As proven previously, the most feasible and effective method to remove CO_2 from flue gas in Taiwan (also in the world) will be the absorption process using appropriate absorbent.

There are two major concerns in the absorption process: (i) selection of appropriate solvent system and (ii) design of the absorber. In the selection of appropriate solvent system, Figure 4 shows the parameters interaction leading to the choice of the possible CO_2 absorbent. Parameters like the controlled operational data, operational cost, and basic property data contribute to the selection of the possible CO_2 absorbent. The possible CO_2 absorbent will then be economically assessed to select the best CO_2 absorbent based on the lowest cost per amount of CO_2 treated.

To date, there are two known CO_2 absorbent system, the aqueous alkanolamine solutions and the room-temperature ionic liquids. These two systems have their own advantages and disadvantages to offer. Figure 5 illustrated the various advantages and disadvantages. The aqueous alkanolamine solutions is still considered as the most feasible solvent system for CO_2 sequestration based on the cost but recent advances on chemical synthesis now designed a less expensive and easy to synthesize ionic liquid in the form of Deep Eutectic Solvent (DES) but this solvent system is still on experimental stage

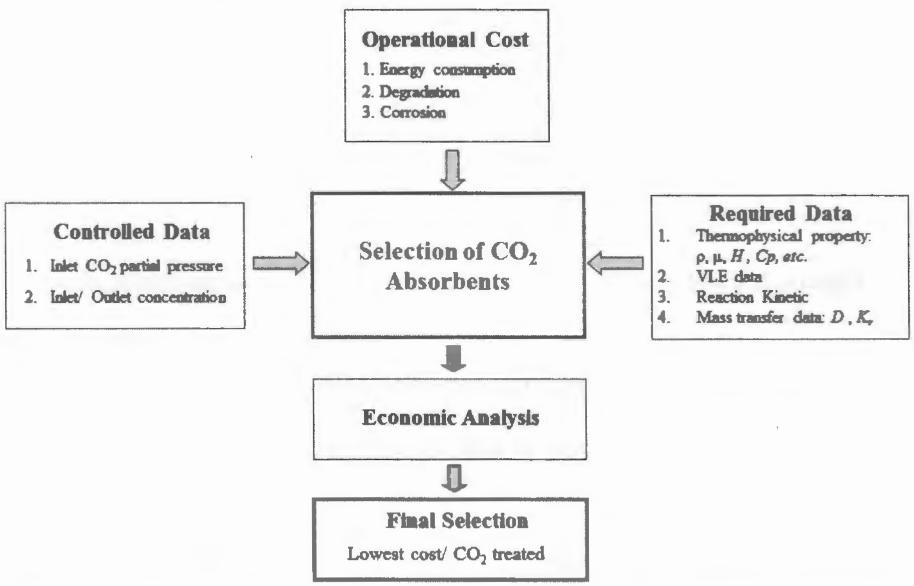

Figure 4. Parametric diagram on the selection of CO_2 absorbent system

The rationale of the commercial design of absorption equipment is all about basic studies on the synthesis of new absorbent and the design of the absorption equipment to have more efficiency. The efficiency of the absorption equipment depends very much on the basic absorption data such as VLE, Henry's constant, diffusion coefficient, reaction kinetics, etc. and on the thermophysical properties such as density, viscosity, refractive index, surface tension, electrolytic conductivity, heat capacity, etc. Since these properties are very essential on the design process, a need to characterized and develop correlations to generally represent these properties is required. In Taiwan, it is common to see researches on this field. In a global scale this type of research activity is also acknowledge. In fact, there are many respectable journals that associate this kind of research.

Aqueous Alkanolamine Solutions	Room-Temperature Ionic Liquids	
☑ Advantages - cheap - widely studied	☑ Advantages - low vapor pressure - high thermal stability - green solvents - designer solvents	**DES** - less expensive - easy to synthesize
☒ Disadvantages - corrosion problems - amine loss and degradation - high energy consumption	☒ Disadvantages - little is known (new substance) - expensive	

Figure 5. Aqueous alkanolamine solutions versus room-temperature ionic liquids

Recommendations

The basic research is one of the areas of research, which is normally intentionally left behind or not included in the research agenda of most institutions especially in private sectors. We cannot blame these private companies since they are the ones that will fund these researches. However, we also need to bear in mind that for most countries, research outputs, in general, is one of the barometers for quantifying economic growth. There is no distinction whether it is applied or basic research outputs. So for the Philippines to move forward, let us not restrict with only one research agenda (typically based on applied research). Let the researchers do what they are most comfortable doing and do not put additional constraints.

The research agenda on carbon dioxide capture covers both basic and applied component of research. It is the basic part that helps establish the guiding principles in developing the technology to design the process of carbon dioxide capture. The talk clearly showed the importance of basic data gathering and correlation development in coming up with the design of the process for carbon dioxide capture. Unfortunately, there is not much researchers engage in this kind of research activities. You can count them in your hands. The reason for this is not merely attributed to the research agenda of their institutions or by the government but also to the policies set by the government. To date, there is no policy regarding the carbon dioxide capturing. In other countries, they are imposing the carbon credit program where they give tax incentives to companies that try to capture and sequester carbon dioxide. For this research to move forward, the government should impose some concrete policies addressing the issues. With the Philippines at the mercy of the expected climate change consequences, now is the perfect time to do this. Strengthen the basic research on the areas of carbon dioxide capture to increase our research outputs and encourage those from industries to conduct a follow through research or technology development using these outputs.

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