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Progress in carbon dioxide separation and capture: A review

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Abstract

This article reviews the progress made in CO_2 separation and capture research and engineering. Various technologies, such as absorption, adsorption, and membrane separation, are thoroughly discussed. New concepts such as chemical-looping combustion and hydrate-based separation are also introduced briefly. Future directions are suggested. Sequestration methods, such as forestation, ocean fertilization and mineral carbonation techniques are also covered. Underground injection and direct ocean dump are not covered.

Key words: coal; flue gas; carbon dioxide; sorbent; absorption; adsorption; membrane; separation; sequestration

Introduction

The 20th century has seen the rapid increase of population and explosive growth in energy consumption. As more countries becoming industrialized, it is expected that more energy will be consumed in 21st century. EIA predicts 57 percent increase of energy demand from 2004 to 2030 (EIA, 2007).

Table 1 shows the comparisons of energy use, population and per capita consumption in 1900 and 2001 (Song, 2006). In current stage over 85 percent of world energy demand is supplied by fossil fuels. Fossil-fueled power plants are responsible for roughly 40 percent of total CO_2 emissions, coal-fired plants being the main contributor (Carapellucci and Milazzo, 2003). Environmental issues due to emissions of pollutants from combustion of fossil fuels have become global problems, including air toxics and greenhouse gases (GHG). The CO_2 emission from human activity was on the order of 7 Gt/a in the late 1990's (Yamasaki, 2003). This includes the combustion of fossil fuels in all major industries and other factors such as deforestation and desertification.

Through the studies of the past five decades, particularly the past 15 years, increased GHG levels in atmosphere is believed to cause global warming. Among these GHG, CO_2 is the largest contributor in regard of its amount present in the atmosphere contributing to 60 percent of global warming effects (Yamasaki, 2003), although methane and chlorofluorocarbons have much higher greenhouse effect as per mass of gases. There are increasing concerns for global warming caused by the effects of GHG, particularly CO_2. International Panel on Climate Change (IPCC) predicts that, by the year 2100, the atmosphere may contain up to 570 ppmv CO_2, causing a rise of mean global temperature of around 1.9°C and an increase in mean sea level of 38 m (Stewart and Hessami, 2005). Also accompanied is species extinction.

The total amount of carbon on earth is constant and its distribution among lithosphere, atmosphere and biosphere was relatively balanced until the advent of era of industrialized civilization. The CO_2 concentration in the atmosphere is increasing. Fig. 1 shows the change of atmospheric CO_2 level over the years between 1000 and 1997 and actual CO_2 level during 1958–2004 (Song, 2006). CO_2 level increased from 280 ppmv in 1000 to 295 ppmv in 1900 based on Antarctica ice core data. It increased to 315 ppmv in 1958 and further to 377 ppmv in 2004 based on actual data logged in Hawaii.

There are three options to reduce total CO_2 emission into the atmosphere, i.e., to reduce energy intensity, to reduce carbon intensity, and to enhance the sequestration of CO_2. The first option requires efficient use of energy. The second option requires switching to using non-fossil fuels such as hydrogen and renewable energy. The third option involves the development of technologies to capture and sequester more CO_2.

To enhance the sequestration of CO_2, options are sought to accelerate the fixation of carbon in lithosphere and biosphere, either CO_2 fixation by the enhancement of natural sinking process, such as forestation, ocean fertilization and

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