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Carbon capture and storage—Solidification and storage of carbon dioxide captured on ships

Peilin Zhou, Haibin Wang*

Department of Naval Architecture and Marine Engineering, University of Strathclyde, G4 0LZ Glasgow, UK

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ABSTRACT

To meet the International Maritime Organization (IMO) target of 20% reduction of CO_2 emissions from marine activities by 2020, application of Carbon Capture and Storage (CCS) on ships is considered as an effective way to mitigate CO_2 emissions while other low carbon shipping technologies are being developed. Literature reviews on CCS methods for onshore applications indicate that the current CCS technologies could not be implemented on boards directly due to various limitations on ships. A novel chemical CO_2 absorption and solidification method for CO_2 storage on-board is proposed, presented and analyzed. Technical feasibility with explanation of principles and cost assessment are carried out for a case ship with a comparison to a conventional CCS method. The paper also presents results obtained from laboratory experiment including factors that affect the absorption. Theoretical study and laboratory experiment illustrate the proposed CO_2 solidification method is a promising, cost effective and feasible method for CO_2 emissions reduction on ships.

1. Introduction

Climate change has become a popular topic simply because it leads the melting glaciers, rising sea levels and the extinction of endangered species. It is well-known that greenhouse gases (GHG) are the cause of the climate change which is mainly contributed by the carbon dioxide (Houghton, 2004). According to IPCC report, the current CO_2 concentration in the atmosphere is increased by 100 ppm which is about 34% increment compared with the pre-industrial level (Rogner et al., (2007)). Fig. 1 presents the growing of CO_2 emissions from 2000 to 2009 (Boden et al., 2010). Although the emissions are a little bit declined from 2008 to 2009, the tendency of the curve is obviously climbing.

For the global economy, international shipping have an immeasurable effect as it is the most effective way for large quantity and long distance transportation of international trade. Referring to the report of Second IMO GHG Study 2009, international shipping is estimated to have 870 million tones CO_2 emitted in 2007 which is about 2.7% of the global CO_2 emissions (Buhaug et al., 2009). There are numbers of methods to reduce the ship GHG emissions. EEDI, EEOI and SEEMP stipulated by IMO are focusing on increasing the energy efficiency. With high energy efficiency, the fuel consumed will be reduced so that the CO_2 generated will be decreased. EEDI, EEOI and SEEMP regulations are proposed to be entered into force on 2013 with an aim to reduce about 180 million tons of CO_2 emissions from international shipping annually by 2020. It is about 20% of the current emissions level. Thus, so many projects emerge with a target of 20% reduction of CO_2 emissions.

CCS is an effective way to mitigate and even eliminate the effect of global warming caused by CO_2 emissions. It is now only used on shore based power plants and industrial processes (Global Carbon Capture and Storage Institute). Fig. 2 presents three general ways of CCS that are available for onshore application. The principles of pre-combustion method are to remove carbon component from the fossil fuel priory to its combustion. Oxy-fuel capture method is to burn the fossil fuel with pure oxygen rather than oxygen in air so that only CO_2 and water vapor are produced after combustion and CO_2 can be easily captured by condensing the flue gases. Post-combustion capture method is to have CO_2 captured from the flue gases after the combustion of the fossil fuel.

Although these methods could help capture carbon from fuel oil, mechanically installation of the systems on ships will bring great impacts on shipping performance. For instance, additional power consumption will increase fuel consumption, more space taken leads a reduction of cargo transported and storage of CO_2 on ships in a form of gas or liquid state is difficult and unsafe. No matter what kind of method is considered, the impacts on shipping performance should be minimized.

* Correspondence to: Department of Naval Architecture and Marine Engineering, Henry Dyer Building, 100 Montrose Street, University of Strathclyde, G4 0LZ, Glasgow, UK. Tel.: +44 141 548 3344; fax: +44 141 552 2879.
E-mail address: haibin.wang.100@strath.ac.uk (H. Wang).

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Nomenclature

CCS	carbon capture and storage
CFD	computing fluid dynamic
CPCS	chemical processes for carbon Solidification
D	diameter
DWT	deadweight tonnage
EEDI	energy efficiency design index
EEOI	energy efficiency operational indicator
EIGA	european industrial gases association
EOR	enhanced oil recovery
GHG	greenhouse gases
H	height
HSFO	high sulfur fuel oil
ICP	inductively coupled plasma
IMO	international maritime organization
IPC	inductively coupled plasma
IPCC	intergovernmental panel on climate change
ITTC	international towing tank conference
LBP	length between perpendiculars
LOA	length overall
M	molar mass
m	mass
MCR	maximum continuous rating
n	molar number
P	power
p	profit
R	rate
SEEMP	ship energy efficiency management plan
SFOC	specific fuel oil consumption
t	time
V	volume
π	pi
ρ	density

Chemical substances

$Ca(OH)_2$	calcium hydroxide
$CaCO_3$	calcium carbonate
CaO	calcium oxide
CO_2	carbon dioxide
CO_3^-	carbonate ion
H_2O	water
Na_2CO_3	sodium carbonate
$NaOH$	sodium hydroxide
NO_x	nitrous oxides
SO_x	sulfur oxides

Atomic and molar weight

Carbon (C)	12
Hydrogen (H)	1
Oxygen (O)	16
$Ca(OH)_2$	74
$CaCO_3$	100
Calcium (Ca)	40
CaO	56
CO_2	44
H_2O	18
Na_2CO_3	106
$NaOH$	40
Sodium (Na)	23

Units

L	litre
L/min	litre per minute
mol	mole number
ppm	parts per million

A novel carbon capture method is proposed in order to reduce the power requirement, save spaces on board and avoid CO_2 storage in a gas or liquid form on ships. This method applies two chemical processes and a physical step to absorb CO_2 from exhaust gases, precipitate the CO_3^- ion and separate $CaCO_3$ from the absorption solution on ship board.

In this study, the results obtained from laboratory experiment are extended to apply on a case ship. An economical assessment is presented by comparing the chemical processes for carbon solidification (CPCS) with the CO_2 compression and liquefaction

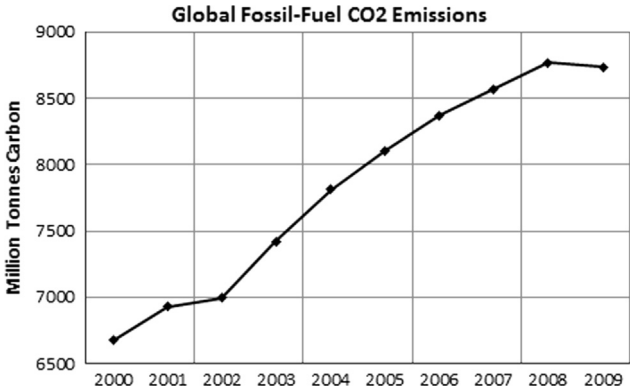

Fig. 1. Tendency of CO_2 emissions from 2000 to 2009.

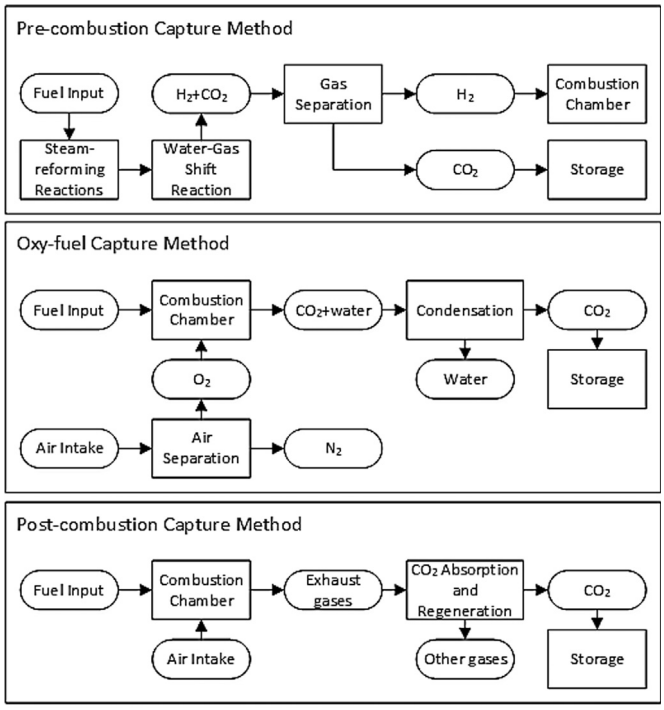

Fig. 2. General carbon capture methods.