Marine Pollution Bulletin 88 (2014) 292–301

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Environmental policy constraints for acidic exhaust gas scrubber discharges from ships

H. Ülpre *, I. Eames

University College London, Torrington Place, London WC1E 7JE, United Kingdom

ARTICLE INFO

Article history:
Available online 3 October 2014

Keywords:
Turbulent jet
Acid–alkali chemistry
Scrubber
Seawater

ABSTRACT

Increasingly stringent environmental legislation on sulphur oxide emissions from the combustion of fossil fuels onboard ships (International Maritime Organization (IMO) Regulation 14) can be met by either refining the fuel to reduce sulphur content or by scrubbing the exhaust gases. Commonly used open loop marine scrubbers discharge warm acidic exhaust gas wash water into the sea, depressing its pH. The focus on this paper is on the physics and chemistry behind the disposal of acidic discharges in seawater.

The IMO Marine Environment Protection Committee (MEPC 59/24/Add.1 Annex 9) requires the wash water to reach a pH greater than 6.5 at a distance of 4 m from the point of discharge. We examine the engineering constraints, specifically size and number of ports, to identify the challenges of meeting regulatory compliance.

1. Introduction

The main products in the combustion of fossil fuels in air are carbon oxides (CO_x) and water (H_2O). The most common by-products are sulphur oxides (SO_x), nitrogen oxides (NO_x) and carbon based matter (soot, smoke). The by-products exist in small quantities but have a disproportionate effect on the environment. SO_x is generated in combustion due to sulphur compounds that have not been removed from the fossil fuels. NO_x is the result of combustion at high temperatures and the carbon based matter (*e.g.* CO_x, soot) is formed due to incomplete combustion. All of these by-products are polluting and their release, therefore, has to be mitigated. The absorption of CO_2 by seawater is the main reason for anthropogenic ocean acidification (Raven et al., 2005). Shipping accounts for 2.7% of the global total CO_2 emissions and as of January 1st 2013 (IMO, 2009). As a result the IMO has implemented mandatory measures to increase the energy efficiency of new ships (MEPC 62/24/Add.1 Annex 19). NO_x emissions fall under IMO Regulation 13 and a number of methods can be used to meet the emission limits (Blatcher and Eames, 2013). IMO Regulation 14 dictates the emission limits for SO_x and carbon particles from ships. Naturally occurring low sulphur fuel is scarce and refining to reduce sulphur content is expensive. An alternative is to use cheaper high sulphur content fuel in combination with an exhaust gas scrubbers to mitigate SO_x emissions.

Commonly used exhaust gas scrubbers on ships are open loop meaning that seawater is taken onboard, used to clean the exhaust gases and then discharged back into the ambient. The principle of the scrubber (see Fig. 1) is to spray the flue gas with seawater capturing the carbon particles as well as the SO_x gas that forms sulphuric acid (H_2SO_4) on contact with water. Before the wash water's discharge into the ambient, it is filtered from sludge created by carbon particles and other particulate fuel impurities. Depending on onboard treatment and discharge pipe configuration it is likely that the wash water will be in the form of a warm acidic jet. The immediate effects of the acidic discharge are mitigated due to rapid pH recovery back to ambient levels in the vicinity of the discharge nozzle. The long term effects are out of the scope of this paper.

Emissions Control Areas (ECA), shown in Fig. 2a, cover the Pacific and Atlantic coasts of the United States and Canada, the Gulf of Mexico, Hawaiian Islands and the North and Baltic seas. The ECA are defined in MEPC 60/22 Annex 11 for the Americas and the limits of the North Sea are defined by the International Hydrographic Organization. In these regions the SO_x emissions limits are very severe (a maximum of 1% of fuel weight can be sulphur as of 1st of July 2010) meaning that exhaust gas scrubbers are likely to be used. Outside of the ECA the sulphur content can be up to 3.5% of fuel weight. Modern diesel and gas turbine ships are supported by auxiliary engines that are used for electricity generation and manoeuvring. Depending on the size of the ship a number of scrubbers may be fitted to allow for the independent running of main

* Corresponding author.
E-mail address: h.ulpre@ucl.ac.uk (H. Ülpre).

http://dx.doi.org/10.1016/j.marpolbul.2014.08.027
0025-326X/

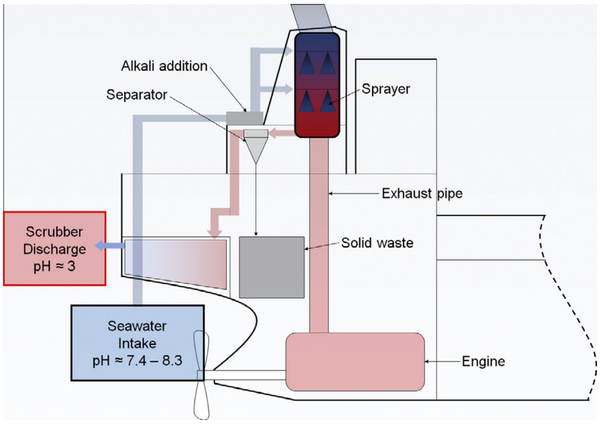

Fig. 1. Schematic of a typical wet open loop exhaust gas scrubber setup.

and auxiliary engines. The acidic scrubber discharges need to comply with the MEPC 59/24/Add.1 Annex 9 regulation:

> The wash water pH should comply with one of the following requirements which should be recorded in the ETM-A or ETM-B as applicable:
>
> (I) The discharge wash water should have a pH of no less than 6.5 measured at the ship's overboard discharge with the exception that during manoeuvring and transit, the maximum difference between inlet and outlet of 2 pH units is allowed measured at the ship's inlet and overboard discharge.
>
> (II) During commissioning of the unit(s) after installation, the discharged wash water plume should be measured externally from the ship (at rest in harbour) and the discharge pH at the ship's overboard pH monitoring point will be recorded when the plume at 4 m from the discharge point equals or is above pH 6.5. The discharged pH to achieve a minimum pH units of 6.5 will become the overboard pH discharge limit recorded in the ETM-A or ETM-B.

The acronyms ETM-A and ETM-B refer to technical manuals from the manufacturer (EGC system – Technical Manual). The seawater pH varies approximately from 7.5 to 8.5 meaning that a discharge of fluid at a pH of 5.5 is permitted in certain conditions (*e.g.* north-eastern regions of the Baltic Sea) in the case of (I). However, in the case of (II) there is no limit to the discharge pH as long as it recovers to a pH of 6.5 within a distance of 4 m from the nozzle.

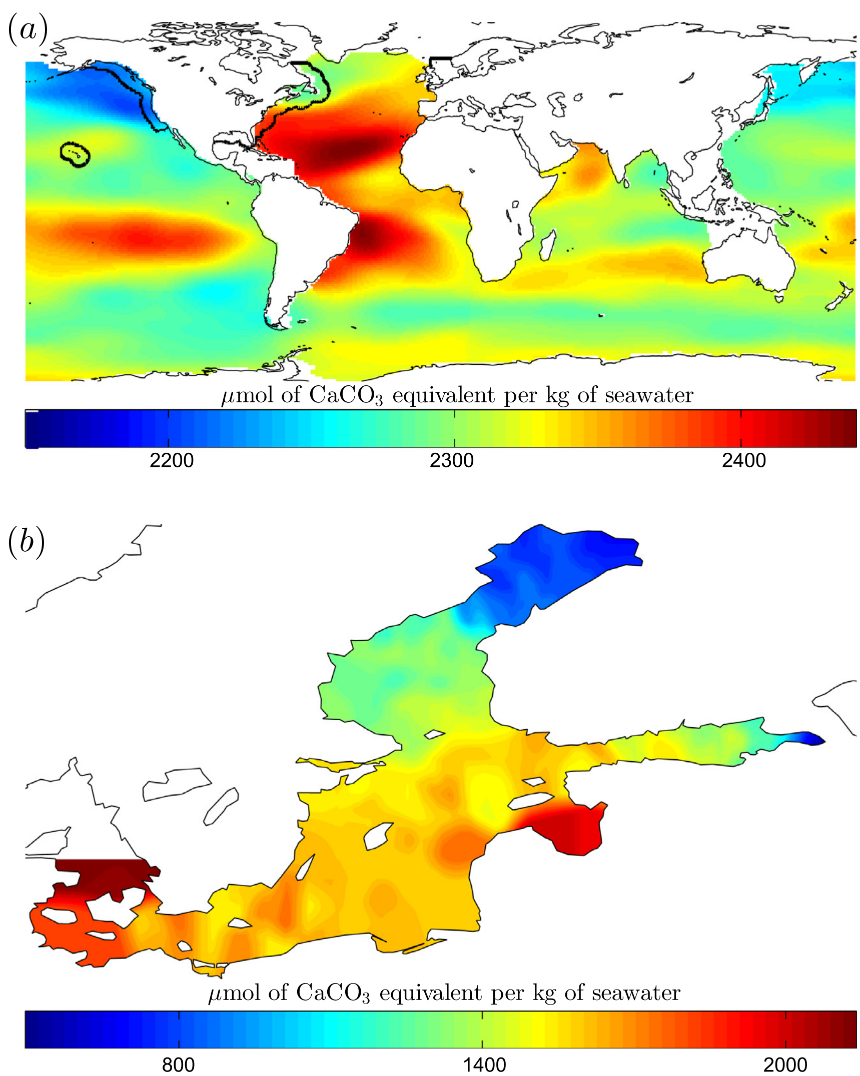

Fig. 2. In (a), the global estimate of the total potential seawater alkalinity (µmol/kg) based on seawater salinity (Key et al., 2004). The Emissions Control Areas (ECA) are highlighted with thick black lines. In (b), the estimate of the average seawater alkalinity (µmol/kg) between 2000 and 2012 in the Baltic Sea (ICES, 2011). The Savitzky–Golay filter was applied to the data in Matlab R2013b.