OPEN LOOP EXHAUST GAS CLEANING SYSTEM AND ITS EFFECT OVER THE BARCELONA PORT WATER pH

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Keywords

Open loop, water pollution, acidification, wet scrubbers.

Abstract

Nowadays the air pollution prevention has become a priority objective in our society, but it is being expressly noteworthy into the maritime industry and shipping business. The last is because there is a strong regulatory framework which establishes requirements fuel oils used on board the ships must meet. Among these requirements we should note those regarding to the fuel oils with a sulphur content not exceeding that specified in regulation 14 of Annex VI Marpol Convention [1].
To deal with these requirements, some shipowners have chosen to use open-loop exhaust gas cleaning systems on board their ships. Main feature of these systems is regarding to the continuous discharges of wash water to the sea. One of the properties of this wash water is its low pH level, notably acid.
This paper is talking about the Barcelona port water pH evolution, specifically from the South Basin port water, after receiving weekly 2-3 ships which are using the open-loop exhaust gas cleaning system and discharging residual wash water from the exhaust gas cleaning process on the port water.
The pH values of samples analyzed in the laboratory of the Institute of Environmental Assessment and Water Research (IDAEA-CSIC) are presented in this paper. We will check the evolution of Barcelona South Basin port water pH level, the trend of pH port water and finally we are going to value the observed impact that has the use of open-loop exhaust gas cleaning systems on this port water.
Finally, we will analyse current situation and talk about the studies or research on this topic and the real need for improving the operation of open-loop exhaust gas cleaning systems, avoiding their contribution to the port water acidification.

1. INTRODUCTION

Shipping business is nowadays becoming more and more committed with environment protection. The awareness on board the ships about pollution prevention must not be only a company policy but it is about a duty. This is because behind of shipping business there is a strong regulatory framework regarding the pollution prevention from ships.

The International Convention for the Prevention of Pollution from Ships, commonly known as Marpol Convention [2], is the main international convention for looking after the pollution prevention of the marine environment caused by ships.

Marpol Convention is formed by six Annexes and the one that has had a great impact in recent years on shipping business has been the Annex VI, Prevention of Air Pollution from Ships [3], specifically the regulation 14.1.3, sulphur oxides and particulate matter [1]. Last amendment came into force on 1st January 2020 and sets the prohibition on the use of a non-compliant fuel oil for combustion purposes on board the ships. Non-compliant fuel means, after entering into force the above-mentioned amendment, a fuel with a sulphur content limit exceeding 0.5% mass by mass.

Greater percentage of ships that are calling the port of Barcelona are using a compliant fuel oil during their calls. A compliant fuel must be a fuel oil with a sulphur content not exceeding 0.5% mass by mass used during ship's sea passage and 0,1% mass by mass during the ship's call in port. These fuels are commonly known as Very Low Sulphur Fuel Oil (VLSFO) and Marine Gasoil (MGO),

There are mainly two problems associated with the use of a compliant fuel (VLSFO and MGO). One of them is the ship's reliance on the availability of this fuel oil in each port and its price per tonne. Other problem on board the ships which are using very low sulphur fuel oil for combustion is the quality of fuel oil provided. As we are going to check later the segregation of tanks is strongly recommended for VLSFO from different providers due to the lack of compatibility among their products.

Other way to deal with sulphur caps that shipping companies can choose is the use of alternative fuels. Currently there are several kinds of alternative fuels which are used on board the ships, where we can highlight among them the natural gas, methanol, ammonia, hydrogen, etc. Installation of natural gas propulsion on board an existing ship supposes a great investment and the lack of enough space on board. Usually requires a long time in a dry dock for ship. Currently, ship's owners are mainly using this option for new ships.

The other main option to deal with this Regulation is to install on board the ships, an exhaust gas cleaning system (EGCS), also known as "scrubbers". These systems suppose a great investment for shipping companies furthermore the profitability of the latest is strongly joined to the ship's life. Exhaust gas cleaning systems are classified generally in two main groups, as follows: dry scrubbers and wet scrubbers. Dry scrubbers basically, are removing sulphur oxides from exhaust gases through granules of hydrated lime. During exhaust gas cleaning process, dry scrubbers do not generate wastewater to discharge into the sea.

Wet scrubbers are using water which is sprayed over the exhaust gas cleaning system during cleaning process, to remove sulphur oxides. Wet scrubbers are also classified in three main groups: open loop system, closed loop system and hybrids.

Currently we are focused on an investigation over the effects of wash water discharges from open-loop system to the pH level of Barcelona port water. This is because, as we are going to analyse later, one of the main features of open loop type which is the residual water discharge overboard, after being used during the exhaust gases cleaning process.

2. ANALYSIS OF THE CURRENT SITUATION

As mentioned before, one of the main problems that ships companies have on their ships which are not fitted with an exhaust gas cleaning system, is the evolution of price per tonne of the Very Low Sulfur Fuel Oil. Currently, the price of VLSFO in a European port like Rotterdam is 690 $/mt (figure 1). In last months the price of fuels in general have experienced a strong upward trend and the specific case for VLSFO we can assert that has barely stopped increasing since ends of 2021 when the price per tonne of VLSFO was about 529 $/mt.

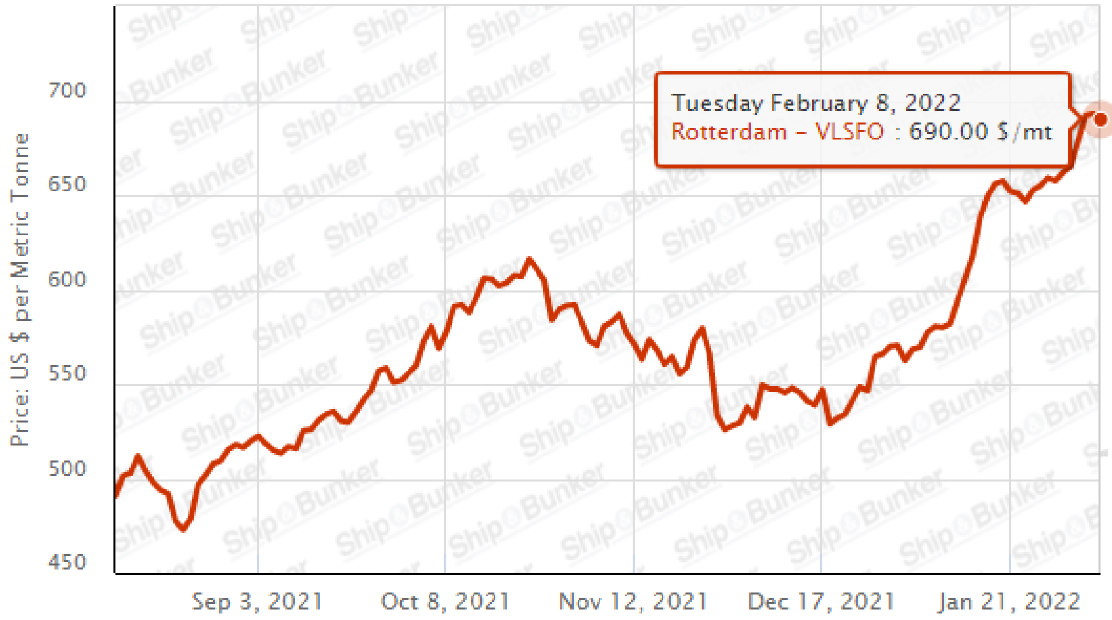

Figure 1. Evolution of price per tonne of VLSFO. Source: shipandbunker.com

In the case of MGO, we can assert that situation is even worst than VLSFO. Currently the price per tonne in Rotterdam is about 835.50 $/mt (figure 2). Furthermore, its price has experimented a strong upward trend from ends of 2021 when the price per tonne of Marine Gas Oil was about 605 $/mt.

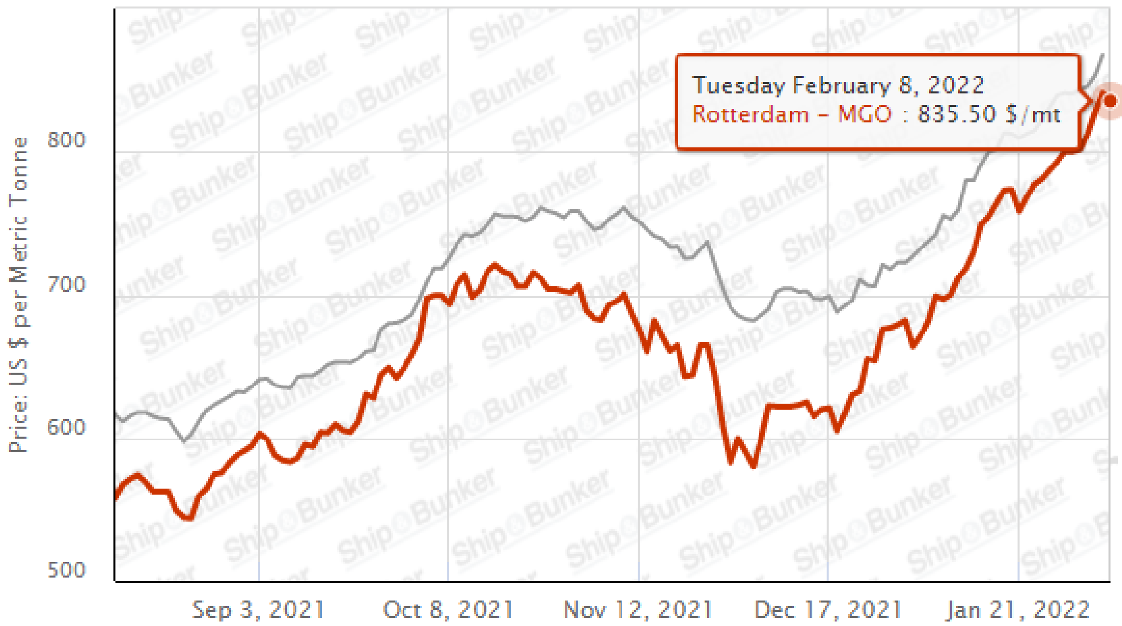

Figure 2. Evolution of price per tonne of MGO. Source: shipandbunker.co

There are no indications to suppose that fuel prices are going to decrease in a near future.

Another problem regarding the VLSFO dependency is the availability and quality of this fuel. Very Low Sulphur Fuel Oil, in general terms, can be produced by refineries through different processes. One of them is based on the blending of high sulphur fuel oil residue, from refineries (IFO 380 or similar) with different cutters of sulphur until the on-specification product is created.

Other way to produce VLSFO is blending very low sulphur residues from refineries from processing very low sulphur crudes. This second option is the cheapest and easiest way for refiners. But there is an associated problem to this option, and it is the low availability of very low sulphur crude.

A third way to produce VLSFO is through atmospheric and vacuum residue desulphurisation which has the feature that desulphuration process reduces the aromaticity of the final product. This aromaticity reduction can result in compatibility problems when the product is blended with high aromatic products. In this case the cracking of product and the sludge formation could be generated. Once the sludge is formed and depending on the area the blend of fuels has reacted, sludges may produce a clog of pipes if sludge precipitation has occurred in fuel tanks and pipes. Also, this fuel oil with sludge precipitation can arrive to the filters, producing the plugging or blocking of these. This can generate the reduction of fuel supplying to the engine, even causing the main engine or auxiliary engines stop.

More and more frequently ships are reporting cases of engine failure which are due to the fuel quality and the presence of sludges in pipes and tanks (figure 3) causing the blockage of filters.

Figure 3. View of VLSFO tank with sludges formation inside. Source: ameydemarine.com

Despite the latest, the use of a compliant fuel is the most chosen option by ship owners on their ships for complying the global sulphur cap regulation. There are several reasons because ship owners rather the use of very low sulphur fuel oil instead the exhaust gas cleaning system installation. One of them is the lack of enough space on board the ship for the installation of scrubbers. It supposes among others the installation of a set of pipes, pumps, tanks, scrubbing tower, etc. and depending on the type of ship the space option is very limited. The investment that supposes the installation of an exhaust gas cleaning system is another reason. Final investment of a scrubber installation depends on several factors, but according to Bureau Veritas publication from June 2020 [4], the average cost is about €2 million per scrubber. The return of investment period for the installation of an exhaust gas cleaning system on board the ship, has a strong dependency of fuel market and prices but can take, as per BV study, from 1 to 4 years.

Finally, we must mention that an exhaust gas cleaning system installation on board the ship requires the dry docking of ship, and she will be stopped several weeks until scrubber installation is performed. This supposes, depending on the type of ship and traffic is intended, an extra high cost for the shipping company.

3. EXHAUST GAS CLEANING SYSTEM (EGCS)

3.1 Introduction

As mentioned above, Marpol Convention on its Annex VI [3], regulation 14 [1], stablishes that ships cannot use a fuel with a sulphur concentration cap over limits prescribed on regulations 14.1 and 14.4. Regulation 4 [5] of same Annex defines what should be understood as “equivalents”. Equivalents concept, as per Annex VI [3] definition, is any fitting, material, apparatus or appliance to be installed on board of a ship as well as any alternative fuel, procedure or compliance method used as an alternative to the required by the Annex VI [3] of Marpol Convention [2], if such fitting, material, apparatus or appliance to be installed on board of a ship as well as any alternative fuel, procedure or compliance method are at least as effective in terms of emission reductions, so in this case, we are talking about sulphur oxides emission reductions, as that required by this Annex.

If we analyse the above-mentioned regulation, we can extract that the Administration of a Party may allow to its ships the use of any of the mentioned options, to be in compliance, for instance, with regulation 14 [1]. So, the exhaust gas cleaning systems are considered, effectively, equivalents or an equivalent arrangement. In this way, is stated on the supplement, also known as Record of Construction and Equipment, to International Air Pollution Prevention Certificate of a ship fitted with a scrubber system approved by the Administration. We can check on section 2.3 of this supplement, if ship is fitted with an equivalent arrangement approved in accordance with regulation 4.1 [5] and that is at least as effective in terms of sulphur oxides emission reductions as compared to using a fuel oil with a certain sulphur content limit.

Exhaust gas cleaning systems are basically an air pollution control system, which is used to remove certain particulates, specifically sulphur oxides particulates from the exhaust gases of a ship. Generally, the molecules of sulphur oxides that are part of exhaust gases from engine, are separated from the gas flow when they meet a liquid. This liquid may be only water, a chemical compound, or a combination of both.

This technology has been used in chemical industry from several years ago, mainly to remove certain pollutant gases, for example, hydrogen sulphide, sulphur dioxide, dioxins, hydrogen fluoride, heavy metals as well as certain methane compounds and carbon dioxide (biogas).

3.2. Types of EGCS

These systems are classified generally in two main groups, as follows: dry scrubbers and wet scrubbers. Dry scrubbers basically, are removing sulphur oxides from exhaust gases through granules of hydrated lime. During exhaust gas cleaning process, dry scrubbers do not generate wastewater to discharge into the sea.

Wet scrubbers are using water which is sprayed over the exhaust gas cleaning system during cleaning process to remove sulphur oxides. Wet scrubbers are also classified in three main groups: open loop system, closed loop system and hybrids. In this paper, we are going to analyse the open loop system which is being the focus of our investigation.

3.3 Open loop exhaust gas cleaning system

Open loop exhaust gas cleaning systems are basically formed by a set of pumps whose main goal is to provide the system with sea water through the scrubber inlet valve. Furthermore, there are a set of water pipes which conduct seawater until the scrubbing tower. Before its use in the scrubbing tower, seawater has been analysed by a set of sensors which are placed next to inlet water valve to get the seawater parameters which has been used in each moment.

On the scrubbing tower, the exhaust gases from engines are subjected to cleaning process which consists in a continuous spraying seawater over the exhaust gases, at several height levels. Through this cleaning process, the sulphur content of emissions is greatly reduced. In this process is used one of main characteristics of water, the alkalinity. Alkalinity is defined as the capacity of water to neutralize acids. This is the water feature that allows the system to remove sulphur oxides from exhaust gases.

According to the Article (2021) [6] the water alkalinity is provided by the presences of carbonates and hydroxides which are obtained generally from decomposition of minerals in soil. But the concentration of these compounds in sea water are being reduced due to the CO2 absorption process. CO2 in sea water is forming carbonic acid and the latest is causing the hydrogen ion releasing. Theses ions are consuming the carbonates at the time they associate with them to form bicarbonates. So, the alkalinity is not an unlimited property of sea water.

Once the sea water has been used during the exhaust gases cleaning process, residual wash water from scrubbing tower is conducted through a set of pipes to the overboard discharge valve. The wash water discharged must comply with the wash water discharge criteria which is specifically regulated by Marine Environment Protection Committee (MEPC) of International Maritime Organization (IMO). This regulation is established through the Resolution MEPC.259(68) 2015 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS [7]. Water parameters regulated by Resolution MEPC.259(68) [7] are, acidity (pH), Polyciclic Aromatic Hydrocarbons concentration (PAH), heavy metal/ashes concentration (turbidity) and nitrates concentration without forgetting the wash water additives and other substances used in exhaust gas cleaning systems. The wash water discharged from ship must comply with limits established by Resolution MEPC.259(68) [7] regarding the above-mentioned water parameters.

Next, we will check the requirements established by this Resolution [7] regarding the wash water discharge from exhaust gas cleaning process, being the pH criteria, the focal point of our investigation.

<u>3.3.1 pH criteria</u>

Resolution MEPC.259(68) [7] establishes that the wash water used during exhaust gas cleaning process and intended to be discharged overboard, should comply with one of the <u>following requirements</u>:

1) The discharged wash water should have a pH of no less than 6.5 measured at the ship's overboard discharge, considering the next exception applied for ships which are under manoeuvring or in transit. For the above-mentioned ships, is allowed a maximum difference between inlet and outlet of 2 pH units, measured at the ship's inlet and overboard discharge.

2) The minimum value that the water discharge pH will achieve, at the overboard monitoring position (outlet), is the value which will <u>not be lower of pH 6.5 measured at 4 meters from the overboard discharge point</u> with the ship stationary, and this minimum pH value at the overboard monitoring position, is to be recorded as the overboard pH discharge limit in the Exhaust Gas Technical Manual for scheme A or for scheme B. This overboard discharge limit can be determined, as per the above-mentioned Resolution, either by means of direct measurement, or by calculation-based methodology, which can be based in computational fluids dynamics or in an equally scientifically established empirical formulae. If option chosen is the calculation-based methodology, this should be approved by Administration. Furthermore, and for both cases, the determination of pH discharge limit should be in accordance with certain conditions, established in Resolution MEPC.259(68) [7] and recorded in the Exhaust Gas Technical Manual for scheme A or for scheme B.

We must clarify that all Technical Manuals consulted so far, from several ships fitted with a hybrid or open-loop exhaust gas cleaning system, are using the second option regarding the pH control of wash water discharges. In the case of a ship fitted with open loop exhaust gas cleaning system, we find that the pH data recorded in the exhaust gas cleaning record book are truly low. It is clear that pH data is going to change depending first of all on the pH value of sea water collected by ship's inlet, but also depends on the size of ship, on the power of their engines and the engine load in each case, among others.

We have found cases of EGCS manufacturers which, as mentioned before, are using the second option of pH discharge criteria established by the Resolution [7] and according to this, the lowest pH level of wash water discharge allowed on their systems and measured at overboard discharge is around 2.6 pH units.

For having an example of latest, analysing the wash water monitoring data recording of a ship fitted with a open loop exhaust gas cleaning system and regarding the pH values recorded, we found a pH values as follows:

Inlet water pH	Outlet water pH	pH difference	Main Engine load (%)
8,64	4,02	4,62	81,1
8,64	3,69	4,95	80,5
8,64	3,81	4,83	85,3
8,64	3,76	4,88	88,3
8,64	3,59	5,05	86,5
8,64	3,63	5,01	89,5
8,13	3,83	4,3	42,7
8,13	3,79	4,34	42,1
8,13	3,62	4,51	42,6

Table 1. Extract from electronic monitoring data record of pH inlet and outlet values from a ship operating EGCS in open loop mode (at open sea). Source: The Authors.

Considering the pH data showed in the table, we can assert that residual wash water discharged (open loop) from the exhaust gas cleaning system has a clear acidic component. The sea pH value in the worst case is reduced more than 5,0 units of pH after being used by the system. Also, we must consider the engine load which in the above-mentioned case was around 89.5%. Although and comparatively when this ship is operating with main engine load at 42,6% we can observe that for a reduction greater than 50% of engine load, the pH reduction continuous being high.

We must also consider the specific case of a ship that is using scrubbers operating in open loop mode when she is berthed at port. During ships call in port, usually the ship's main engine is stopped and only is operating through auxiliary engines, one or two depending on the type of ship, cargo operations and on any other electric service required by ship. As obvious and due to the power of auxiliary engines in comparison with main engine, the reduction between pH at inlet and at outlet is less than before but it is still considerable.

Inlet water pH	Outlet water pH	pH difference	Aux. Engine load (%)
8,21	5,3	2,91	61
8,21	5,3	2,91	61
8,21	5,3	2,91	60
8,21	5,3	2,91	63
8,21	5,3	2,91	63
8,21	5,4	2,81	60
8,21	5,3	2,91	61
8,21	5,4	2,81	61
8,21	5,3	2,91	62
8,21	5,3	2,91	63

Table 2. Extract from electronic monitoring data record of pH inlet and outlet values from a ship operating EGCS in open loop mode (in port). Source: The Authors.

Other parameters to take into account in the wash water discharges are:

3.3.2 PAH criteria

Resolution MEPC.259(68) [7] establishes in a clear way that, the maximum continuous PAH concentration in the wash water should not be greater than 50 µg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration. The PAH concentration in the wash water should be measured downstream of the water treatment equipment, but upstream of any wash water dilution or other reactant dosing unit, if used, prior to discharge.

3.3.3 Turbidity / Suspended Particle Matter

For turbidity and suspended particle matter, Resolution [7] establishes a limit in the residual wash water discharges, being the maximum continuous turbidity in washwater allowed of 25 FNU (formazin nephlometric units) or 25 NTU (nephlometric turbidity units) or equivalent units, above the inlet water turbidity. Furthermore, establishes special requirements during periods of high inlet turbidity, where indicates that the precision of the measurement device and the time lapse between inlet measurement and outlet measurement are such that the use of a difference limit is unreliable. Therefore, all turbidity difference readings should be a rolling average over a 15-minute period to a maximum of 25 FNU. In addition, this regulation set up that the wash water should be measured downstream of the water treatment equipment but upstream of wash water dilution prior to discharge.

3.3.4 Nitrates

As in the previous cases for the above-mentioned residues, Resolution MEPC.259(68) [7] provides a clear limitation for nitrates discharges dragged by wash water discharges from the exhaust gas cleaning processes. Thus, the established requirement is that wash water treatment system should prevent the discharge of nitrates beyond that associated with a 12% removal of NOX from the exhaust, or beyond 60 mg/l normalized for wash water discharge rate of 45 tons/MWh whichever is greater.

3.3.5 Wash water additives and other substances

In the case of wash water additives which are used in those system requires the action of additional substances during the exhaust gas cleaning processes, Resolution [7] establishes less strict requirements. It could become insufficient as far as only requires an assessment of wash water which take into account relevant guidelines such as the Procedure for approval of ballast water management systems that make use of active substances (G9) and, if necessary, additional washwater discharge criteria should be established.

4. CURRENT SITUATION ON EGCS WASH WATER DISCHARGES

Nowadays there is a global concern regarding the environment protection in general terms. We can assert that the awareness of our society about the pollution prevention and the use of alternative fuels and clean energies are in an upward trend.

Currently more and more countries do not allow or establishes strong restriction regarding the use of exhaust gas cleaning systems which implies the residual wash water discharges into their territorial waters, inland waters, ports, and estuaries.

As per North of England P&I group publication from December 2021 [8], there are several countries which have banned the use of scrubbers operating in open loop mode. Some of the countries which directly prohibited discharges of wash water from EGCS are Argentina, Belgium, Brazil, China, Egypt, Finland, France, Germany, Gibraltar, India, Ireland, Latvia, Lithuania, Panama, Singapore, Sweden, several areas of United Kingdom, several States of the USA, among others.

In the case of Spain waters, currently the discharges from scrubbers operating in open loop mode are banned in the ports of Algeciras, Valencia, Cartagena and Huelva. The used of these systems are restricted in other ports like Bilbao and Cadiz. The specific case for Barcelona port is currently under study the proposal of establish strong restrictions or banning the EGCS operating in open loop mode.

4.1 Residues generated

The exhaust gas cleaning process generates several kinds of residues, among there are nitrates, ashes, heavy metals, polycyclic aromatic hydrocarbons, acidic water, etc. In the case of a closed loop EGCS, residual wash water from the exhaust gas cleaning process is conducted to the water treatment system/plant where is going to be treated and returned to the system for being used again. From the water treatment process a volume of residues is generated (sludges) which depending on the manufacturer is stored into sludge tanks or these sludges are separated from wash water through a filter press (figure 4) and the water is returned to the system. When filter press is used, the sludges formed are usually stored as dry residue (figure 5) into big bags for its delivery to the MARPOL Annex VI ports facilities.

Figure 4. View of a filter press from a hybrid EGCS installed on board of a ship. Source: The Authors.

Figure 5. View of dry residue generated in a hybrid EGCS installed on board of a ship. Source: The Authors.

As we can observe, the residues generated during the exhaust gas cleaning process have a completely pollutant looking.

During the wash water is in compliance with set out by Resolution MEPC.259(68) [7], there is no need for treat these residual wash water before is being discharged. Therefore, these residues, in the case of an open loop exhaust gas cleaning system or hybrid EGCS operating in open loop mode, are to be found dissolved into the discharged residual wash water.

5. Research findings

Since 05th January 2021, the research is focused in determine how the residual wash water discharges from open loop scrubbers, are affecting to the pH level of South Basin Barcelona port water. The research is being carried out in collaboration with the Institute of Environmental Assessment and Water Research (IDAEA-CSIC) laboratory which is analysing each sample is taken periodically, from South Basin port water. Furthermore, the analysis of pH South Basin Barcelona port water carried out per IDAEA-CSIC laboratory used on this research is complemented with samples which are taken and pH analysed more frequently using in this case, a specialized equipment which was acquired specifically for sea water pH measurements. Additionally, other water parameters are being analysed such the Oxidation Reduction Potential, density, and salt concentration of South Basin port water.

Results obtained so far does not indicate that residual wash water discharges from open loop exhaust gas cleaning system into the South Basin Barcelona port water have a great impact on its pH level. We have observed that during certain period after ships call in South Basin Barcelona port and using the open loop scrubber, the pH level of water is being decreased slightly but is being recovered again to its normal value which is being around 8,20 pH units. The latest defines the great capacity of South Basin Barcelona port water to neutralize the acidic water from open loop scrubber's discharges. This water property regarding the acid-neutralizing capacity, it is known as alkalinity.

The alkalinity of sea water is being reduced progressively at the time that the acidification of water is increasing [6]. A low alkalinity in the sea water would suppose a low resistance to withstand changes in pH. On this scenario and once the buffer capacity of sea water or its alkalinity has been reduced enough, a hard drop of sea water pH and a strong upward trend of acidity could take place.

As mentioned before, pH value of South Basin Barcelona port water has been analysed since beginnings of 2021 and an extract of results obtained is showed as follows:

Date	Location	pH value (CSIC)	pH value (specific equipment)
05/01/2021	South Basin	8,39	N/A
01/03/2021	South Basin	7,95	7,98
03/03/2021	South Basin	N/A*	7,98
05/03/2021	South Basin	N/A*	7,94
08/03/2021	South Basin	7,96	7,99
11/03/2021	South Basin	8,04	8,08
16/03/2021	South Basin	8,1	8,12
23/03/2021	South Basin	8,13	8,16
25/03/2021	South Basin	8,1	8,12
29/03/2021	South Basin	N/A*	8,02
31/03/2021	South Basin	N/A*	8,14
06/04/2021	South Basin	N/A*	8,08
15/04/2021	South Basin	8,09	8,09
20/04/2021	South Basin	N/A*	8,13
29/04/2021	South Basin	8,03	8,05
06/05/2021	South Basin	8,03	8,06
10/05/2021	South Basin	N/A*	8,01
13/05/2021	South Basin	8,07	8,09
17/05/2021	South Basin	N/A*	7,93
19/05/2021	South Basin	N/A*	8,07
28/05/2021	South Basin	8,19	8,21
01/06/2021	South Basin	N/A*	7,98
03/06/2021	South Basin	8,07	8,1
09/06/2021	South Basin	N/A*	8,1
28/06/2021	South Basin	8,04	8,07
30/06/2021	South Basin	N/A*	8,08
07/07/2021	South Basin	N/A*	8,08
08/07/2021	South Basin	8,1	8,11
14/07/2021	South Basin	N/A*	8,09
19/07/2021	South Basin	N/A*	8,07
21/07/2021	South Basin	8,08	8,08
26/07/2021	South Basin	N/A*	8,11
29/07/2021	South Basin	8,12	8,12
31/08/2021	South Basin	N/A*	7,97

Table 3. Extract of pH values obtained from the South Basin Barcelona port water samples analysis. Source: The Authors.

*Result from CSIC laboratory not available due to there was not sample analysed by them on this date.

6. Conclusions

Considering that research is in progress, sampling of South Basin Barcelona port water and its analysing by IDAEA laboratory is going to be carried out until the end of 2022, the conclusions obtained so far are as follows:

- The residual wash water discharged from open-loop exhaust gas cleaning systems has a clear acidic component. As we have observed in several cases, the minimum pH of wash water to be discharged overboard can achieve values of 2.6 pH units.

- Currently there is not an apparently urgent need for implementing measures for avoiding an immediate drop of South Basin Barcelona port water pH level. Nevertheless, the implementation of new regulations in front of wash water discharges from open-loop exhaust gas cleaning systems are necessary for improving the process and preventing the formation of acidic wash water.

- We have observed that the South Basin Barcelona port water should have a very high alkalinity and the same the time has a strong capacity to neutralize the acidic wash water spilled from the exhaust gas cleaning systems of ships which are operating in open-loop mode.

- Variations of South Basin Barcelona port water pH level observed during the sampling period performed, show small changes Thosemore significative are related to the large periods of absence of rains. Although and as mentioned before, we have observed that after ship's call using the open-loop exhaust gas cleaning system, South Basin Barcelona port water usually shows a small and transitory drop of pH level,after is being recovered to its normal level.

- We expect to continue with the South Basin Barcelona port water pH analysis, collecting all the results obtained and checking the behaviour of its pH level from beginning of research until the end of sampling which will be until the end of 2022.

- Before the period of sampling is being finished, we expect to introduce a system which helps to improve the normal operative of open-loop exhaust gas cleaning systems and avoids the current and problematic acidic wash water discharges.

- Introduction of exhaust gas cleaning systems in the shipping business was a step further to the ships emissions reduction but it was not the final solution.

- Despite the acidification of ocean is unfortunately a process with a very difficult repair due to the magnitude of the problem, the appliance of preventive technics into the ships operations which help to reduce their contribution to the acidification should be considered.

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