

Title: “Method and apparatus for treating an exhaust gas flow of a marine engine”

DESCRIPTION

Technical field

The present invention relates to the field of techniques for removing pollutants
5 and climate-changing agents from the exhaust gases deriving from maritime or inland
waters shipping.

More specifically, the present invention relates to a method and an apparatus for
treating an exhaust gas flow of a marine engine.

10 *State of the art*

Marine engines are typically fueled with various types of liquid fuels (e.g. IFO,
HFO, MGO, MDO, alcohols, LNG, Ammonia, Methanol and biofuels, included their
blends and their dual-fuel use, as well as water-in-fuels emulsions) which, due to their
nature and the combustion conditions typical of marine engines, produce a complex
15 profile of atmospheric emissions.

The combustion process of the marine engines produces both pollutants in
condensed form (e.g. fly ash, sulfates, nitrates, oils and carbonaceous particles) and
gaseous pollutants which include sulfur oxides, nitrogen oxides and carbon compounds
(e.g. CO and CO₂, methane and other unburned hydrocarbons, polycyclic aromatics,
20 etc.), also having climate forcing effects.

Particulate emissions from marine engines are among the most complex in the
anthropogenic emissions landscape, as they involve liquid and solid particles ranging
from a few nanometers to several microns in diameter. Experimental evidence indicates
that most of the particles emitted by marine engines are between 10 and 500 nm in size,
25 with the most likely values generally between 50 and 150 nm.

The largest particles with diameters greater than 500 nm – typically composed of
ash, sulfates, nitrates, and oils resulting from leakage of engine lubricating oil droplets,

the presence of cold spots in the combustion chamber during startup, and poor atomization of heavy fuels – can be efficiently removed by conventional cleaning techniques such as dry or wet electrostatic precipitators or Venturi scrubbers.

However, disadvantageously, these conventional cleaning techniques are not able
5 to efficiently remove the smaller particles, especially those located in the Greenfield gap which covers the range between 50nm and 1µm.

Given the characteristic particle size distribution in exhaust gas of marine engine and considering that the mass of a particle is proportional to the cube of its diameter, it is therefore apparent that the conventional removal techniques allow to reduce the
10 particle mass concentration (commonly referred to as “PM”) without having a significant impact on the particle number concentration (commonly referred to as “PN”).

In order to reduce the particle number concentration in the exhaust gas of marine engines, it is necessary to use technologies capable of efficiently removing fine particles
15 with sizes smaller than 500 nm, especially those between 150 and 50 nm.

Technologies capable of efficiently removing particles smaller than 500 nm are known in the state of the art. However, disadvantageously, these technologies – e.g., regenerative filter and electric field-based cleaning systems – are not suitable for use on board a vessel or in combination with marine engines.

20 Regenerative filter systems, such as Diesel Particulate Filers (DPF) and Diesel Oxidation Catalysts (DOC), are filters made of ceramic substrate coated with a catalytic active phase designed to remove carbonaceous particulate matter from diesel and gasoline engines. The progressive use of these filters leads to the formation of deposits of carbonaceous material, which must be periodically removed by means of thermal
25 and catalytic regeneration cycles to ensure the proper functioning of the filtering system.

It is well known that the regeneration cycles cannot be carried out in the

presence of non-carbon particles, such as mineral fly ash particles, and when the filter is coated with heavy oils that clog its pores. Therefore, disadvantageously, the regenerative filter systems cannot be used in combination with marine engines that are powered by heavy fuel oil (HFO) or Intermediate Fuel Oil (IFO) that produces exhaust
5 gases rich of oils and fly ashes. Also their application to Marine Gas Oil (MGO) is subjected to specific evaluations. Furthermore, application of such filters will result in a much higher backpressure than ship engines can withstand.

The electric field-based cleaning systems, such as wet electrostatic precipitators (WESP) or dry electrostatic precipitators (ESP), use high voltage electrodes (often
10 wires in these applications) configured to electrically charge the exhaust gas particles and grounded surfaces (often tubes for marine application) adapted to attract the electrically charged particles. To achieve high removal efficiency in a conventional wires and tubes unit, these must have an appropriate length-to-diameter ratio, and to handle high flow rates, multiple parallel units must be used. In addition, to limit the
15 length-to-diameter ratio, high electric potentials must be used to increase the level of charge of particles.

It is therefore evident that the WESP and the ESP systems, to properly treat the exhaust gas flows of marine engines, require heavy and cumbersome structures with high energy consumption that are not compatible with the needs of the marine industry.
20 In fact, in the marine industry, it is important to minimize the weight and volume of the equipment in order to reduce the load transfers during navigation and maximize the cargo and passenger capacity of the vessel. It is also important to minimize the electrical power consumption during navigation as this is generated by the engine, burning fuel and producing exhaust gasses that need to be treated. Besides, the mechanical
25 complexity of the system makes is susceptible to the vibration and thermal shocks, leading to an increase of specialistic maintenance costs. Furthermore, the very high voltage ustilized by standard ESP and WESP significantly increases the complexity of

the installation and the potential danger to the ship's crew and passengers.

Scope of the invention

In this context, the object of the present invention is to provide a method and an
5 apparatus for treating an exhaust gas flow of a marine engine that overcomes the
limitations of the known technologies.

In particular, an object of the present invention is to provide a method and an
apparatus optimized to treat the typical particle concentration and size distribution of
exhaust gases of marine engines, fuelled with any kind of fossil or renewable gas or
10 liquid fuel.

It is also an object of the present invention to provide a method and an apparatus
for treating an exhaust gas flow of a marine engine capable of reducing emissions in
terms of both particle mass concentration (PM) and particle number concentration (PN).

Another object of the present invention to provide a method and an apparatus for
15 treating an exhaust gas flow of a marine engine capable of achieving high removal
efficiency of both fine ($<2.5\ \mu\text{m}$) and submicron ($<1\ \mu\text{m}$) particulate matter, as well as
water-soluble gases, such as SO_2 , NO_2 , etc.

The specified technical object and the specified aims are substantially achieved
by a method and an apparatus for treating an exhaust gas flow of a marine engine
20 comprising the technical characteristics described in one or more of the appended
claims.

Summary of the invention

The present invention relates to a method for treating an exhaust gas flow of a
25 marine engine containing solid particles, liquid particles, and water-soluble gasses to
be removed.

The method comprises a first step of conditioning the exhaust gas flow from the

marine engine in a conditioning unit, to enlarge the solid and/or liquid particles by condensational growth. In this step, the exhaust gas is cooled and supersaturated with water vapor.

The method comprises a second step of electrically charging the particles and ionizing the water-soluble gasses by flowing the exhaust gas flow, leaving the gas conditioning unit, through a gas ionizing unit (gas ionizer/particle ionizer unit).

The method also comprises a third step of scrubbing the exhaust gas flow, leaving the ionizing unit, with a scrubbing washing liquid flow, in the form of electrically charged liquid droplets, to remove the solid and liquid particles and the water-soluble gas from the exhaust gas flow.

The particle enlargement by condensational growth in the conditioning step improves the sensitivity of the particles to the subsequent charging and scrubbing steps, thereby enhancing their capture rate.

Advantageously, the particle enlargement increases the ability of the particles to store electric charge and therefore their maximum level of charge after the charging step (i.e. at the gas ionizing unit outlet). For example, a 50 nm particle grown to 100 nm or 200 nm increase its capacitance (i.e. ability to store electric charge) by approximately 4 and 10 times, respectively. The higher level of charge of the solid and liquid particles in the exhaust gas generate stronger electrical interactions with the electrically charged liquid droplets of scrubbing liquid, increasing the particle removal efficiency regardless of particle size.

Advantageously, the particle enlargement by condensational growth increases the electrical charging efficiency of the solid particles by coating them with a aqueous conductive liquid layer. This helps both to increase the level of charge of the solid particles after the charging step (i.e. at the gas ionizing unit outlet) and to reduce the electrical power consumption of the ionizing unit.

Advantageously, the particle enlargement increases also the probability of

physical interactions between the particles in the exhaust gas and the liquid droplets of scrubbing liquid during the scrubbing step.

Moreover, advantageously, the aqueous liquid layer that is formed on the solid particles in the conditioning step promotes their integration into the liquid droplets of scrubbing liquid and reduces the risk of rebounding.

It is therefore evident that the synergistic effects between the conditioning, the charging, and the scrubbing steps allows to improve the electrical and physical interactions between the particles of the exhaust gas and the electrically charged liquid droplets of the scrubbing washing liquid, enhancing the removal efficiency of both fine and submicron particulate matter, as well as water-soluble gases such as SO₂.

It is also object of the present invention an apparatus for treating an exhaust gas flow of a marine engine by implementing the above-reported method.

This apparatus comprises a gas conditioning unit configured to condition the exhaust gas flow to enlarge the solid and/or liquid particles by condensational growth, a gas ionizing unit configured to electrically charge the solid and liquid particles and ionizing the water-soluble gases in the exhaust gas flow, and a scrubbing unit configured to scrub the exhaust gas flow with electrically charged liquid droplets to remove the aerosol of solid and liquid particles and water-soluble gas.

Advantageously, the high removal efficiency of the method allows to provide a lightweight and compact apparatus with low energy consumption, which fits well with the need of the marine industry.

BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the present invention will appear more clearly from the indicative, and therefore non-limiting, description of a preferred but not exclusive embodiment of a method and apparatus for treating an exhaust gas flow of a marine engine as illustrated in the enclosed drawings in which:

- Figure 1 shows a schematic representation of a first embodiment of an apparatus for treating an exhaust gas flow of a marine engine according to the present invention;

- Figure 2 show a schematic representation of a second embodiment of an apparatus for treating an exhaust gas flow of a marine engine according to the present invention;

- Figure 3 shows a schematic representation of a third embodiment of an apparatus for treating an exhaust gas flow of a marine engine according to the present invention;

- Figure 4 shows a schematic representation of a fourth embodiment of an apparatus for treating an exhaust gas flow of a marine engine according to the present invention;

- Figure 5 shows a block diagram of a method for treating an exhaust gas flow of a marine engine according to the present invention.

DETAILED DESCRIPTION

The present invention relates to a method for treating an exhaust gas flow F produced by a marine engine 1 and to an apparatus 100 configured to implement such method.

In the context of the present invention, the term “marine engine” is used to indicate internal combustion engines suitable for the propulsion of a vessel, from those fueled by liquefied natural gas (LNG) to those fueled by heavy fuel oil (HFO). For example, the marine engine 1 can be fueled with IFO, HFO, MGO, MDO, LNG, Alcohols, Ammonia, Methanol or biofuels, including their blends or dual fuel usage and the use of water in fuel emulsions.

The exhaust gas flow F of the marine engine 1 to be treated contains an aerosol of solid particles F_S , liquid particles F_L and water-soluble gases F_G . The method and the apparatus 100 object of the present invention are adapted to remove the solid particles F_S , liquid particles F_L and water-soluble gases F_G from exhaust gas flow F .

In the context of the present invention the solid and liquid particles F_S , F_L are assumed to be spherical, therefore their size is defined by their diameter.

With reference to block A of figure 5, the method according to the present invention comprises a step of conditioning the exhaust gas flow F from the marine engine 1, wherein the solid and/or liquid particles F_S , F_L are enlarged by condensational growth.

Specifically, in the conditioning step, the exhaust gas flow F is cooled and supersaturated with water vapor to form an aqueous liquid layer on the solid and liquid particles F_S , F_L which increases their size.

Advantageously, the particle enlargement and the aqueous conductive liquid layer improve the ability of particles F_S , F_L to take and store electric charges. This enhances the sensitivity of solid and liquid particles F_S , F_L to the following method steps, facilitating their separation from the exhaust gas flow F .

Preferably, in the conditioning step, the exhaust gas flow F is cooled to a temperature between 80°C and 50°C.

Advantageously, this temperature range allows to further improve particle capture mechanisms through foretetic forces effects.

Preferably, in the conditioning step, the exhaust gas flow F is saturated with water vapor reaching local water vapor supersaturation levels between 5% and 15% for a time interval comprised between 0.1 and 0.25 seconds or local water vapor supersaturation levels above 1% for at least 1 second.

Advantageously, these saturation levels allow the solid and liquid particles F_S , F_L to grow sufficiently to improve their sensitivity to the subsequent method steps without significantly increasing the risk of coulombic fission in the electrical charging step described below. It should be noted that an indiscriminate increase in the condensate phase will increase the risk of coulombic fission when the particles F_S , F_L are electrically charged. The coulombic fission is undesirable because it causes the particle

to explode and fragment into numerous smaller sub-particles that more difficult to remove.

Preferably, in the conditioning step, the solid and/or liquid particles F_S , F_L are enlarged by condensational growth until they reach diameters below 600nm, in particular between 200 nm and 600 nm.

It should be noted that if the diameter of the aerosol particles is increased too much (above 600 nm), the particles tend to sediment and settle on the walls of a gas ionizing unit 3 (introduced below). Disadvantageously, this further increase the risk of coulombic fission.

According to a first embodiment of the present invention shown in figure 1, in the conditioning step, the exhaust gas flow F is cooled and supersaturated by spraying the exhaust gas flow F with a water-based washing liquid 20. In other words, in the first embodiment, the conditioning step comprises the sub-step of cooling and supersaturating the exhaust gas flow F by spraying the exhaust gas flow F with the water-based washing liquid 20.

Advantageously, in addition to increase the solid and liquid particles F_S , F_L sizes by condensational growth, the water-based washing liquid 20 scrubs the exhaust gas flow F and remove part of the solid and liquid particles F_S , F_L , in particular those with diameters bigger than 500nm.

The water-based liquid 20 can be, for example, seawater. The use of seawater as water-based liquid 20 is preferable because it can be easily recovered from the sea during navigation and port area. Seawater can also contribute to the removal of acid gases as SO_2 and NO_2 due to its higher buffering capacity.

In the conditioning step, the exhaust gas flow F can be at least partially cooled, and possibly also supersaturated, by flowing it through a heat exchanger 21.

Various types of heat exchangers 21 can be used for this purpose. These include plate heat exchangers or shell-and-tube heat exchangers, in particular a shell-and-tube

heat exchanger with finned tubes.

According to one aspect, also gas-gas heat exchangers can be used to this scope: such a unit can adopt the gas leaving the scrubbing unit 4 (described below) as the refrigerant fluid for the heat exchangers of the gas conditioning unit. Advantageously, this gas-gas heat exchanger allows to increase the temperature and reduce the relative humidity of the exhaust gas flow F downstream of the scrubbing unit 4, thereby increasing its buoyancy and improve its dispersion in the atmosphere. According to a second embodiment of the present invention shown in figure 2, in the conditioning step the exhaust gas flow F is cooled and supersaturated by flowing it through a heat exchanger 21. In other words, in the second embodiment, the conditioning step comprises the sub-step of cooling and supersaturating the exhaust gas flow F by flowing it through a heat exchanger 21.

In the second embodiment, the condensational growth is promoted by condensation of moisture in the exhaust gas flow F. To achieve this results, it is necessary to use a heat exchanger that lets the gas “dehumidify” more slowly than it cools down. For example, this can be achieved by using a shell-and-tube heat exchanger with finned tubes or any other heat exchanger capable of rapid cooling.

According to a third and fourth embodiments of the present invention respectively shown in figures 3 and 4, in the conditioning step the exhaust gas flow F is cooled and supersaturated by both spraying the exhaust gas flow F with the water-based washing liquid 20 and flowing it through the heat exchanger 21.

Specifically, in the third embodiment, the exhaust gas flow F is at first cooled by flowing it through the heat exchanger 21 and then further cooled and supersaturated spraying it with the water-based washing liquid 20.

Differently, in the fourth embodiment, the exhaust gas flow F is at first initially cooled by spraying it with the water-based washing liquid 20, then further cooled by flowing it through the heat exchanger 21, and finally cooled and supersaturated by

spraying it with the water-based washing liquid 20.

According to one aspect, the conditioning step also comprises a sub-step of filtering the exhaust gas flow F by means of a demister 25 in order to eliminate the spray and/or condensation droplets having sizes greater a predetermined value, for example diameters greater than 20 μm .

With reference to block B of figure 5, the method object of the present invention comprises a step of electrically charging the solid and liquid particles F_S, F_L and ionizing the water-soluble gases F_G . This is achieved by flowing the exhaust gas flow F from the gas conditioning unit 2 through a gas ionizing unit 3 of the apparatus 100.

According to one aspect, in the charging step, the solid and liquid particles F_S, F_L are charged by means of field charging and/or diffusional charging phenomena.

It should be noted that, in order to guarantee an adequate level of charge, the particles F_S, F_L grown above 400 nm can be charged by exposure to high electric fields (field charging), while the ones with diameters between 100 nm and 400 nm are preferably charged by means both field and diffusional charging.

With reference to block C of figure 5, the method object of the present invention further comprises a step of scrubbing the exhaust gas flow F, leaving the gas ionizing unit 3, with a scrubbing washing liquid 40 flow, in the form of electrically charged liquid droplets 40d, to remove the solid particles F_S , the liquid particles F_L and the water-soluble gases F_G from the exhaust gas flow F.

In use, the electrically charged droplets 40d interact physically, electrically, and chemically with the aerosol of solid particles F_S , liquid particles F_L , and water-soluble gases F_G , removing them and cleaning the exhaust gas flow F.

In a preferable embodiment, the electrically charged liquid droplets 40d are charged with a sign opposite to the sign of charge given to the solid particles F_S , liquid particles F_L , and water-soluble gases F_G in the gas ionizing unit 3.

Preferably, the solid and liquid particles F_S, F_L are charged with negative electric

charges while the charged liquid droplets 40d are charged with positive charges.

However, in alternative embodiments, the electrically charged liquid droplets 40d are charged with the same sign of charge given to the solid particles F_S , liquid particles F_L , and water-soluble gases F_G in the gas ionizing unit 3.

5 Preferably, the charged liquid droplets 40d have a diameter between 100 and 800 μm which is optimal for removing the growth solid and liquid particles F_S , F_L with diameters between 200 and 500 μm .

 The scrubbing washing liquid 40 is preferably seawater. The use of seawater as scrubbing washing liquid 40 is preferable because it can be easily recovered from the
10 sea during navigation and in ports. A side effect of seawater is the higher absorption capacity for water-soluble gasses, e.g. acid gases as SO_2 and NO_2 .

 According to one embodiment, the scrubbing washing liquid 40 flow and the exhaust gas flow F are in a co-flow or cross-flow configuration, although countercurrent flow can be in principle adopted.

15 Advantageously, these configurations, unlike the counter-flow configuration, allow to avoid the formation of clogs in the scrubbing unit. In particular, the co-flow and cross-flow prevent the solid particles F_S to accidentally clog the nozzle of the electrosprays 41 of the scrubbing unit 4. More details regarding the electrosprays and the scrubbing unit 4 components are provided below.

20 According to an aspect, the exhaust gas flow F leaving the scrubbing unit 4 can be either used as refrigerant fluid for the gas conditioning unit 2 – using a gas-gas heat exchanger (see above) – or as refrigerant for the service fluids used in the gas conditioning unit 2, in a separated heat exchanger (not shown) placed downstream of the scrubbing unit 4. The use of scrubbing unit off-gases for this scope as two
25 advantages. First it allows to limit the use of service fluids for heat transfer and second, it allow warming up the gas leaving the process, thus increasing its buoyancy and improve its dispersion in the atmosphere.

It is also object of the present invention an apparatus 100 for treating an exhaust gas flow F of a marine engine 1 by implementing the method above.

Referring to figures 1-4, the apparatus 100 comprises a gas conditioning unit 2 configured to receive the exhaust gas flow F from the marine engine 1 and perform to the conditioning step described above. The gas conditioning unit 2 is therefore configured to condition the exhaust gas flow F to enlarge the solid particles F_P and/or liquid particles F_L by condensational growth. Specifically, the gas conditioning unit 2 is configured to cool and supersaturate the exhaust gas flow F so as to cover the solid and liquid particles F_P , F_L with a layer of water.

10 In the embodiment of figure 1, the gas conditioning unit 2 comprises washing elements 22 configured to spray the exhaust gas flow F with the water-based washing liquid 20 (e.g. seawater). Specifically, in use, the washing elements 22 cool and humidify the exhaust gas flow F by washing it with a stream of droplets of the water-based washing liquid 20.

15 Preferably, the gas conditioning unit 2 comprises a quencher 23 having the washing elements 22.

In the embodiment of figure 2, the gas conditioning unit 2 comprises a heat exchanger 21 configured to reduce the temperature and supersaturate the exhaust gas flow F.

20 Preferably, the heat exchanger 21 is shell-and-tube heat exchanger, more preferably a shell-and-tube heat exchanger with finned tubes.

In the embodiments of figures 3 and 4, the gas conditioning unit 2 comprises both the washing elements 22 and the heat exchanger 21.

25 In particular, In the embodiment of figure 3, the heat exchanger 21 is arranged upstream of the washing elements 22. Therefore, in use, the exhaust gas flow F passes sequentially through the heat exchanger 21 and the washing elements 22. The heat exchanger 21 promotes an initial cooling of the exhaust gas flow F, the washing

elements 22 further cool and supersaturate the exhaust gas flow F.

In the embodiment of figure 4, the heat exchanger 21 is arranged between the washing elements 22.

Preferably, always in the embodiment figure 4, the washing elements 22 comprise
5 first washing elements 22a configured to promote an initial cooling of the exhaust gas flow F and second washing elements 22b configured to further cool and supersaturate the exhaust gas flow F. The second washing elements 22b are arranged downstream of the first washing elements 22a and the heat exchanger 21 is arranged between the first and second washing elements 22a, 22b. Therefore, in use, the exhaust gas flow F passes
10 sequentially through the first washing elements 22a, the heat exchanger 21, and the second washing elements 22b.

Preferably, the gas conditioning unit 2 comprises a demister 25 configured to eliminate the spray and/or condensation droplets having sizes above a predetermined value, for example diameters greater than 20 μm .

15 Advantageously, the demister 25 prevents the spray and/or condensation droplets from entering and damaging the gas ionizing unit 3 described below.

Referring to figures 1-4, the apparatus 100 comprises a gas ionizing unit 3, arranged downstream of the gas conditioning unit 2, configured to perform the electrically charging step described above. In use, the gas ionizing unit 3 receives the
20 exhaust gas flow F from the gas conditioning unit 2 and electrically charges the particles F_S , F_L and ionizing the water-soluble gasses F_G therein.

According to one aspect, the gas ionizing unit 3 charges the particles F_S , F_L and ionizes the water-soluble gasses F_G by means of field charging and/or diffusional charging.

25 Preferably, the gas ionizing unit 3 comprises charging elements 31 (e.g. high-voltage electrodes and grounded counter-electrodes) configured to generate electric discharges by direct current corona effect or non-thermal plasma process with pulsed

current.

Always referring to figures 1-4, the apparatus 100 further comprises a scrubbing unit 4 arranged downstream of the gas ionizing unit 3 and configured to perform the scrubbing step described above. The scrubbing unit 4 is therefore configured to scrub
5 the exhaust gas flow F to remove the aerosol of solid and liquid particles F_P , F_L and water-soluble gasses F_G .

The scrubbing unit 4 comprises one or more electrospays 41 configured generate a flow of electrically charged liquid droplets 40d of a scrubbing washing liquid 40 which physically, electrically and chemically interacts with the exhaust gas flow F from
10 the gas ionizing unit 3 to remove the particles F_P , F_L and water-soluble gasses F_G within it.

In use, feeding means 42 (e.g. hydraulic pump) feed the scrubbing washing liquid 40 to the electrospays 41 which generate the flow of electrically charged liquid droplets 40d.

15 Preferably, the electrospays 41 are configured to generate electrically charged liquid droplets 40d having diameters between 100 e 800 μm .

For example, the electrospays 41 comprise a plurality of nozzles and electrodes (not shown in the attached figures) configured to generate a stream of electrically charged droplets when fed with the scrubbing washing liquid 40.

20 In a preferable embodiment, the electrospays 41 are configured to electrically charge the charged liquid droplets 40d with a sign opposite to the sign of charge given to the solid particles F_S , liquid particles F_L , and water-soluble gasses F_G in the gas ionizing unit 3.

Referring to the embodiment of figures 1-4, the gas ionizing unit 3 may comprise
25 a condensate accumulator 32 configured to remove liquid droplets and films formed between the gas conditioning unit 2 and the gas ionizing unit 3.

According to one aspect, the gas conditioning unit 2 and the scrubbing unit 4

comprise a respective washwater treatment unit. Specifically, the gas conditioning unit 2 and the scrubbing unit 4 comprises a first washwater treatment unit 24 and a second washwater treatment unit 44, respectively.

The first and second washwater treatment units 24, 44 are configured to
5 independently treat the water-based washing liquid 20 and the scrubbing washing liquid 40. Specifically, the first washwater treatment unit 24 is configured to treat the water-based washing liquid 20 to allow the water-based washing liquid 20 to be recirculated or rinsed and discharged into the sea; the second washwater treatment unit 44 is configured to treat the scrubbing washing liquid 40 to allow the scrubbing washing
10 liquid 40 to be recirculated or rinsed and discharged into the sea, independently from the water-based washing liquid 20.

It should be noted that the water-based washing liquid 20 and the scrubbing washing liquid 40 have different characteristics. Indeed, in use, the water-based washing liquid 20 captures the most of the oils and particles larger than 500 nm
15 contained in the exhaust gas flow F, whereas the scrubbing washing liquid 40 mainly captures particles smaller than 500 nm. The scrubbing washing liquid 40 can therefore be recirculated more easily and for a longer time than the water-based washing liquid 20.

Advantageously, the independent washwater treatment units 24, 44 allow to the
20 treatment to be optimized to the specific characteristics of the liquid to be treated (i.e. water-based washing liquid 20), thereby reducing, for example, the consumption of washwater liquids.

Those skilled in the art will obviously appreciate that several changes and variants may be made to the arrangements as described hereinbefore to meet incidental and
25 specific needs. All these variants and changes fall within scope of the invention, as defined in the following claims.

CLAIMS

1. Method for treating an exhaust gas flow (F) of a marine engine (1), the exhaust gas flow (F) comprising an aerosol of solid particles (F_S), liquid particles (F_L), and water-soluble gases (F_G) to be removed, the method comprising the step of:
- 5 - conditioning the exhaust gas flow (F) from the marine engine (1) in a gas conditioning unit (2) to enlarge the solid particles (F_S) and/or liquid particles (F_L) by condensational growth, the conditioning step comprising the sub-steps of:
- cooling the exhaust gas flow (F),
- supersaturating the exhaust gas flow (F) with water vapor,
- 10 - electrically charging the solid and liquid particles (F_S, F_L) and ionizing the water-soluble gases (F_G) by flowing the exhaust gas flow (F), leaving the gas conditioning unit (2), through a gas ionizing unit (3),
- scrubbing the exhaust gas flow (F) leaving the gas ionizing unit (3) with a scrubbing washing liquid (40) in the form of electrically charged liquid droplets (40d), to remove
- 15 the solid particles (F_S), the liquid particles (F_L) and the water-soluble gases (F_G) from the exhaust gas flow (F), in a scrubbing unit (4).
2. Method according to claim 1, wherein the electrically charged liquid droplets (40d) are charged with a sign opposite to the sign of charge given to the solid particles (F_S),
- 20 liquid particles (F_L), and water-soluble gases (F_G) in the gas ionizing unit (3).
3. Method according to claim 1 or 2, wherein in the conditioning step the exhaust gas flow (F) is cooled to a temperature between 80°C and 50°C.
- 25 4. Method according to any of the preceding claims, wherein in the conditioning step the exhaust gas flow (F) is supersaturated with water vapor reaching:
- local water vapor supersaturation levels between about 5% and 15% for a time interval

comprised between 0.1 and 0.25 seconds, or

- local water vapor supersaturation levels above 1% for a at least 1 second.

5 **5.** Method according to any of the preceding claims, wherein in the conditioning step the exhaust gas flow (F) is supersaturated by spraying the exhaust gas flow (F) with a water-based washing liquid (20).

10 **6.** Method according to claim 5, wherein the water-based washing liquid (20) is seawater.

7. Method according to any of the preceding claims, wherein in the conditioning step the exhaust gas flow (F) is at least partially cooled by flowing through a heat exchanger (21) of the gas conditioning unit (2).

15 **8.** Method according to claim 7, comprising a heating step wherein:

- the exhaust gas flow (F) leaving the scrubbing unit (4) is used as a the refrigerant fluid in the heat exchanger (21) of the gas conditioning unit (2), or

- the exhaust gas flow (F) leaving the scrubbing unit (4) is used to refrigerate a service fluid of the heat exchanger (21) of the gas conditioning unit (2).

20

9. Method according to any of the preceding claims, wherein in the scrubbing step the scrubbing washing liquid (40) flow and the exhaust gas flow (F) are in a co-flow or cross-flow configuration.

25 **10.** Method according to any of the preceding claims, wherein in the scrubbing step the scrubbing washing liquid (40) is seawater.

11. Method according to any of the preceding claims, wherein in the conditioning step the solid particles (F_S) and/or liquid particles (F_L) are enlarged by condensational growth until said solid particles (F_S) and/or liquid particles (F_L) reach diameters between 200 nm and 600 nm.

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12. Apparatus (100) for treating an exhaust gas flow (F) of a marine engine (1) by implementing the method according to any of the preceding claims, the exhaust gas flow (F) comprising an aerosol of solid particles (F_S), liquid particles (F_L), and water-soluble gases (F_G) to be removed, the apparatus (100) comprising:

- 10 - a gas conditioning unit (2) configured to receive the exhaust gas flow (F) from the marine engine (1) and to condition the exhaust gas flow (F) by cooling and supersaturating with water vapor the exhaust gas flow (F) to enlarge the solid particles (F_P) and/or liquid particles (F_L) by condensational growth,
- a gas ionizing unit (3), arranged downstream of the gas conditioning unit (2),
- 15 configured to electrically charge the solid and liquid particles (F_S , F_L) and ionizing the water-soluble gases (F_G) in the exhaust gas flow (F),
- a scrubbing unit (4), arranged downstream of the gas ionizing unit (3), configured to scrub the exhaust gas flow (F) to remove the aerosol of solid particles (F_S), the liquid particles (F_L) and the water-soluble gases (F_G), the scrubbing unit (4) comprising one
- 20 or more electrosprays (41) configured to be fed with a scrubbing washing liquid (40) and to generate a flow of electrically charged liquid droplets (40d).

13. Apparatus (100) according to claim 12, wherein the one or more electrosprays (41) are configured to charge the charged liquid droplets (40d) with a sign opposite to the

25 sign of charge given to the solid particles (F_S), liquid particles (F_L), and water-soluble gases (F_G) in the gas ionizing unit (3).

14. Apparatus (100) according to claim 12 or 13, wherein the gas conditioning unit (2) comprises a heat exchanger (21) configured to supersaturate the exhaust gas flow (F) and reduce the temperature of the exhaust gas flow (F).
- 5 15. Apparatus (100) according to claim 14, wherein:
- the heat exchanger (21) is of the gas-gas type, and
 - the exhaust gas flow (F) from the scrubbing unit (4) is used as refrigerant fluid in said heat exchanger (21).
- 10 16. Apparatus (100) according to a claim from 12 to 15, wherein the gas conditioning unit (2) comprises washing elements (22) configured to spray the exhaust gas flow (F) with a water-based washing liquid (20).
17. Apparatus (100) according to claim 14 and 16, wherein the heat exchanger (21) is
- 15 arranged upstream of or between the washing elements (22).
18. Apparatus (100) according to 17, wherein:
- the washing elements (22) comprise first washing elements (22a) configured to promote an initial cooling of the exhaust gas flow (F) and second washing elements
 - 20 (22b), arranged downstream of the first washing elements (22a), configured to supersaturate the exhaust gas flow (F) with water vapor,
 - the heat exchanger (21) is arranged between the first washing elements (22a) and the second washing elements (22b).
- 25 19. Apparatus (100) according to claims from 16 to 18, wherein the gas conditioning unit (2) comprises a demister (25) arranged downstream of the washing elements (22).

20. Apparatus (100) according to any claims from 16 to 19, wherein:
- the gas conditioning unit (2) comprises a first washwater treatment unit (24) configured to treat the water-based washing liquid (20) to allow water-based washing liquid (20) to be recirculated or rinsed and discharged into the sea,
 - 5 - the scrubbing unit (4) comprises a second washwater treatment unit (44), distinct from the first washwater treatment unit (24), configured to treat the scrubbing washing liquid (40) to allow the scrubbing washing liquid (40) to be recirculated or rinsed and discharged into the sea.
- 10 21. Apparatus (100) according to a claim from 12 to 20, wherein the gas ionizing unit (2) comprises charging elements (31) configured to generate electric discharges by direct current corona effect or non-thermal plasma process with pulsed current to charge the solid and liquid particles (F_P , F_L) and ionizing the water-soluble gases (F_G).
- 15 22. Apparatus (100) according to claim 21, wherein the charging elements (31) are configured to charge solid and liquid particles (F_P , F_L) and ionizing the water-soluble gases (F_G) with negative sign.
- 20 23. Apparatus (100) according to a claim from 12 to 22, wherein the gas ionizing unit (3) comprises a condensate accumulator (32) configured to remove films of liquids formed between the gas conditioning unit (2) and the gas ionizing unit (3).