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POLLUTION REDUCTION METHODS FOR AN EMERGENCY DIESEL GENERATOR FITTED ONBOARD A LARGE CONTAINER VESSEL

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ABSTRACT

The current study is focused on the analysis of methods and means for reducing marine engine exhaust and greenhouse gases (GHGs). The research method consists in identifying equipments that have been applied in the case of small four-stroke marine engines used as emergency generators on board large ships, specifically the Cummins Qsb6.7-G16 model. The results, which were demonstrated by practical experiences of the different possible configurations for the engine studied showed high potential for reducing emissions, but the most suitable alternative is the Selective Catalytic Reduction (SCR).

KEYWORDS: emission, fuel, generator, pollution, ship

1. Introduction

A situation defined as "power failure" occurs when there is a brief disruption or interruption in the generation or distribution of power. A blackout, or partial or whole loss of electrical power, can occur from a malfunction or overload in the ship's electrical distribution system. The design of the system, its backup mechanisms, and the location of the distribution system failure all affect how big and how severe the disruption is. It is challenging to predict errors in energy distribution systems due to their diversity and abundance of components.

Ships are equipped with their own electrical networks for generating, distribution and connected users. The electrical network of the ship allows it to function independently both at sea and frequently in port. The latter is necessary to guarantee that there is electricity on board even if the ship is not connected to shore power.

There are several approaches to design and fit the electrical network of a vessel. How the electric network is implemented depends on the type of vessel, its intended purpose, and certain design elements. According to the "International

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Convention for the Safety of Life at Sea" (SOLAS), ships engaged in international traffic must be able to generate electricity from two separate sources, each of which is capable of producing enough electricity on its own to keep the ship seaworthy. The ship's generators provide the necessary power for onboard use. They are often propelled by diesel engines and rotate at a steady speed.

Electricity is transmitted from the diesel generators to the main electrical grid, which then supplies electricity to the consumer terminals. A ship may have one or more generators that run on diesel fuel or heavy fuel. The overall number/units and production capacity of the generators will be determined by the ship's electrical power requirements. Another option for generating the necessary power for a ship is to use a generator that is attached to the main engine or a shaft generator. A generator that is directly attached to the propeller shaft, which is turned by the main engine, is known as a shaft generator. An alternative configuration could involve the primary engine turning the propeller shaft, with a generator linked to it via a reduction gear. Most of the time, a shaft generator can provide the ship with all of the electrical power it needs. When the ship is in transit, the shaft generator is typically used. To ensure safety, the necessary electrical energy can be generated by generators driven by auxiliary engines upon arriving in ports or narrow fairways.

As a mandatory rule for all seagoing ships, an emergency power supply, such as a set of batteries or an emergency generator, must be installed on the ship. The emergency electric panel receives the electrical energy generated by the emergency source and then distributes it to the safety-critical devices, such the steering system. The equipment that has been designated as critical determines how much power is needed in an emergency. The choice of emergency power source will therefore be determined by this power need. The majority of ships feature a diesel generator for backup power.

2. Ships Power Distribution System, Power Sources and the Specific Requirements

Diesel generator sets are currently the most often used primary source of electrical energy on ships, providing alternating current for marine electrical systems. Multiple diesel generator sets can be fitted and managed by an advance, custom made, automation system. A cargo or passenger ship operating in international waters it is required to have a minimum of two generator systems or sets installed if it has equipment or auxiliary systems that are powered by electricity.

The technical features of one of the generator units needs to be taylor made and it should be able supply the electricity needed by the ship's equipment. The following applies to ships built after July 1, 1998, when main power availability is required to operate the ship's main propulsion plant and steering system: the power generating system must be designed and equipped so that, in the event that one generator fails, the supply of electricity for the equipment required to operate the propulsion plant and steering system will immediately be restored. Installing multiple diesel generators in tandem and installing automatic transfer switches for the essential equipment will satisfy this requirement.

Most of all, it is necessary to distribute the load among the generators in a way that keeps one from overloading. This can be accomplished by modifying the generators' start-up limitations so that, upon reaching near 85% load, the subsequent generator ignites and it is automatic synchronized into the network to generate the required additional energy.

An emergency power supply, such as a set of batteries or an emergency generator, must be installed on the ship. The decision between the choices is based on the need for electrical power in an emergency (Lamb, 2017). These days, the majority of ships are equipped with diesel generators for backup power. They supply the ship's electrical grid with AC. As opposed to batteries, a diesel generator is a more portable option. In actuality, a diesel generator is used as an emergency power source when there is a greater need for electrical power. Small boats employ batteries as an emergency power source.

Radio devices, navigational equipment, and machine automation all depend on batteries for security of functioning or reliance. When restoring the operation of the main propulsion plant in a ship following a power outage, the capacity of the emergency power system must be dimensioned applying the following principles: if the emergency power source is a generator, the electricity feed for the propulsion plant and any associated equipment must be restored within 45 seconds of the power outage starting. The energy supply must be restored right away if a set of batteries is used as the emergency power source.

2.1. International Convention for the Safety of Life at Sea (SOLAS) requirements on the critical system for the emergence and consequences of power failures onboard ships

The ship's safety is prioritized over the machinery and equipment's protection from failure in the event of disruptions or malfunctions. The propulsion system must continue running as long as feasible in any failure scenarios. Additionally, even in the event that a propulsion system auxiliary or critical component malfunctions, it must be feasible to restart it. Auto-stop is strictly permitted in situations where the propulsion system could sustain significant damage. The goal of ship machinery system design is to replicate all essential operations. Nonetheless, classification agencies acknowledge that a ship might have a single main engine, one shaft line, and one propeller.

The ability to maneuver the ship must be retained both when the propulsion engine is operating and after it has stopped, for example, because of an automation or software malfunction (Chen, 2023). As a result, among the most crucial parts of the ship's electrical network are components of the steering system, such as machinery that transmits steering orders and units that generate steering force, including hydraulic pumps. A primary steering system and a rapidly deployable auxiliary steering system are required for ships.

The burden on the power grid must be evenly distributed by the machine automation system. The machine automation controls the standby generators' synchronization to the network and their start-up in the case of a generator failure. The steering gear and propulsion plant's auxiliary engines are also restarted by the machine automation.

2.2. Requirements in the International Safety Management (ISM) Code

Vessels engaged in international traffic are required by the ISM Code to have a safety management system. Instructions for hiring and acquainting the personnel, as well as instructions for handling different crises such power distribution disruptions, must be included in the safety management system.

Critical components and equipment must be identified in the ship's preventive maintenance system, as per the ISM Code.

The shipowner shall be able to produce proper documentation for machinery and parts to the flag state government or the classification society upon request. Hazardous scenarios could arise if such machine or any of its components malfunction.

The propulsion plant, steering gear, and power distribution system components must be at least included in the list of essential equipment. To enhance the functionality of the safety management system and the preventive maintenance system, the shipping firm must determine the criticality of on board systems based on its own operations.

2.3. Requirements in the Standard of Training, Certification and Watchkeeping for Seafarers (STCW) Code

A set of international laws governing seafarers' certification (competencies), watchkeeping, and training is known as the STCW Convention. The STCW Code, which establishes minimal requirements for seafarers' competency and training, is a part of the STCW. The STCW Code must be followed in terms of the crew's qualifications and training on cargo and passenger ships operating in international waters.

By means of port state controls regulation and national/international agreed inspection procedures, flag states keep an eye on whether ships are adhering to regulations. Every state has its own regulations governing the equipment requirements for ships and the degree of qualification required of seafarers.

3. The Cummins Qsb6.7-G16 Emergency Diesel Generator

The studied emergency diesel generator, a CUMMINS QSB6.7 model, is fitted onboard a container vessel with a 46.344 tones deadweight, 246,86 meters in length overall, a maximum beam of 32.2 meters and a maximum draught of 12.3 meters. Her container capacity is 3500 TEU. The main engine onboard is a MAN-B&W 9K80MC-C − 2 stroke, 9 cylinder, 800 x 2.300 mm, diesel engine with a power of 32.490 kW at 104,0 rpm. The electric system is driven and feed by 4 auxiliary engines/ plants each 450 V − 2.150 kVA.

The emergency diesel generator has a 250 kVA capacity. Keeping in mind that its power factor equals 0.9, the generated power will be equal with 225 kW, thus meaning it generates a total power of 301 HP. The emergency diesel generator is made by the Cummins company, being manufactured in India (Cummins India Limited, 2015).

Figure no. 1*: The Cummins QSB6.7-G16 emergency diesel generator onboard the container vessel (left) and the CAD projection of it (right)*
(Source: Cummins India Limited, 2015)

The heavy-duty Cummins QSB6.7 generator series features a diesel engine-powered alternator. Along with an after-treatment device and cutting-edge in-cylinder technology to fulfill the most recent emission regulations, it is small and has an ideal power to weight ratio. The diesel generator sets are delivered featuring on of the lowest noise levels in this field, and the engine is built to pass strict exhaust emission tests in accordance with the new environmental regulations.

It is a very efficient and dependable marine equipment. With a service period of under 500 hours per year, all components are optimized to optimum efficiency even at partial loads, resulting in the lowest possible running costs (Cummins India Limited, 2015).

4. Analysis of Gas Emission Pollution Reduction Methods for the Cummins Qsb6.7-G16 Emergency Diesel Generator

4.1. The Selective Catalytic Reduction (SCR) method

The Selective Catalytic Reduction (SCR) solutions are predicated on fuels containing a low degree of sulfur (a maximum of 0.1% S) for marine diesel generators operating in Tier III. By using SCR, an exhaust gas treatment technique, NOx produced by marine diesel engines can be brought down to a level that complies with International Maritime Organisation IMO regulations for NOx Tier III.

Following combustion, an SCR reactor can be installed on the exhaust pipe system uses a catalytic process to reduce NOx. By introducing ammonia as a reducing agent, the NOx is catalytically reduced to nitrogen and water in the SCR reactor. As seen in the image below, the catalyst in the reactor is made up of building blocks with several channels that provide a vast surface area for the catalytic process to occur.

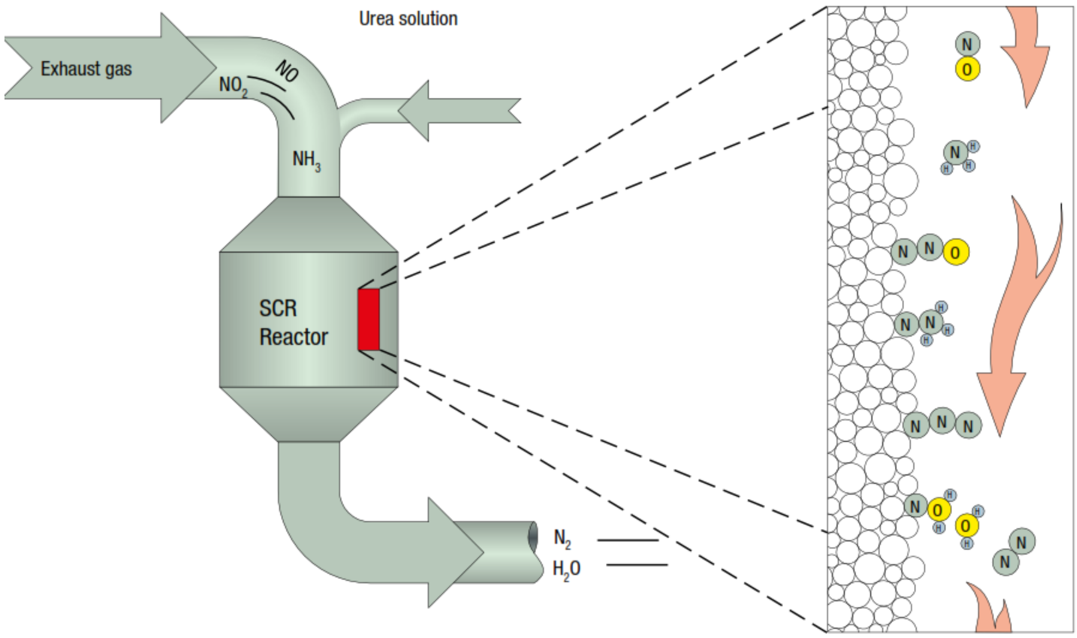

Figure no. 2: *The SCR system layout principle*
(Source: Pulkrabke, 2020)

The overall reaction that the equipment follows to reduce NOx:

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$
$$2\,NO + 2\,NO_2 + 4\,NH_3 \rightarrow 4\,N_2 + 6\,H_2O$$
$$2\,NO + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O$$

Aqueous urea is typically used to introduce ammonia into the system for safety concerns. When injected into the vaporizer, this breaks down into carbon dioxide and ammonia.

$$(NH_2)_2CO_{(aq)} \rightarrow (NH_2)_2CO_{(S)} + x\,H_2O_{(g)}$$
$$(NH_2)_2CO_{(S)} \rightarrow NH_{3(g)} + HNCO_{(g)}$$
$$HNCO_{(g)} + H_2O_{(g)} \rightarrow NH_{3(g)} + CO_{2(g)}$$

However, a very high temperature (above the nominal set value) will cause the catalyst to generate more SO_3 than it would be necessary. After then, SO_3 and water react to produce sulfuric acid, which manifests as an unwanted white foam. As the temperature of the exhaust gas reaches around 500°C, a further undesirable reaction that further restricts the mean maximum temperature for the Selective Catalytic Reduction (SCR) operation is the oxidation stage of NH_3. This means that more NH is required into the system. In addition, temperatures exceeding the 500-550°C range can cause the catalyst material to begin even to sinter.

Put another way, maintaining exhaust gas temperatures within a specific temperature window is essential to ensuring a robust SCR operation. Low pressure low sulfur (LP LS SCR) or high pressure low sulfur (HP LS SCR) installations are the two options available for low sulfur SCR systems (Lamb, 2017).

4.2. The Selective Catalytic Reduction SCR Process – High Pressure

The hybrid vaporizer/mixer equipment and the Selective Catalytic Reduction (SCR) reactor are basic parts of the SCR line, where the HP LS SCR process is carried out. This process is depicted in the image below. By putting the reducing agent into the vaporizer, that will vaporize and mix with exhaust gas, the catalytic process is being prepared.

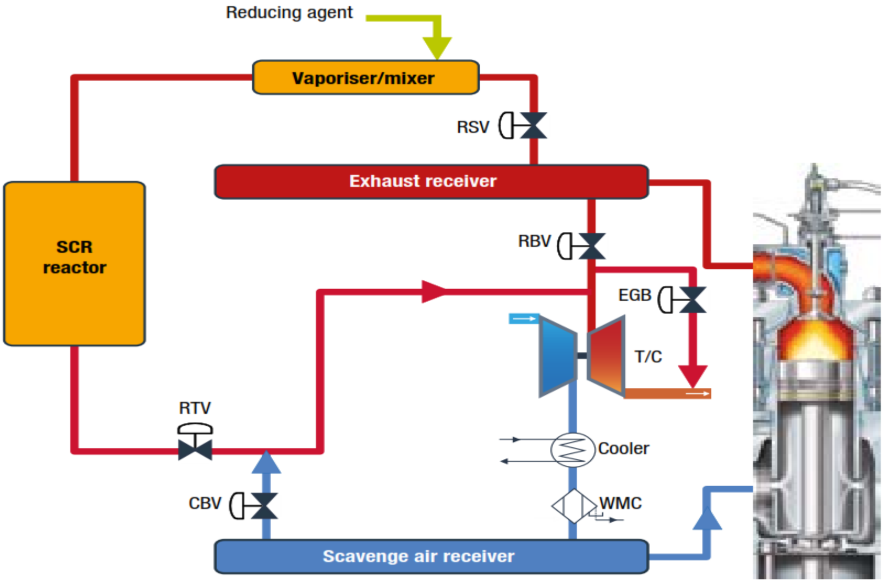

Figure no. 3: *High pressure LS SCR system diagram*
(Source: Shrivastava, Padmesh, Walavalkar, 2015)

The Reactor Throttle Valve (RTV) and Reactor Sealing Valve (RSV) shut scrubber unit when it is functioning in the "Tier II mode". Since the reactor bypass valve (RBV) is active, the turbocharger receives exhaust gas directly. Additionally, the system has an exhaust gas by-pass valve (EGB) to enable "Tier II" low-load EGB adjustment. The Selective Catalytic Reduction (SCR) system will activate when the system is in Tier III operation. The RBV valve will remain closed while the RSV and RTV valves open the SCR line.

4.3. The Selective Catalytic Reduction (SCR) Process – Low Pressure

Installing a low pressure SCR system inside the overall system is feasible if the sulfur level in the fuel (heavy fuel or marine diesel fuel) is limited to 0.1% S or less during the SCR operation. Because the SCR line in this system is positioned behind the turbo charger, there is flexibility in how the SCR installation is organized. Three main parts make up the LP LS SCR system, as shown in the image below: an AIG (ammonia injection grid) mixer, an SCR reactor, and a Decomposition Unit (DCU).

This DCU is made up of a vaporizer, a heater (burner) and a blower. It is positioned on a gas evacuation positioned somewhere between the mixer inlet and reactor exit. A mix of vaporised ammonia is created when the reducing agent is fed into the vaporizer. The mix is then driven by the blower into the mixer and ultimately the Selective Catalytic Reduction (SCR) reactor. The bypass will cause the SFOC to rise in accordance with the necessary temperature. Despite the extremely low fuel sulfur level, ABS production cannot be completely prevented. Using the DCU to heat and transport the right quantity into the reactor to dissolve the resulting matter is one way to do it.

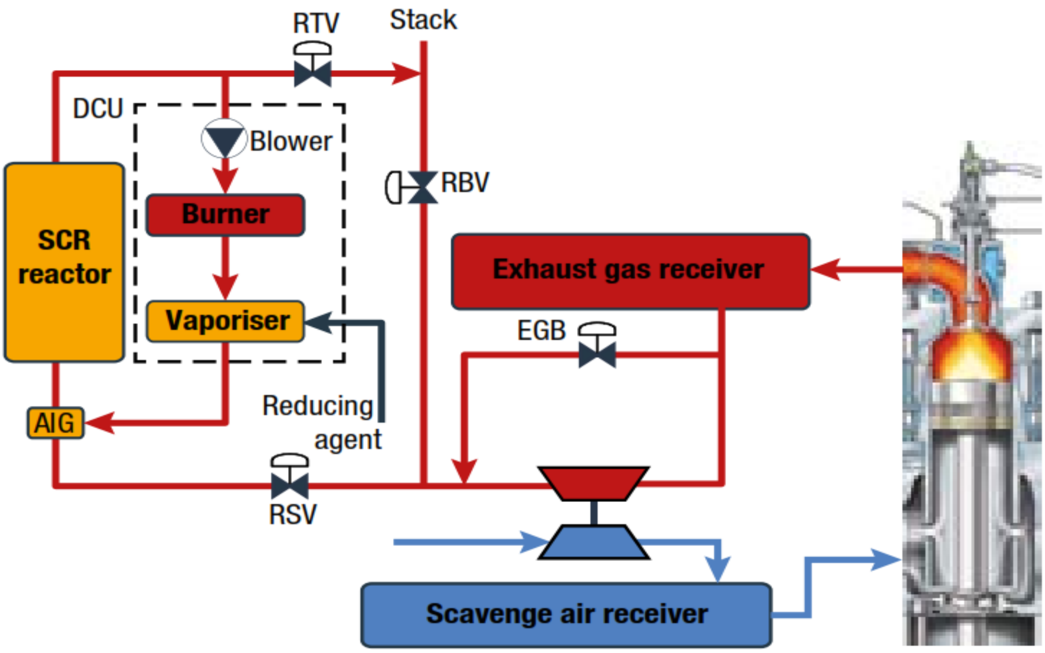

Figure no. 4: *Low pressure LS SCR system diagram*
(Source: Shrivastava, Padmesh, Walavalkar, 2015)

4.4. Operational profile

The ship's main boiler is somewhat impacted by how well the SCR operates. Ammonium Bisulfate (ABS) resulting deposits may form on the cooler surfaces of the exhaust gas boiler as a result of ammonia inside the SCR system slipping and the sulfur contained by the diesel fuel. The low sulfur concentration will minimize the production of ABS despite leaks from the Selective Catalytic Reduction (SCR) system being increased. Furthermore, using conventional cleaning techniques to remove deposits occurred in the boiler during reduced-sulfur functioning is quite simple.

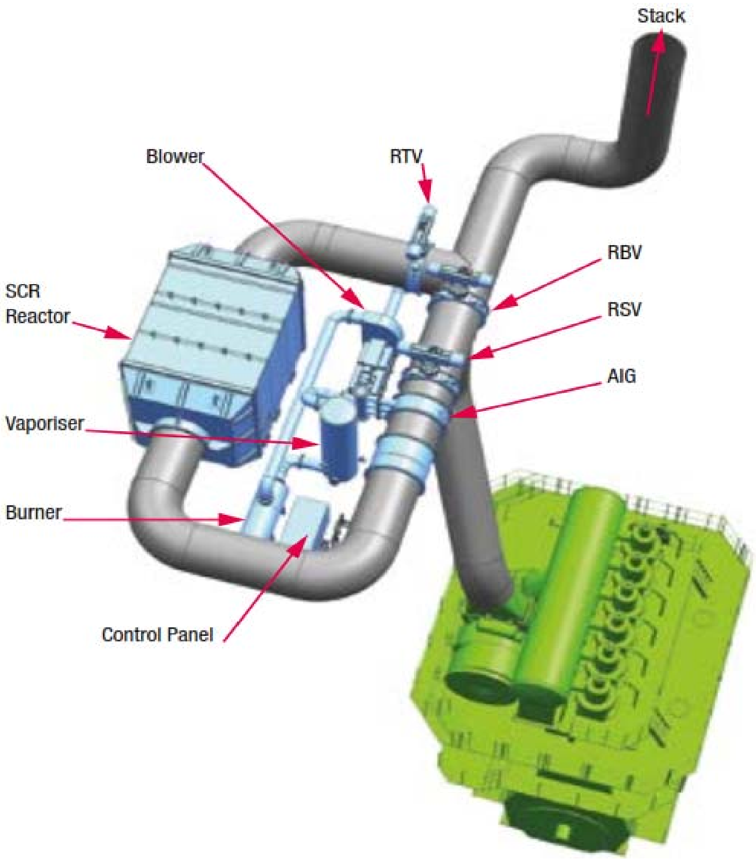

Figure no. 5: *The SCR type used on the CUMMINS QSB6.7-G16 emergency diesel generator* (Source: Cummins India Limited, 2015)

4.5. The Selective Catalytic Reduction (SCR) auxiliary systems

Supply system for reducing agent – Anhydrous ammonia (NH_3), aqueous ammonia (25% NH_3), or aqueous urea (32.5% or 40% solution) are the three types of reducing agents utilized in the SCR process. Urea is a practical substitute for anhydrous ammonia in marine applications since it provides no substantial risks, unlike ammonia, which is toxic and harmful. Furthermore, the supply chain for urea is simpler than that for anhydrous ammonia, despite the fact that urea is consumed and stored in larger volumes. Furthermore, urea necessitates a more intricate mixing and vaporizing procedure, which affects the Selective Catalytic Reduction (SCR) system's design.

Aqueous ammonia (25% NH_3) – Even if caustic and hazardous to human health and the environment, this substance can be treated similarly to urea with the right care. The injection is carried out using compressed air in addition to the chosen reducing agent. Effective execution of the reducing agent's injection and mixing processes is crucial. Any unused ammonia, also known as the "ammonia slip", runs the danger of forming some sorts of deposits inside the exhaust gas system, when it reacts with exhaust gas generating ammonium bisulfate (NH_4HSO_4), when the temperature drops.

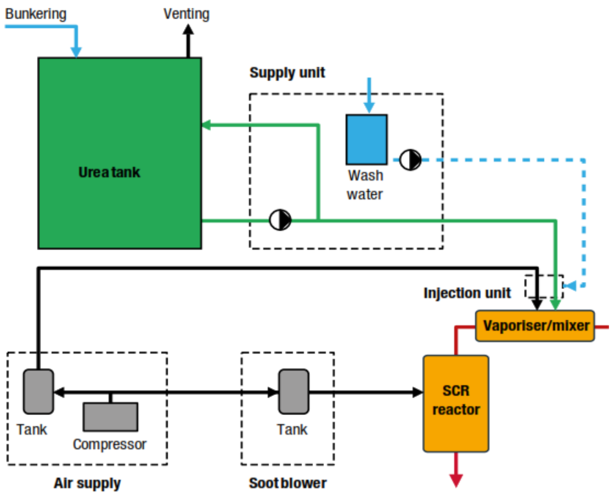

Figure no. 6: *Typical diagram of urea supply system*
(Source: Pulkrabke, 2020)

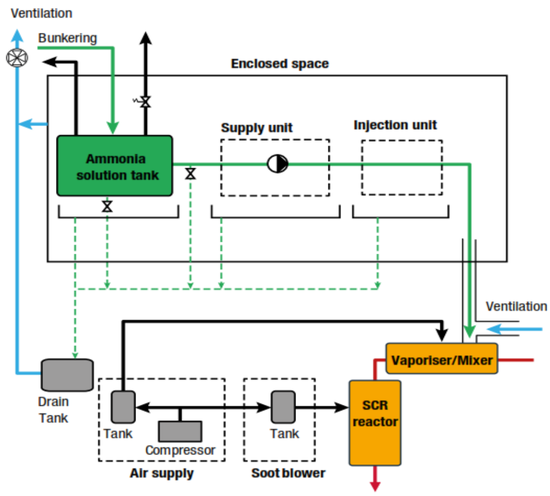

Figure no. 7: *Example of supply system for aqueous ammonia*
(Source: Pulkrabke, 2020)

Urea and ammonia (NH_3 anhydrous) – The accompanying image above depicts an example of a urea delivery system. Urea is pumped using a urea dosage pump from the storage tank to the vaporizer/mixer. In addition, the supply unit features yet another pump unit for clearing the injection nozzles and a wash water tank. Urea and compressed air injection into the vaporizer is managed by a control device. To avoid clogging, wash water is used to flush the urea injection nozzles after the SCR process is stopped. Alternatively, urea might be blended and stored as solids on board.

Ammonia (aqueous solution) – Ammonia is categorized as corrosive and environmentally hazardous when it is provided as an aqueous solution of NH_3 (25% solution). The evaporator-containing portion of the supply system and the storage tank need to be located in a different room from the accommodations and the equipment room. This solution's consumption and storage capacity are substantially the same as those of urea. In a similar way, the supply system diagram for this type is displayed above (Chen, 2023).

Soot blower system – Is a soot blower system that uses high pressure air to keep the SCR reactor clean and it is installed in order to reduce potential contamination of the reactor parts. During the SCR process, the soot blower procedure is run on a regular basis. The soot is blasted away from the reactor's elements and then lead out with the exhaust flow.

SCR heating system – Because of their size and bulk, the vaporizer and SCR reactor have substantial heat capacities. In order to ensure that the SCR reactor and vaporizer are working at the proper temperature, the system should typically be engaged in a timely manner prior to entering a NOx ECA. However, the temperature will gradually drop when in port, or when the engine is at a stop, therefore there must be a way to either heat up the system or maintain the necessary temperature. The system must have heat tracing or other suitable mechanisms in order to meet this demand.

SCR Control system – The Emission Reduction Control System (ERCS) is required on all MDT 4 – stroke Tier III marine engines for emergency diesel generators and manages the SCR control. The engine manufacturer provides the ERCS (Cummins India Limited, 2015).

High pressure SCR control system – The ERCS regulates the SCR valves and the amount of reductant dosed in engines with high pressure SCR. Additionally, it manages the interfaces to other subsystems.

Low pressure SCR control system − The ERCS manages interfaces to several subsystems and regulates the reductant dosage quantity on engines with Low Pressure SCR. These subsystems consist of a valve control system, a regeneration system, and a reductant dosing system.

4.6. SOx Scrubber

Using a SOx scrubber is another way to lower the amount of gas pollution produced by a maritime emergency diesel generator. Although it is not a new invention, it is quite effective, and there are numerous manufacturers on the market; however, the best are thought to be those made by the renowned marine manufacturer Alfa Laval.

Compared to heavy fuel oil (HFO), low-sulfur fuels like MDO and MGO are more expensive. As a result, different, inexpensive techniques for cleaning exhaust gases to lower SOx emissions have been developed. Using a dry or wet chemical, exhaust gas cleaning is done in a scrubber unit to get rid of PM and SOx. Wet scrubbers for marine engines are often installed utilizing recirculated freshwater (FW) with chemical addition or readily available seawater (SW).

Water is used in a wet scrubber to clean the exhaust gas as it goes toward the funnel. Water is released from the scrubber's bottom and pumped into the exhaust gas stream. Through a straightforward chemical reaction, the scrubber water dissolves and removes the sulfur oxides produced during combustion as a result of the sulfurous fuel:

$SO_2 + H_2O \rightarrow$ (sulfurous acid) H_2SO_3

$SO_3 + H_2O \rightarrow$ (sulfuric acid) H_2SO_4

Since freshwater (FW), either saltwater (SW) may be employed in the process, different solutions are needed for the installation and operating systems. In essence, two main types of SOx scrubber systems are available on the marine market: closed loop systems that use FW as the medium and open loop systems that use SW. One could install one of the two systems. Moreover, a hybrid solution capable of combining open and closed loop systems with the option to switch (between SW and FW scrubbing) could be implemented when a high level of flexibility is needed (Deligant, Podevin, Descombes, 2021)

Open loop system – An open loop system is selected when using SW for scrubbing, as seen in the image below. The effects of SOx in the scrubber water are offset by the natural chemical makeup of seawater. The scrubber receives its water supply straight from the sea. After passing through the scrubber, the water is released into the ocean untreated. The high water flow through the scrubber satisfies the IMO guidelines' discharge standards.

The open loop technique is usually applied in open waters where the seawater's alkalinity is high enough to allow for efficient scouring. In terms of installation and running costs, the system is the least complicated and most affordable option. On the other hand, an open loop system is less flexible when low alkalinity or restricted discharge conditions cause municipal rules to prohibit or restrict the system's operation. With a 2.7% sulfur HFO, open loop operation needs a SW quantity of about 45 m^3/MWh.

Closed loop system – A closed loop system is selected when FW is used for scrubbing, as seen in the image below. Chemical addition is required to neutralize the sulfuric acid in the scrubber water. This could be the result of the following process where sodium hydroxide (NaOH) becomes a sulfate:

$H_2SO_3 + 2NaOH + 1/2O_3 \rightarrow Na_2SO_4 + H_2O$

$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + H_2O$

Scrubber water, however, becomes contaminated with sulphate and particulate matter (PM) during the combustion process.

The sulfate and PM need to be regularly removed in order to prevent the system from becoming more contaminated and salinized. This is accomplished by injecting FW to restore the lost volume after bleeding off scrubber water from the system. Distilled water from the combustion process recovers the majority of the fresh water (FW) during the cleaning phase.

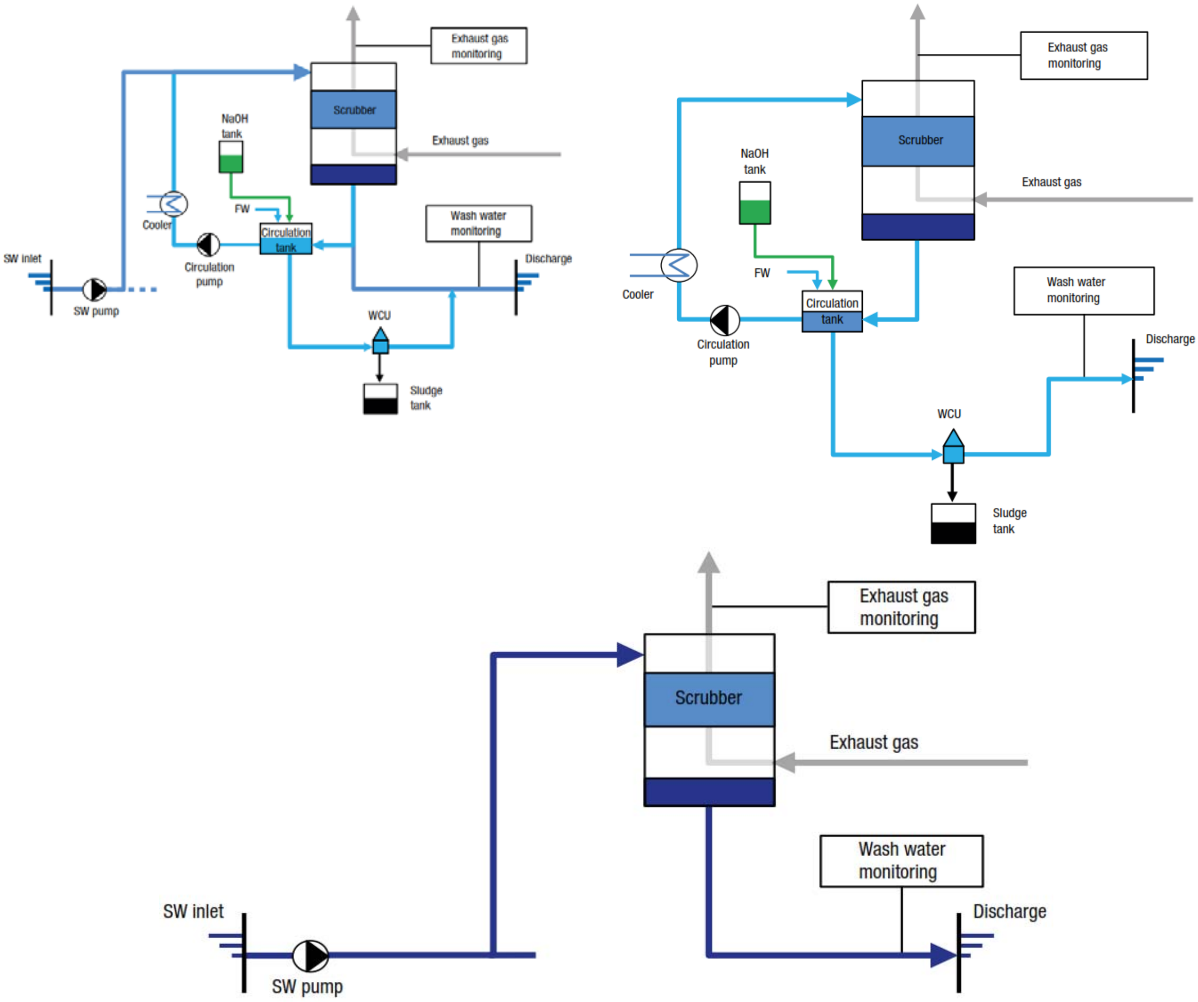

Figure no. 8: *Layout difference between (middle) open loop system, (right) closed loop system and the hybrid system (left)*
(Source: Gustafsson, Bergman, Jonsson, 2003)

The scrubber water is passed via a chiller prior to being injected into the scrubber in order to reduce the amount of FW that escapes with the exhaust gas. To stop droplets from escaping through the funnel, a demister is added.

Hybrid system (Open/Closed loop system) – The two systems are combined to create the hybrid system seen in the above image. The hybrid system has the most flexibility but is also the most difficult because of the mix (Gustafsson, Bergman, Jonsson, 2003). When the alkalinity is high enough for efficient scrubbing, open waters are the usual settings for the open loop mode. The closed loop method is utilized in harbors, estuaries, and some enclosed environments where the saltwater has a low alkalinity. In addition, to ensuring that resulting substances do not harm protected areas with minimal transfer, this combination maximizes chemical use.

5. Conclusions

Emissions of SOx and PM are regulated by the sulfur content of any fuel used on board ships. The rules of SOx and PM apply to all ships, no matter the date of ship construction. When sailing inside SOx emission control areas (SOx ECA), the sulfur content must not exceed 1.0%. This limit is reduced to 0.1% from 1 January 2015. Any abatement technology reducing the emission of SOx and PM to a level equivalent to the emission level when using the accepted fuels will be accepted provided the relevant guidelines are followed.

For four-stroke engines, the Cummins engine manufacturer provides two different ways to satisfy the Tier III NOx regulation. Exhaust gas recirculation (EGR), an internal engine operation, is the first approach to stop NOx generation by managing the combustion process. The second technique, known as selective catalytic reduction (SCR), is an after-treatment strategy that lowers the amount of NOx produced during combustion by utilizing an additive and a catalyst.

Because SOx levels in the emission control areas demand low sulfur fuels to include 0.1% or less, the current SCR solutions are made for these fuels. A more sophisticated solution involving a SOx scrubber should be required upon request in the event that a Tier III solution for high sulfur fuel is required.

"The Onboard Survey Method is similar to the well-known Unified Survey Method developed and delivered with numerous engine manufacturers through the last 15 years. The Onboard Survey Method utilized the performance parameter methodes described in MARPOL Annex VI and the NOx Technical Code" (Gustafsson, Bergman & Jonsson, 2003). The compliance is confirmed by reading or measuring specific performance metrics and comparing to limit values. Similar to the Onboard Survey Method provided with ordinary Tier II engines, the Onboard Survey Method for Tier II mode on a Tier III engine is also available. A few more parameters are added for the Tier III mode. In terms of EGR, the O2 concentration of the combined new intake air and cleaned recirculated exhaust gas is directly proportional to the reduction of NOx. The EGR ratio is likewise controlled by this setting. O2 has been added as an Onboard Survey parameter for EGR as a result. When it comes to SCR, the system's complete functionality is tested using an exhaust emission concentration sensor and the consumption of reducing agent.

Reducing agent consumption is one of the SCR onboard survey parameters. The control system uses the concentration sensor to detect two distinct events that point to a system issue: Higher than predicted NOx concentration, suggesting a possible breakdown in the NOx reduction system; Lower than expected NOx concentration, suggesting an overdose of reducing agent and hence a potential risk of ammonia slip. A system diagnostic should be run in response to the two indications in order to identify any potential issues. If an issue is discovered, potential fixes will be recommended.

When a ship is sailing inside a NOx Emission Control Area, the engine must be run in Tier III mode. It is the operator's responsibility to ensure that the engine is run in compliance with the regulations. A logging system might be used to record Tier III compliance, but the engine control system does not provide this feature. In order to make this easier, Cummins engines come with an engine control system that produces a signal that indicates the engine's emission mode. There are two available status signals for Tier III compliance.

These signals are activated when 1) a Tier III mode command has been issued to the engine control system, and 2) the Tier III system is working (no failures, auto mode).

As soon as NOx reduction starts, these signals are triggered. When the ship crew issues a Tier III mode command, the first signal permits logging; when the engine is truly running at a lower NO emission level, the second signal permits logging. Specific operational circumstances or the startup time cause the difference between the two signals. In some circumstances, even when the operator has given the instruction and the system is not lowering NOx, there will be no errors. This might occur in the subsequent circumstances: The guidance load change curve is slower than the engine load change; rough seas that cause the engine load to fluctuate; the duration of the control valve engagement and disengagement; Engine load or external circumstances beyond the emission control system operational field, as indicated in the NOx Technical File (Lamb, 2017). The goal of Tier III systems is to reduce these instances. The engine is still regarded as being in Tier III mode even when NOx reduction is not taking place because it is a Tier III certified engine and these are temporary circumstances not covered by the certification cycle. The engine control system will provide an alert code and SMS message in the event of a system failure, enabling the issue to be fixed. Furthermore, the two Tier III compliance signals are eliminated.

REFERENCES

Chen, M.Y. (2023). *Thermal Load Analysis of Supercharged and Intercooled Diesel Engine.* Kunming University of Science and Technology, China.

Cummins India Limited. (2015). *Diesel Generator Set QSB6.7 Series*. Power Generator Technical Book.

Cummins India Limited. (2015). *Emission Project Guide – Cummins four-stroke marine diesel generator*. Technical Book.

Cummins India Limited. (2015), *Waste Heat Recovery System (WHRS) – For reduction of fuel consumption, Emissions and EEDI for marine diesel generator*. Technical Book.

Cummins Power Generator – *“Cummins QSB6.7 Engine Automation Systems”*, Doc No. 810.0000.705-01.

Deligant, M., Podevin, P., & Descombes, G. (2021). Experimental identification of marine engine mechanical friction losses. *Energy Journal, Vol. 39*, 388-394.

Gustafsson, R.U.K., Bergman, M., & Jonsson B.R. (2003). Emission and performance evaluation of a 25 cc stratified scavenging four-stroke engine. *SAE paper number 2003-32-0047*, 82-88.

Lamb, A. (2017). *The Running and Maintenance of Marine Diesel Engines*. Marine Technology, Sitxh Edition.

Lüddecke, B., Nitschke, P., & Dietrich, M. (2015*).* Unsteady Thrust Force Loading of a Marine Engine during Ship Operation. *Journal of Engineering Gas Turbines Power, Vol. 17*, 80-95.

Pulkrabke, W. (2020). *Engineering Fundamentals of Internal Combustion Engines*. Willard, Section Edition.

Shrivastava, S., Padmesh, M., & Walavalkar, D. (2015). *Modeling IC Engine Thermal Management using ANSYS CFD-ANSYS Inc*.