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Contributions to the study of service characteristics of cooling water used for marine engines

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Abstract: Even if the cooling system of a marine engine is regarded as an auxiliary system of less importance, this is absolute necessary for its operation. Recent research in advanced cooling system showed that there is a potential of greenhouse gasses reduction and fuel economy, but operational issues related to corrosion, fatigue and scale formation still remain.

1. Marine engine – temperatures of components in operation, functional clearances.

During the operation of the engine, it is reached a condition temperature for each component (piston rings, piston, cylinder) and it is maintained a clearance between them, named functional clearance, on which depends the clearance at assembly.

Clearances piston-cylinder

a) In operation
b) Assembly temperatures

$D_{PM}[mm]$ – piston diameter in the area of piston's jacket
$D\ [mm]$ – diameter of cylinder

	Assembly temperature	Function
Piston	D_{PM}	$D_{PM}\,[1+\alpha_p \cdot \Delta t_p]$
Cylinder	D	$D\,[1+\alpha_{cil} \cdot \Delta t_{cil}]$
Clearence	$D - D_{PM}$	$D\,[1+\alpha_{cil} \cdot \Delta t_{cil}] - D_{PM}\,[1+\alpha_p \cdot \Delta t_p]$

- It is required functioning clearence and it is determined the clearence at temperature during assembly of engine;
- Knowing cylinder's diameter and the clearence during assembly, it is determined diameter of the piston during assembly.

$\alpha_p\ [°C]^{-1} -$ thermal expansion coefficient of the piston's material;
$\alpha_{cil}\ [°C]^{-1} -$ thermal expansion coefficient of the cylinder's material;

$\Delta t_p = t_{p_f} - t_{p_m}$ [°C] – temperature difference of the piston;
$\Delta t_{cil} = t_{c_f} - t_{c_m}$ [°C] – temperature difference of the cylinder.

Numerical example:
$D = 450\ [mm]$;
$j_f = 0{,}5\ [mm]$;
$\alpha_p \approx \alpha_{cil} = 13 \cdot 10^{-6}\ [°C]^{-1}$;
$t_{c_f} = 120\ [°C]$;
$t_{c_m} = 20\ [°C]$;
$t_{p_f} = 160\ [°C]$;

$$t_{p_m} = 20\ [°C]$$

$$D_{Pm} = \frac{450 \cdot [1 + 13 \cdot 10^{-6} \cdot 100] - 0{,}5}{1 + 13 \cdot 10^{-6} \cdot 140} = \frac{450{,}085}{1{,}00182} = 449{,}27\ [mm]$$

Clearance with engine cold will be: $J_M = 0{,}73\ [mm]$.

	Assembly	Operation
Piston ring lenght	$L_{S_m} = \pi D - f_m$	$L_{S_f} = [\pi D - f_m] \cdot [1 + \alpha_s \cdot \Delta t_s]$
Cylinder circle lenght	πD	$\pi D\ [1 + \alpha_{cil} \cdot \Delta t_{cil}]$
Seat	$f_m = \pi D - L_{S_m}$	$\pi D\ [1 + \alpha_{cil} \cdot \Delta t_{cil}] - [\pi D - f_m] \cdot [1 + \alpha_s \cdot \Delta t_s]$

It is required piston ring seat F_f and it is determined piston ring seat during assembly on the cylinder jacket.

Numerical example:
$F_f = 1\ [mm]$;
$\Delta t_s = 160\ [°C]$;
$t_{s_m} = 20\ [°C]$;
$t_{s_f} = 180\ [°C]$;

$\pi \cdot 450[1 + 13 \cdot 10^{-6} \cdot 100] - [\pi \cdot 450 - f_m] \cdot [1 + 13 \cdot 10^{-6} \cdot 160] = 1$
$\pi \cdot 450[1 + 13 \cdot 10^{-6} \cdot 100] - 1 = \pi \cdot 450[1 + 13 \cdot 10^{-6} \cdot 160] - f_m[1 + 13 \cdot 10^{-6} \cdot 160]$

Result:

$$f_m[1 + 13 \cdot 10^{-6} \cdot 160] = \pi \cdot 450 \cdot 13 \cdot 10^{-6}(160 - 100) + 1$$

$$f_m = \frac{\pi \cdot 450 \cdot 13 \cdot 10^{-6} \cdot 60 + 1}{1 + 13 \cdot 160 \cdot 10^{-6}}$$

$$f_m = \frac{1{,}102687 + 1}{1{,}00208} = 2{,}09832\ [mm]$$

2. Energy flow required for cooling of cylinder liner

For engines in supercharged 4 stroke cycle, scavenging is produced during the cycle starting with opening of air intake valves until closing exhaust valves on an angular period of 100° - 140° crankshaft rotations. During this process it is ensured internal cooling of the upper part of cylinder jacket, piston head, cylinder cover and exhaust valves. For 2 stroke croshhead engines with uniflow scavenging (scavenging ports and exhaust valves), scavening air ensures internal cooling of cylinder jacket on the whole height, piston head, cylinder cover and exhaust valve. Scavenging is produced when piston is located in the lower dead center area. Using the relations of determining piston's displacement, it is determined volume variation of engine fluid which assures internal cooling with air of cylinder.

$X_p = \frac{S}{2}\left[(1-cos_\alpha) + \frac{1}{\lambda}\left(1-\sqrt{1-\lambda^2 \cdot sin^2\alpha}\right)\right]$ - formula of exact displacement of the piston. [2.1]

$X_p = \frac{S}{2}\left[(1-cos_\alpha) + \frac{\lambda}{4}(1-\cos 2\alpha)\right]$ - relation of approximate displacement of the piston. [2.2]

V_{X_p} – volume of piston's stroke;

$$V_{X_p} = X_p \cdot \frac{\pi D^2}{4} \ [m^3]$$

V_{f_m} – volume of engine's fluid;

$$V_a = V_S + V_{CA}$$

$$V_{f_m} = V_{CA} + V_{X_p}$$

$$V_{f_m} = V_{X_p} + \frac{V_S}{\varepsilon - 1} = \frac{\pi D^2}{4} \cdot \frac{S}{2}\left[(1-cos_\alpha) + \frac{\lambda}{4}(1-\cos 2\alpha)\right] + \frac{V_S}{\varepsilon-1} \quad [2.3]$$

$$V_{f_m} = V_S\left\{\frac{1}{2}\left[(1-cos_\alpha) + \frac{\lambda}{4}(1-\cos 2\alpha)\right] + \frac{V_S}{\varepsilon-1}\right\} \quad [2.4]$$

$$V_{maxf_m} = \frac{\pi D^2}{4} \cdot S + V_C = V_s + V_C$$

ε – compression ratio;

$$\varepsilon = \frac{V_S + V_{CA}}{V_{CA}} = \frac{V_S}{V_{CA}} + 1 \quad [2.5]$$

$$\varepsilon - 1 = \frac{V_S}{V_{CA}} \rightarrow V_{CA} = \frac{V_S}{\varepsilon - 1} \quad [2.6]$$

T_{X_P} – engine's fluid temperature at position X_P of the piston;

<u>During compression:</u>

$$T_{X_P} = T_a \cdot \left(\frac{V_a}{V_{fm}}\right)^{n_c^{-1}} \quad [2.7]$$

3. Cooling water requirements

3.1 Engine designer and manufacturer

The primary scope of the cooling system is to conduct heat out of the engine hot components directly or indirectly in order for engine to keep the physical properties and to maintain the temperature in the specified range during operation.

The main supply of cooling system is to be provided with two sea water inlets which will provide sea water necessary to cool various liquids which circulate the engine through minimum two sea water pumps, one serving as a main pump and other as stand by pump. Capacity of the pumps are calculated and dependent of necessary flow to cool down main engine components such as: cooling of shaft line bearings, cooling of reduction gear lubricating oil, cooling of hot well, fresh water cooling flow for main engine, cylinder jacket heads cooling, turbo charger cooling, piston cooling, crankcase lubrication oil cooling and charge air cooling. Each system listed above is regarded as separate installation and for each the mass flow rate of coolant is calculated.

Unless otherwise specified, the cooling water system shall include also the following design features:

- The fresh water cooling system shall use distilled or treated water provided by fresh water generator system on board and is passed through a heat exchanger (shell and tube type), part of central fresh water system;
- Cooling water flow through cylinder jackets must be maintained interrupted, quality of water being free of scale, impurities and non-corrosive;
- Depending on the engine type and purpose, manufacturers are setting a temperature range and a maximum temperature rise in the cylinder jackets for cylinder jacket water cooling water. For a two stroke engine most common range for temperature is between 63-68°C with a maximum temperature rise of 10°C; [8]
- Design pressure is also established by manufacturer and usually is not to be less than 5.2 bar working pressure with a test pressure of 8 bar; [8]
- Each sub-system cooling outlets shall be fitted with thermometers;
- The system shall be provided with an external connection for draining with the purpose of washing and cleaning of the whole installation;
- Last but not least, cooling system shall be equipped with protection devices which will signal and audible and visual alarm in case of one of the parameters included by the manufacturer is under or over the limit, in some cases this leading to emergency stop of the engine. Typical list of protection devices for cooling system is illustrated in table below and this can be extended as per diversity of the installation.

Table 1 – typical list of monitoring and alarms for cooling system [1]

Component	**Alarm**
Water expansion tank level	Monitoring alarm high/low level
Jacket water temperature outlet - engine	Monitoring alarm high level
Jacket water pressure outlet- engine	Monitoring alarm high/low level
Jacket water temperature inlet – heat exchanger	Monitoring alarm high/low level
Jacket water pressure inlet- heat exchanger	Monitoring alarm high/low level
Jacket water temperature out – heat exchanger	Monitoring alarm high/low level
Jacket water pressure out- heat exchanger	Monitoring alarm high/low level
Jacket water pump temperature inlet	Monitoring alarm high/low level
Jacket water pump pressure inlet	Monitoring alarm high/low level
Governor oil cooler water temperature-outlet	Monitoring alarm high/low level
Governor oil cooler water pressure - outlet	Monitoring alarm high/low level
Cooler A water pressure - outlet	Monitoring alarm high/low level
Cooler A water temperature - outlet	Monitoring alarm high/low level
Circulating pump water temperature - inlet	Monitoring alarm high/low level
Circulating pump water pressure – inlet	Monitoring alarm high/low level
Scavenge air cooler – water temperature in	Monitoring alarm high/low level
Scavenge air cooler – water pressure in	Monitoring alarm high/low level
Generator bearing cooler water temperature – in	Monitoring alarm high/low level
Generator bearing cooler water pressure - in	Monitoring alarm high/low level

3.2 Classification societies

Classification societies' general requirement on cooling system is relying on manufacturer specified limits during all operations and under all inclination angles of the vessel. Rules are also making reference of permanent availability of the cooling system and redundancy of the sea water pumps and/or other main components. In case one of the components is malfunctioning, the cooling has to be maintained even with the risk of partial reduction of propulsion capacity, but with safe operation of the ship. The rules on cooling systems are divided in several parts: for centralized cooling systems, individual cooling of propulsion engines, cooling of other essential equipment and arrangement of cooling systems.

3.2.1 Centralized cooling systems

In the case of such system serving main engine, auxiliary engines and other equipment it is mandatory that the installation to be equipped with a sea water pump which may be engine driven, one stand by pump of same capacity and two heat exchangers each with 50% capacity of the total necessary cooling water needed to serve the system. In case of several propulsion engines with a total output not exceeding 375 kW the stand by pump may be replaced by an independent external pump ready to be connected at any time.

3.2.2 Individual cooling system for main engine

The difference from centralized cooling system is that the stand by pump has to be independently driven and only one heat exchanger of enough capacity is sufficient. This individual system applies to modern type propulsion engines with more than one engine connected with their own propeller constituting an independent system, in which case a complete spare pump identical to those serving the engine but driven independently has to be provided for each system. This may be an external ballast pump or other pump of sufficient capacity.

3.2.3 Fresh water cooling system

Fresh water cooling system shall include one main cooling pump and a stand by pump as redundancy, which can be omitted if the fresh water system has an emergency connection to a suitable sea water system with the ease possibility of change over when required. Since usually this installation is fitted with an expansion tank used in case it is necessary to re-fill this closed loop system, general rules for new construction applies like in case of any tank, has to be equipped with a drain, a filling device, a level indicator and a de-aerating possibility.

Fresh water cooling system is usually cooling systems handling fuel oil or lubricating oil and therefore there is a high risk of oil contamination which may result in a rapid failure of the system. Class societies are imposing obligation to fit a protective device in order to detect contamination of water by fuel or oil. Also since fresh water is used also to in heating coils of various tanks, these have to be seamless type, with no detachable connections in order to minimize risk of mixing oil and water.

3.3 ISM requirements

International Safety Management is ensuring the safety of life and ship on the sea through various best practices and procedures implemented on board. It is based on three goals: safety of people, ship and environment. In issuing the specific management code there are three authorities working altogether: owner through shipping company, ship's crew and flag authorities which may work through delegates such as class surveyors. ISM is also reflecting and influencing the good management of machinery in engine room, cooling system being one of them. In most of the vessels, cooling system is also included, as per item 10.3 of ISM code, in the critical equipment list which requires specific procedures and measures to be taken in case of an operational failure of the whole system or one of its components.

In order to ensure safety of the propulsion and its auxiliary systems ISM code is reaching a very basic issue: proper maintenance on board ship. This includes but is not limited to:

- Proper training of engine's crew with regards to cooling system, its scope and risks;
- Regular inspections of various components according to maintenance manual;
- Identify on time any technical non-conformity and take necessary action;
- Weekly testing of equipment and systems
- Keeping a records of maintenance done, breakdowns and replaced spare parts.

3.4 Planned maintenance

Planned maintenance is nowadays a software based system which allows ship owners and operators to carry out maintenance according to manufacturer intervals or classification society requirements. It will include maintenance instructions, maintenance intervals, reporting, jobs history, breakdowns and failures. Cooling system is added as well in this system, but is not regarded as a whole complete system but its components such as: main sea water pumps, circulating pumps, feed water pumps, heat exchangers, coolers, thermostats. Each component has its own manufacturer, therefore different maintenance intervals, different specifications.

4. Cooling water treatment

4.1 Products

The environment of the cooling water is a natural medium for development of microorganisms and not only. The biofilm can plug the passage of water inside piping and accelerate the corrosion. Mechanical damages caused by poor cooling water quality are usually related to: blocked exhaust valves, insufficient cooling of cylinder heads due to blocking of cooling water bores, decreased lifetime of coolers due to deposits and blocking of cooling water inlets, but also reduced heat transfer in engine components which is leading to thermal overload, resulting cracks and leakages.

In order to prevent these problems, three prevention methods were adapted in the marine cooling water systems over the time:

- Cleanliness: cooling water must be used free from rust and any deposits done by descaling and acid recirculation
- Usage of deionized freshwater produced in freshwater generator
- Water treatment on regular basis with corrosion inhibitor.

Therefore, adding correct inhibitor and the correct quantity is of crucial importance to ensure safe operation without any breakdown of main engine. The scope of corrosion inhibitor is to provide a protective layer on engine components and piping installation which is contact with cooling water. There are several chemical suppliers on the market, presented in table 1 below:

Table 1 – Main corrosion inhibitor suppliers and their products. [5]

Supplier	Product name	Dosing for 1000 liters	NO_2 concentration (ppm)	Na-Nitrite concentration (ppm)
Drew Marine	Liquidewt	15 ltr	700	1050
Unitor	Rocor NB Liquid	21.5 ltr	2400	3600
Nalfleet Marine	Nalfleet EWT	3 ltr	1000	1500
Nalco	Nalcool 2000	30 ltr	1000	1500
Maritech AB	Marisol CW	12 ltr	2000	3000
Uniservice	Colorcooling	24 ltr	2000	3000
Marinchem	D.C.W.T.	48 ltr	2400	-
Marine Care	Caretreat 2	16 ltr	4000	6000

Vecom	Cool Treat NCLT	16 ltr	4000	6000

4.2 Instructions for using corrosion inhibitor

Dosage recommendations for cooling water treatment is depending on manufacturer specifications, there are no general formulas for quantity of chemical to be added. As general rule a slight overdosing is better than under dosing but large overdosing, 2 or 3 times more than maximum value specified in the instructions manual may cause corrosion as well due to deposit formation.

Decision regarding the quantity of dosing is taken usually by chief engineer on board, after weekly complete water analysis. This is performed with a special test kit provided by chemical supplier, providing a complete cooling condition evaluation. Table 2 below shows regular tests carried weekly onboard and nevertheless to mention that the levels are only typical, the correct and exact values are depending on manufacturer guidance.

Table 2 – Regular tests carried out weekly on cooling water [5]

Test	**Typical level**
pH	8-11
Nitrite	500-2500 ppm
Chlorides	Less than 40 mg/l
Suphates	Less than 100 mg/l
Iron	Less than 1 mg/l
Nitrate	Less than 200 mg/l
Copper	Less than 1 mg/l

Regarding chemical feed there are many methods of controlling addition of chemical feed inhibitor product in cooling systems and these may be: manual feed, timer control feed, constant feed, chemical injection, proportional feed and active tracer monitoring. In the modern marine cooling systems, active tracer monitoring is the most used chemical feed control which means providing real control of the inhibitor level, but also proportional feed which is far superior than active tracer monitoring. Proportional chemical feed system is quite simple and is based on measuring the amount of water flow and activating a chemical pump through a timer to add the correct amount of inhibitor proportional to the amount of water. Another advantage of this system is the possibility of handling directly from the product container, eliminating the risk of being in contact with this hazardous chemical, as can be seen in figure 1 below:

Figure 1 – Proportional Chemical Pump Feed System [4]

4.3 Instructions for preventing accidents

It is mandatory that chemicals supplied on board are provided with relevant material safety data sheet, which is posted in the immediate vicinity of the storage place for chemicals. This document is containing important information regarding: name of the product, identification mark, category, registered supplier, emergency contacts, classification of product with regards to flammability, toxicity, reactivity and blending, chemical composition, fire fighting measures, environmental precautions, disposal, handling, storage, physical properties, toxicological effects and medical first aid instructions.

In view of this issue, in the company ISM Manual, as well as in material safety data sheet of the product there are specific precautions to be taken when handling corrosion inhibitor product. It is utmost important to use safety glasses with side shields, chemical goggles, safety gumboots and chemical protective suit, especially when manual dosage method is used. Material safety data sheet is providing information on material type of the personal protective equipment to be used, for example most of companies are recommending PVC for chemical protective gloves and suit and rubber for protective boots, but these specifications may vary from manufacturer to manufacturer (eg. Neoprene, nitrile, Teflon, PVA). Other recommendations would be that the products must be stored in a well ventilated area and free of sources of heat due to flammability risk of the corrosion inhibitor, but also because this product may decompose and after decomposition is no longer suitable to use.

4.4 Measures in case of accidents

Since all corrosion inhibitors contain similar chemical components in different quantities, the first aid measures are basically the same for all products and illustrated in the table 3 below. Material safety data sheet is containing the measures to be applied in different situations, but can offer medical advice on immediate basis in case of contamination.

Table 3 – Measures in case of accidents by ingesting, inhaling or contact with corrosion inhibitor [9]

Eye contact	Skin contact	Inhalation	Ingestion
If the product comes in contact with eye, these have to be washed with fresh water. Ensure complete irrigation of eye by keeping eyelids apart and way from eye and moving eyelids by lifting upper and lower lids	If the product comes in contact with skin, flush skin with fresh water and soap.	If fumes, aerosols or combustion products are inhaled together with inhibitor vapors, remove the sources immediately.	This is the most dangerous case and if swallowed, medical attention has to be obtained without delay. Before transportation to hospital, vomiting has to be induced with fingers down the back of the throat.

Conclusions

Poor cooling water treatment and control will increase ship operating costs via destruction of one of the most expensive installation onboard, increase energy use and operating costs. Selecting a cooling water management programme and manufacturer based on design of the system, total capacity and on some knowledge of chemistry and controls will increase the probability of obtaining a good efficiency with maximum heat transfer at a low cost. Even if this system is regarded as a low importance installation, a good management through ISM system, devoting sufficient time and resource for keeping the cooling system in good order will be rewarded with a safe and reliable operation of the propulsion engines.

Abbreviations

ISM – International Safety Management
PVA – Polyvinyl Acetate
PVC – Polymerizing Vinyl Chloride

References

[1] Bureau Veritas, Rules for the Classification of Steel Ships, 2017
[2] Caterpillar, Cooling Systems, 2011
[3] Caterpillar, Know your cooling system, 2008
[4] Keister Timothy, Cooling Water Management, 2008
[5] MAN Diesel and Turbo, Service Letter SL2014-584, Cooling Water System
[6] MAN Diesel and Turbo, Service Letter SL2016-623, Cooling Water Treatment and Periodical Test of the Cooling Water
[7] Marichem Marigases, *Marine Chemicals and Equipment*,2016
[8] Nintonye Samson, *Design Calculations for the Cooling Water System of a Tug Boat*, World Journal of Engineering Research and Technology, 2017
[9] Wilhelmsen Ship Service, Marine Chemicals, 2017