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# Power Management of Power Back-up Equipment

# The Institute of Marine Engineers (India)

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# EDITORIAL

*There are two kinds of forecasters: those who don't know, and those who don't know they don't know.*

*- John Kenneth Galbraith*

The New Year cometh... While 20 and 21 were the pandemic pair, we have pushed the 21 firmly out. The 20 appears to be sticking around with the new 22. The 2022 dawns with the Omicron ominously threatening to trigger another wave. The Covid virus had spread and spread and along the expected lines, has been mutating. The Delta variant and Omicron are the villains seen so far.

Will Omicron be less severe?

Would the double vaccine model suffice?

The science is searching for answers but there are forecasts for a fourth wave (Is the third one gone yet as a ripple?), lockdowns, booster shots and more mutating combinations. The delmicron variant sounds like B-grade Hollywood flicks of the horror-combination genre ('Crocraptor', 'Zillaconda' variety). The forecast is that this spreads faster, but could be milder... and could be throaty (persistent cough, sore throat). Withstanding the forecasts, the palliatives remain: Mask, Jab, Jab, clean, clean... and stay clear of crowds. Bamboozled with the forecasts we can only wait hoping that the forecasters were as lost as us.

## In this issue...

We are in the midst of the Power Management series and at an interesting part. In this third part, Dr. Veda elucidates reliability checks on the power back-up systems. Discussing Emergency Generators and UPS, the determinants of failure rates, demand for back-up, this Part C also accentuates the factors (number of generators, footprint, weight and costs) which matter for the redundant machines. The major takeaways for the marine engineers would be the section on motors and the AMB (Active Magnetic Bearings).

Submersible pumping solutions have prevailed for decades and improvements are but inevitable. Prasanna Kumar and Ajantha Devi propose an automated purging solution for FRAMO pumps. But the description starts with autonomous ships and veers into degrees of automation and regular ideas on unmanned state of vessels before presenting the case. FRAMO pumping systems have been synonymous with deep-well and submersible solutions. Automating a crucial part of the O & M schedule would be food for thought for innovation ideas. The IoT based model is worth a study with actual equipment to gain some merit.

In our next essay on emissions, Dr. Rajasekhar *et al.*, take us through an easy read on the modern nano-technology application to fuels. Listing out the various materials which are being considered for the 'nano' adaptation, the Scientists illuminate the preparation and mixing of nano-particle additives in a brief manner. The essay features a simple on-board case study. The merit of the NOx reduction is sensed from the study and the Authors extend emission estimations with illustrations based on a web based tool. The method is worth adopting for few on board studies and creating records for compliance. It would amount to a scientific approach.

Under Technical Notes, Agaram Ramanujan concentres to conclude on entire quantity loss in his study of oil tanker collision and damage stability. And Sanjiv analyses the oil scrapped from engine cylinder, which should be absorbing for the practicing engineers.

This January also brings hope for a healthy year. This forecast will find favour, no doubt.

Happy New 2022 and hope you find the January issue interesting.

**Dr Rajoo Balaji**
Honorary Editor
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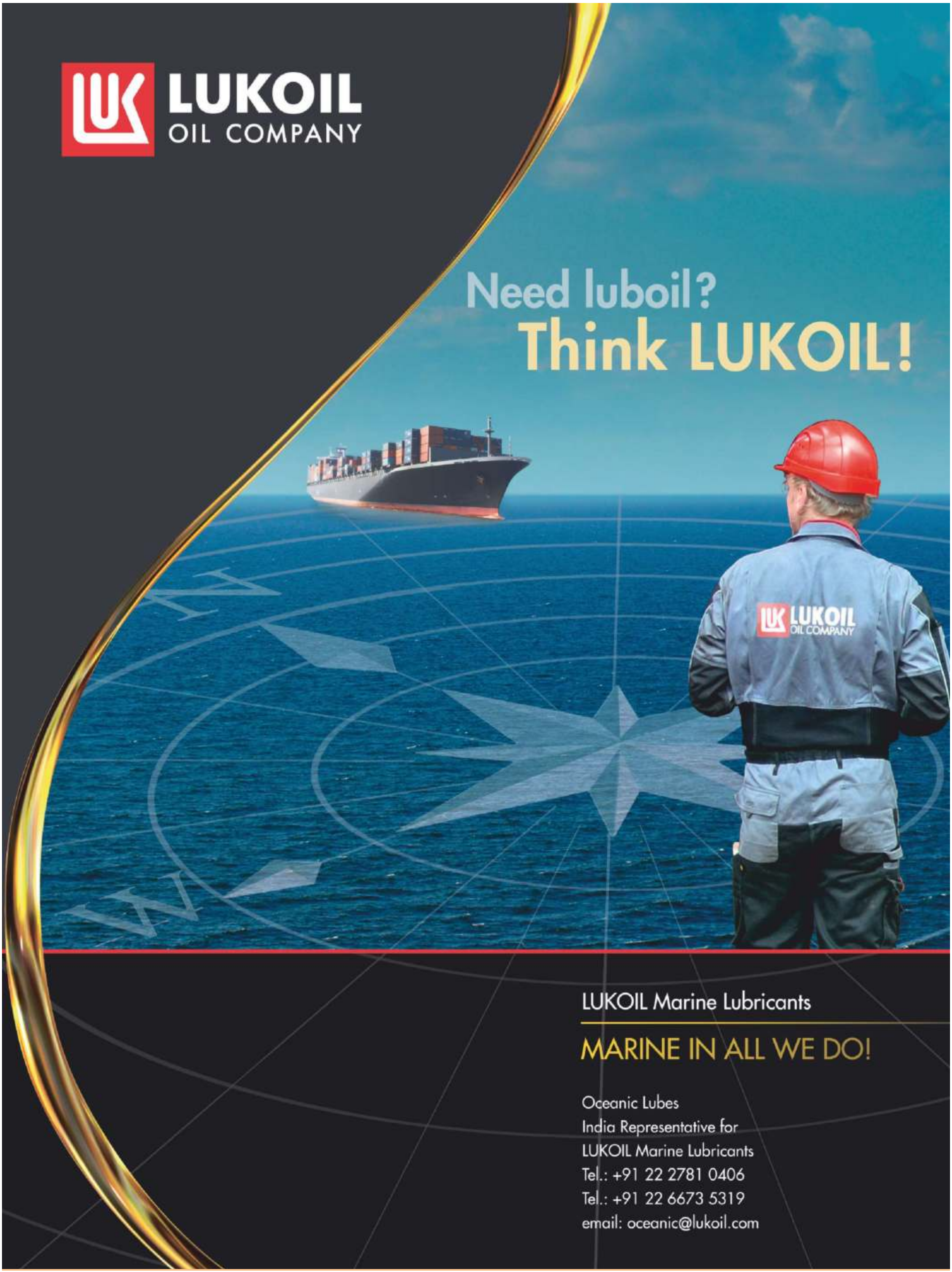
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# In This Issue

## ARTICLES



## COLUMNS



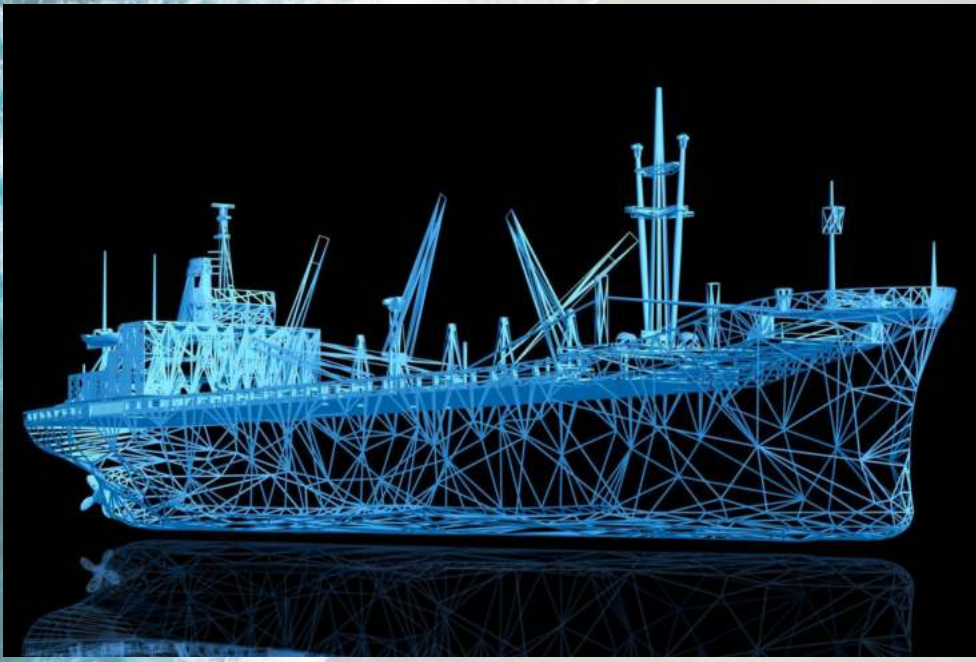

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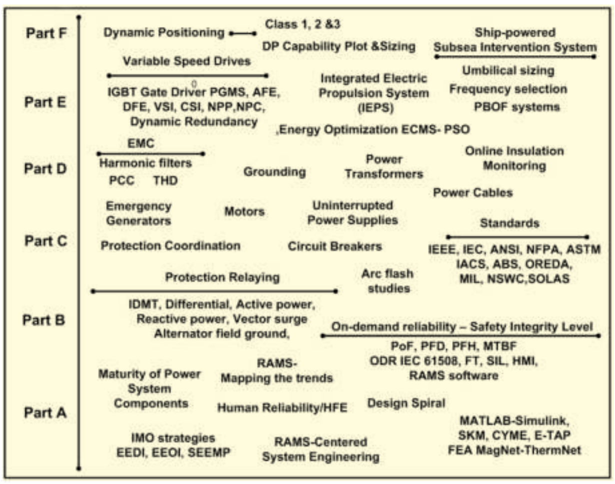
Photo: **Active Magnetic Bearing**

# RAMS-CENTERED SYSTEM ENGINEERING AND OPERATIONS OF MODERN MULTI-MEGAWATT CAPACITY MARINE POWER SYSTEMS (PART C)

N.Vedachalam

## ABSTRACT

This article in six parts (this is the third, Part C) discusses the importance, trends and integrated approach to RAMS-centred system engineering, key design and operational considerations for low- and medium-voltage marine power systems, including alternator protection, effective protection coordination, integrity requirements of relaying, emergency diesel generators and uninterrupted power supplies, significance of grounding, condition monitoring of power transformer, cables, motors, harmonics filters and the methodologies for realising fault-tolerant voltage source inverter based variable speed drives and dynamic positioning systems.




Part A (first part) and Part B (second part) of the series were published in the November 2021 and December 2021 issues respectively.

**Index terms**: Active Magnetic Bearing, Emergency power, Motors, Transformers.

## EMERGENCY POWER SOURCES

In marine power systems, Emergency Diesel Generators (EDG) is used during mains blackouts and Uninterrupted Power Supply (UPS) while transiting to EDG. Hence it is important to determine the Probability of Failure on-Demand (PFD) and the Proof Test Interval (PTI) for ensuring the required Safety Integrity Level (SIL) of the EDG and the UPS. The methodology based on IEC 61508 adopted for computing the PTI essential for maintaining their safety reliability in various SIL for EDG/UPS is shown in **Figure 1**.

> *"Thus with appropriate redundancies in the power plant generator configuration, the likelihood of outage of the vessel mains power outage /blackout is brought to once in 5 years"*

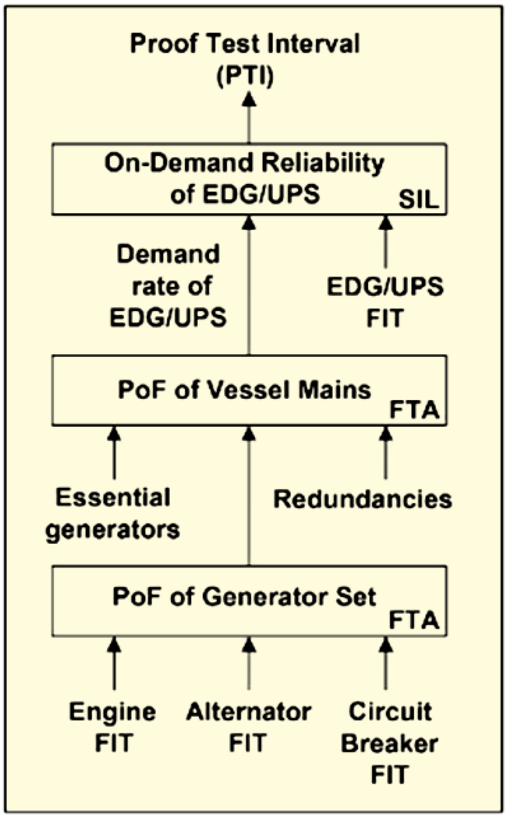



**Figure 1. Methodology for identification of PTI for EDG & UPS**

The key parameters include the failure rate of the power plant generators, configuration of the power plant including essential and redundant generators, failure rates and demand frequency of the EDG/UPS. The methodologies were described in the second part of the series and applied for maintaining the safety integrity of circuit breakers with upstream device coordination.

## Mains Failure Probability and Generator Redundancy

Based on the propulsion and utility power requirements, the vessel power generation plant comprises of multiple multi-megawatt capacity diesel generator or/and steam turbine driven alternators. The power distribution network architecture is designed to ensure maximum availability of the power plant for vessel operations. Providing redundant generators in the power generation plant decreases the probability of failure (PoF) of the power plant.

Hence identifying the trade-off between the required reliability, number of generators and the footprint, cost, and weight of the redundant generators is essential. Reliability analysis based on fault tree analysis (FTA) helps to identify the PoF for multiple combinations of essential generators required to meet the peak loads and identify redundancies. For performing the FTA, the failure rate of the generators is an essential parameter.

The failure rates for the DG sets were initially reported by Iado National Engineering Laboratory (INEL, under US DoE) based on the failure returns from about 100 generators collected during 1987-1993 clocking ~1000 machine-years. The failure rate is ~250000 FIT (Failure-In-Time) and the corresponding Mean Time Between Failure (MTBF) is ~0.5 years.

In 2007, IEEE-493 reported generator failure rates of ~20000 FIT, the MTBF of ~6 years. A recent study was made by Power Secure company based on the failure returns from about 2000 generators (including a dozen major manufacturers) running >14h/day during the period 2016-18 clocking ~5000 machine-years [1]. Based on this study, the failure rate is ~17000 FIT. The corresponding PoF and MTBF are 14% and 7 years, respectively.

Modelling and simulations are done using GRIF reliability analysis software FTA module for architectures involving various combinations of essential DG requirements and redundancies. The failure rate for the DG is computed as 28000 FIT (with 17000 FIT for engines and 11000 for alternator systems).

The FTA simulation results showing the PoF for a power generator configuration involving 3 essentials and 1 redundant (represented as gate KoutofN3 in **Figure 2**) in a period of 1 year is 3.78%. The redundancy helps to reduce the PoF from 63% to 3.78% in 1 year. The FTA is carried out for various combinations and the results are plotted in **Figure 3**.

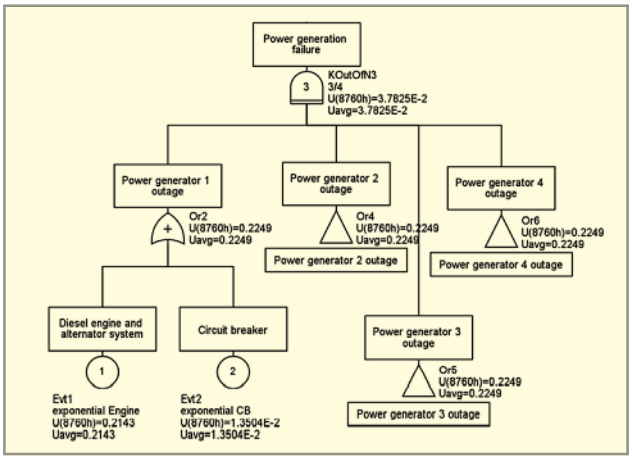



**Figure 2. FTA for identifying the PoF for 3oo4 configuration**

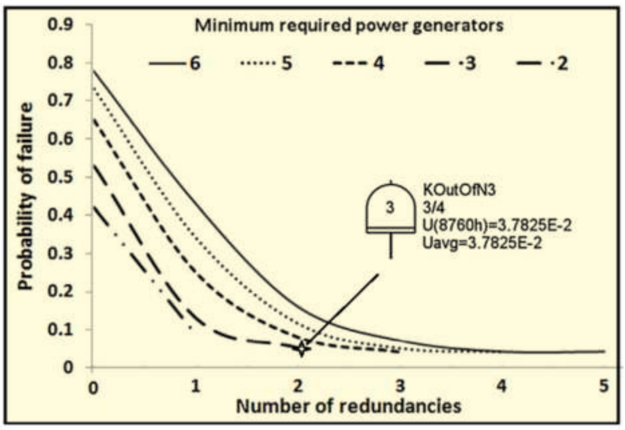



**Figure 3. Advantage of redundant generators in reducing the PoF**

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It is identified that, in a power plant comprising 6 generators, 1 and 2 redundant DG shall reduce the PoF from 77% to 50% and 18%, respectively. The MTBF of the power generating plant could thus be increased from 0.6 years to 1.4 and ~5 years, respectively.

Thus with appropriate redundancies in the power plant generator configuration, the likelihood of outage of the vessel mains power outage /blackout is brought to once in 5 years. Hence the likely demand on the EDG and the UPS is once in 5 years. Thus the ODR of the EDG and UPS shall come under the SIL low-demand rate category, as the demand frequency is ≤1 per year.

## Emergency Diesel Generator Sets

According to the International Maritime Organization (IMO) - Safety of Life at Sea - SOLAS 74 convention, in the event of ship mains failure, the EDG are used for powering the vessel's critical loads including emergency lighting, navigation and communication equipment, steering gear, fire and sprinklerpumps, bilge pump, water-tight doors and lifts.

According to the SOLAS 19 regulations, EDG sets shall be self-contained and independent of the other engine room systems. They need to have independent systems for starting, fuel oil, lubrication oil, cooling, preheating capable of starting at an ambient temperature of 0ºC and operating with a vessel list and trim of 10º and 22.5º, respectively.

SOLAS recommends the automatic starting system and the characteristics of the prime-mover should ensure that the EDG carries the required load as quickly as is safe and practicable, and within a maximum period of 45 seconds, and cater continuous power (18h for cargo and 36h for passenger vessels) [2]. The EDG failure-to-start during a crisis leads to catastrophic conditions and hence it should always be available on-demand. Hence it is important to identify the PTI for the EDG to ensure that it is always available on-demand.

The failure rate of the well-maintained EDG set (failure-to-start) during a demand is obtained from the data published by National Renewable Energy Laboratory (NREL) [3], in which an MTBF of 2410 hours was computed based on frequentist analysis with 90% confidence interval, which indicates a PoF in a period of 1 year as 97.5%.

The ODR analysis is carried out for a configuration with redundant EDG sets. The FTA is modeled and simulated and the PoF is 95% in a period of 1 year (**Figure 4**). Based on the identified PoF, the ODR analysis is performed using GRIF SIL module (**Figure 5**) and it is found that a PTI of 21h (~1 day) is required to maintain the EDG in SIL3 and 7.5 days in SIL2.

## Uninterrupted Power Supplies

Uninterrupted Power Supplies (UPS) that are connected from the vessel main and emergency switchboards are

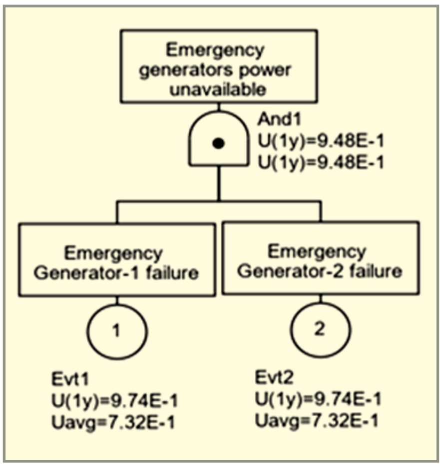


**Figure 4. PoF of redundant emergency generator sets**

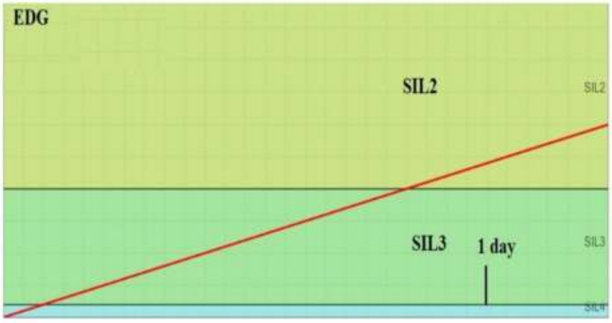


**Figure 5. PTI for redundant EDG sets**

used as a transitional power for powering the critical loads. The requirements for the UPS units are defined by the SOLAS regulations refer to International Electro-technical Commission (IEC) guideline IEC 62040. The key considerations include battery capacity, endurance, functionality (online/offline), temperature rise and the ventilation.

The major components of the UPS include the rectifier, battery bank and the 3-phase inverter. The ODR analysis is done to identify the PTI for the off-line UPS. The failure rates of the rectifier, 12V lead-acid batteries and the inverter reported in IEEE database [4] and US Department of Energy (DOE) [5] are 2500, 3240 and 42000 FIT, respectively. The failure of the battery bank could be reduced by providing redundant batteries.

The PoF in 1 year period for a battery bank comprising of 6 numbers of 12V batteries is 17%, for which the MTBF is ~5 years. Reliability analysis is done using FTA to identify the redundancy requirements and to reduce the PoF of the battery bank. It is found (**Figure 6**, Gate KOutofN N2) that two additional batteries (with 20% more capacity), reduces the PoF to 1.4%.

Thus, majority of the failures are contributed by the rectifier and inverter sections of the UPS. From the ODR analysis performed using SIL tool (**Figure 7**), it is identified that SIL3 compliance requires a PTI of ~3 days. In case of on-line and line-interactive UPS systems, all the subsystems are in operational mode and any failure will be immediately noticed.

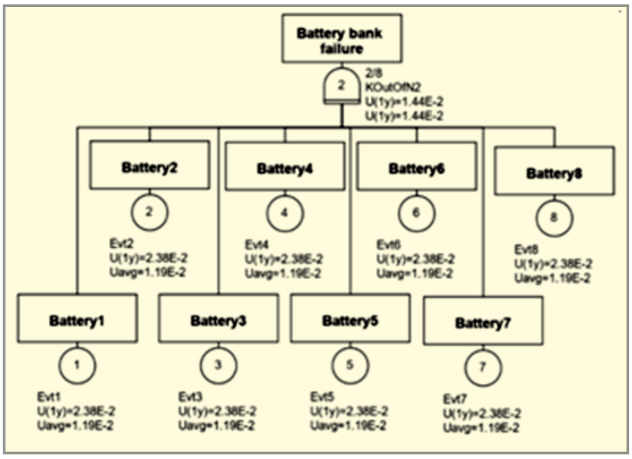


Figure 6. PoF of UPS battery bank with 20% redundant batteries

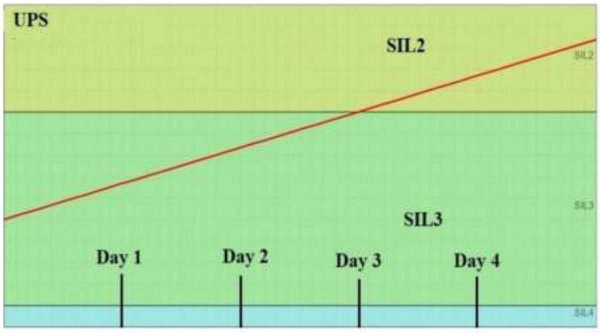


Figure 7. PTI for off-line UPS with 20% redundant batteries

The influence of including redundant batteries in the battery bank of various capacities (10-60 kWh) comprising of 12V-100Ah batteries is summarised in **Figure 8**. It can be seen that a 30kWh battery bank requires 3 and 4 redundant batteries to comply with SIL2 and 3, respectively.

## Power Transformers

In marine power systems, transformers are used for stepping down the voltage to the utility levels and as converter transformers for higher capacity Variable Speed Drive (VSD) applications.

The converter transformers (**Figure 9**) serve multiple purposes including providing galvanic isolation between the VSD and the mains, reducing the mains voltage level suitable for the VSD rectifier, suppression of the harmonics (by cancellation of the harmonics by 30º phase shifted windings, Yy0d11) generated by the VSD from polluting the ship mains, limiting the short circuit currents, reducing high frequency disturbances, and providing suitable reactance to ensure proper commutation of the power electronic switching devices.

**A continuously operating power transformer can produce around 2ppm of moisture per year**

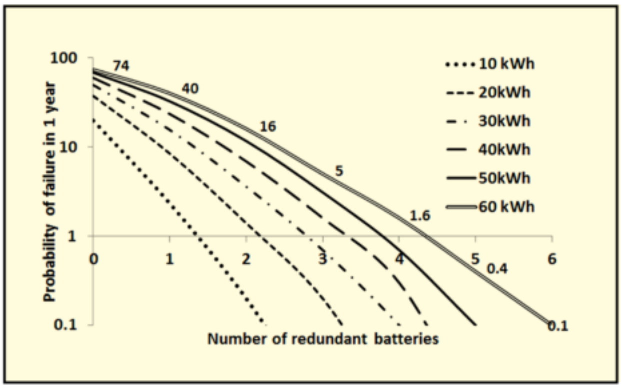


Figure 8. Redundancy requirements for battery banks(10-60kWh)

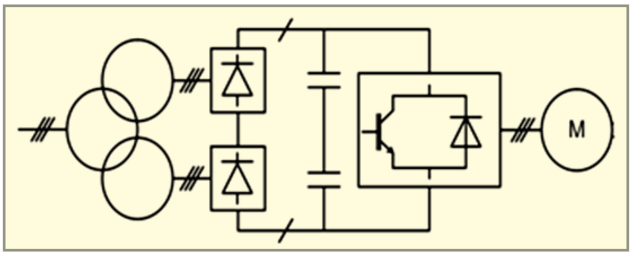


Figure 9. Converter transformer connected in a 12-pulse VSD

Hence VSD transformers experience increased voltage stress due to harmonic components. Based on the ANSI/IEEE C57 standards, K-4 rated transformers are designed to handle harmonic generating loads.

According to IEEE-493 database, the PoF of transformers < 10MVA and >10MVA in a period of 1 year are 3% and 7% respectively.

Based on the return of experiences from 188 failures in the transformers [1] of capacities > 10MVA, the most common causes of failure include ageing of the insulating material (oil and paper), overloading, operational problems and inadequate maintenance. Hence condition monitoring based on insulation deterioration products allow timely warning of developing problems.

The power transformers operate with the core and windings in an insulation oil-filled environment. The main functions of the insulating oil are to provide insulation, cooling, protection against chemical attack and prevent sludge build-up. During operation, water molecules are produced due to degradation of transformer insulation paper.

A continuously operating power transformer can produce around 2ppm of moisture per year. A 15MVA oil-filled power transformer with ~1 ton of insulation paper holds 22kg of water and 10kL of insulating oil. For maintaining the water content in the oil below 20ppm, free water should always be < 0.3kg. Thus, the water produced has to be removed to maintain the dielectric strength of oil.

*Ageing, excessive vibration and poor lubrication are found to be the contributors for 60% of the motor failures*

On the other hand, the free water present in the oil, if absorbed bythe transformer paper insulation, accelerates ageing. The lifetime of the paper insulation reduces by a factor of 10, for every 1% increase in the water content. Thus the free water content has to be maintained to prevent aging of the insulation paper [6].

**Over-drying of oil results in the complete removal of the water from the paper, and results in the shrinking of paper. Due to shrinkage, the mechanical integrity will be affected and the transformer cannot handle the mechanical forces generated during electrical faults.** Hence the water content in oil has to be maintained within limits. When water mixes with the oil, first it dissolves and, after saturation, appears as free water.

A typical mineral oil can take 20ppm of water content, and any increase beyond this level needs attention. The mineral oil that has a dielectric strength of 30kV with 10ppm water content reduces to 10kV at 40ppm. Recently developed synthetic transformer oils can handle up to 800ppm of water, without degradation in the dielectric performances. Therefore, the transformer oil has to be conditioned periodically to maintain the water content and, in turn, the oil dielectric properties.

Traditionally, water removal from oil is done by heating the oil in vacuum, taking care that the oil temperature is within recommended limits. Regular sampling and testing of insulation oil is a valuable technique in a preventative maintenance program. If a proactive approach is adopted based on the condition of the transformer oil, the life of the transformer can be extended.

**Table1. Key tests for transformer oil quality determination [4]**

| Test | Purpose |
|---|---|
| IEC 814 | Determination of the water content |
| IEC 156 | Dielectric strength (decided by the quantity of water, sediment and conducting particles) |
| IEC247 | Dissipation factor (measure of leakage current through oil) |
| ASTM 9744 | Acidity (that originate from oil decomposition/oxidation products). |
| IEC 567 | Oil gas analysis (for early detection of incipient faults) |
| ASTM D971 | Interfacial tension measurement (measure of the presence of oil decay products and soluble polar contaminants from solid insulating materials) |

The key tests in a preventive maintenance program are summarised in **Table 1**. The ratio of the interfacial tension and neutralisation number provides a numerical value which is an excellent means of evaluating oil condition, namely Oil Quality Index (OQIN) or Myers Index Number (MIN), for a typical new oil, it is 1500, i.e., 45/0.03.

The mechanical properties of insulating paper can be established by direct measurement of its tensile strength or degree of polymerisation (DP). These properties are used to evaluate the end of the reliable life of paper insulation. DP values of 150-250 represent the lower limits for end-of-life criteria for paper insulation; for values below 150, the paper is without mechanical strength.

Analysis of the paper insulation for its DP value requires removal of a few strips of paper from suspectedlocations. This procedure canconveniently be carried out during transformer overhaul.

## MOTORS

In view of their excellent speed-torque characteristics, higher reliability over DC machines, lower weight and smaller footprint, marine propulsion systems are dominated by VSD-operated induction (asynchronous) motors. According to the IEEE_493 data base, out of 304 induction motor (>200hp) failures, the majority were due to failure of bearings and windings [1] (**Table 2**). The PoF in 1 year is 33% with a corresponding MTBF of ~2.5 years.

The failure contributor and the underlying reasons for the failure are summarised in **Tables 3** and **4** respectively. Ageing, excessive vibration and poor lubrication are found to be the contributors for 60% of the motor failures. More than60% the failures could be reduced by using good quality subcomponents, proper installation methods and maintenance practices.

Along with the periodic motor maintenance requirements including motor bearing replacement, lubrication, winding varnishing and drying, the offline tests used to ascertain the condition of the motor include tests for Insulation Resistance (IR), Polarisation Index

**Table 2. Contribution of subcomponents to motor failure [4]**

| Subcomponent | % contribution |
|---|---|
| Bearings | 60% |
| Windings | 30% |
| Rotor | 5% |
| Shaft coupling | 5% |

**Table 3. Physical contributors for motor failures[4]**

| Failure contributor | % |
|---|---|
| Deterioration with age | 25 |
| High vibration | 20 |
| Poor lubrication | 18 |
| Abnormal moisture | 10 |
| Ambient temperature | 10 |
| Others | 17 |

**Table 4. Causes for motor failures[4]**

| Underlying cause | % |
|---|---|
| Inadequate maintenance | 24 |
| Defective component | 20 |
| Poor installation | 16 |
| Improper operation | 10 |
| Poor physical protection | 7 |
| Inadequate electrical protection | 6 |
| Driven equipment mismatch | 5 |
| Others | 12 |

(PI), Partial Discharge (PD) and voltage surge for stator windings.

The on-line monitoring and diagnostics of the motor temperature, lubrication, bearing condition, stator winding inter-turn shorts and rotor condition helps to advance preventive maintenance and reduce critical breakdowns.

The bearing failures are mainly due to overheating causing failure of the lubricant, mechanical stresses due to friction and rotor eccentricity, and the electrical stresses (when unbalanced magnetic flux creates a potential difference between bearing and ground) inducing shaft current flow and heat the lubrication.

The damage of the bearing (including outer race way, inner raceway, cage and ball) could be identified using vibration sensors mounted on the motor drive end and non-drive end, temperature and from the current signature. The current signatures are analysed based on wavelet methods, adaptive time-frequency methods and park vector trajectory methods.

## Winding and Rotor Faults

The stator winding inter-turn faults are identified from the negative sequence currents, negative sequence impedance, and electromagnetic torque harmonics supported by machine learning (ML)/Artificial Intelligence (AI) techniques.

The main reasons for the rotor failures include magnetic stresses caused by the electromagnetic forces/unbalanced magnetic pull, dynamic stresses due to shaft torques, abrasion of the rotor material and mechanical stresses due to the loose laminations.

In medium voltage (MV) motors, a broken rotor bar or a loose connection between one of the rotor cagebars and an end-ring prevents the rotor current from flowing through the broken rotor bar or into the end ring. This leads to unbalanced rotor flux that can be detected from the harmonics induced in the stator current.

From the stator current harmonic analysis (**Figure 10**), when the sideband becomes larger than about 0.5% (-45 dB) of the power frequency current, then the rotor bars are likely to be broken. Rotor defects could also be detected by growler and also by analysing the motor starting current [7].

## Healthy Insulation Needs

Modern VSD inverter-fed MV motors often experience shortrise time and high magnitude voltage surges leading to stator winding partial discharge(PD) that results in the premature aging of stress relief coatings. IEC 60034-18-42 provides tests that motor manufacturers have to perform to ensure the integrity of the insulation and avoid premature failures.

NEMA MG-1 Part 31 insists MV motors to survive an impulse test at 2.04 times the rated phase-to-phase voltage, and the form-wound coils to be tested with an impulse with a crest value of 3.5 times the peak line-to-ground (L-G) voltage. IEC 60034-18-41 recommends tests for random-wound stator windings considering that the windings will not experience PD during its lifetime.

IEC 60034-18-42covers tests for form-wound coil insulations accounting occurrence of PD due to VSD transients during the expected life of a motor. Thus, the expected wave form is defined by the VSD inverter designer based on the output filter and the harmonics. The test should qualify the materials and processes used to build the insulation system and provide a relationship between the service stresses and insulation life for the specific configuration.

## Bearing Failures- Active Magnetic Bearings

About 60% of the induction motor failures are due to bearing damages. The major factors that affect the life and reliability of mechanical bearing (such as ball and roller) over its basic service life ($L_{10}$) are mapped in **Figure 11**. The bearing failures could be reduced by bearing condition

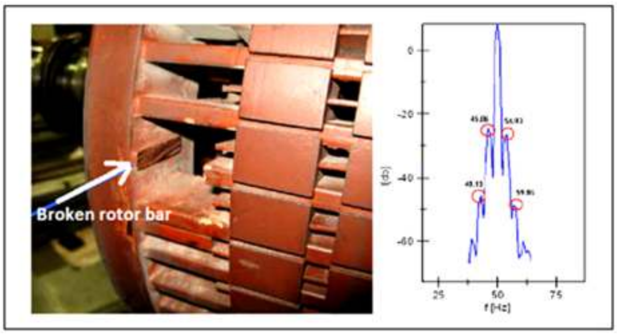


**Figure 10. MV motor rotor bar break and current signature [7]**

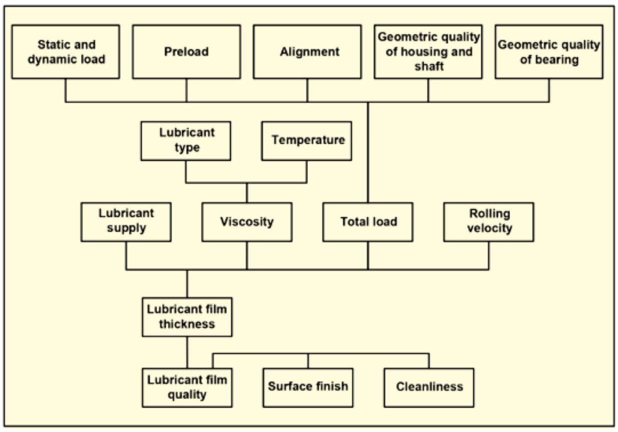


**Figure 11. Factors influencing reliability of mechanical bearings**

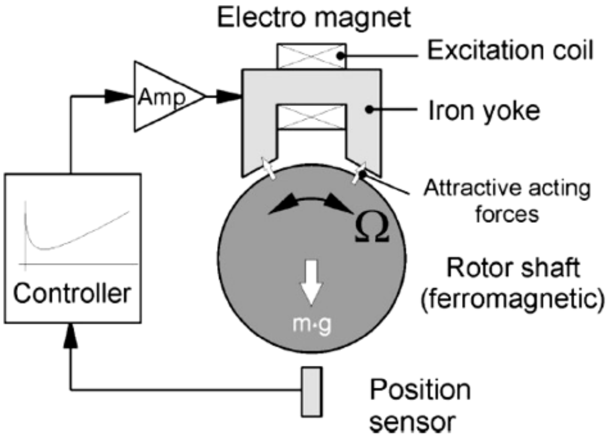


**Figure 12. AMB used in large capacity machines [9]**

monitoring based on ultrasonic, temperature, vibration analysis and shock pulse techniques.

As lubrication is the first line of defense for prolonging bearing life, it is imperative that the lubrication film thickness between the rolling elements and the raceways be measured and monitored.

Modern instrumentation helps in differentiating between bearing surface damage and lubrication film thickness reduction. Signal processing techniques enable analysis of rolling elements, inner raceway, outer raceway and cage that interact to generate complex vibration signatures.

Hence it is evident that the electric motor bearings require periodic maintenance and innovative design to reduce failures, specifically for high speed turbo-machinery. Active Magnetic Bearings (AMB) are reliable as there are no frictional components in the system demanding periodic maintenance.

These AMB which are in development over the past decade, received impetus during the subsea gas compression project developments such as Ormen Lange and Asgard, where equipments needs to be operated continuously and recovery of the equipment to the surface (for maintenance) is costlier than the equipment itself [8].

The AMB comprises of bearing actuators (coils wound around steel pole pieces that carry current and apply magnetic forces to the rotating shaft) for levitation, inductive position sensors for position feedback to the controller. The controller comprises of digital signal processing (DSP) electronics, power supply and amplifiers.

*The bearing failures could be reduced by bearing condition monitoring based on ultrasonic, temperature, vibration analysis and shock pulse techniques*

The bearing actuator currents are controlled and monitored through the controller that uses control algorithm to vary bearing forces to manage the shaft position **(Figure 12)**. The AMB has reliable communication and control interface with the motor VSD so that the AMB could request-a-trip during its internal faults.

Based on the capacity and the speed the AMB could have the control axes varying from 4 to 9. The adaptive algorithms controls the bearing system's response to shaft unbalances in which the shaft is allowed to be around its geometric centre and tightly control the shaft to eliminate the run-out caused by the unbalance.

The current stiffness, displacement stiffness and damping of the AMB can be adjusted in-situ allowing the machine to safely pass through critical speeds. Recent AMB controller algorithm measure the position and regulate the current to actuate 10000 times/second that could support high surface speeds of about 250m/s, equivalent to ~ 4.5 million shaft revolutions.

The AMB design considerations include bearing pre-load, internal clearance between inner race and shaft, bearing race creep, bearing material and the bearing installation and removal methods. The dynamic performance and robustness of the landing (auxiliary) bearings are important during a partial or full landing event. The balls should be free from caging when getting accelerated during rotor touch-down and higher internal clearances should allow thermal expansion.

Based on MIL HDBK 217 standards, the AMB controller electronics have an MTBF of 14 years (~8000FIT) and the control algorithm (based on Markov analysis) have an MTBF of 4.5 years (25000FIT) [10][11]. Reliability analysis is performed using FTA based on these industry-reported failure rates (**Figure 13**) and it is found that the present AMB technology could have a MTBF of 3.46 years (with a corresponding failure rate of 33000FIT).

With the growing experience in AMB technology and the advances in high-speed control techniques, the

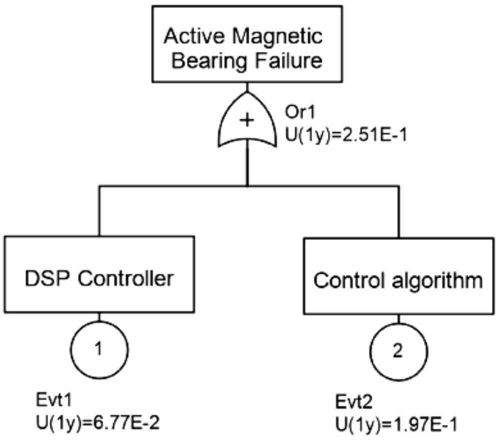


**Figure 13. FTA for AMB failures**

emphasis of reliability design is shifting from hardware redundancy to software-based robust and fault tolerant systems, making the AMB a key component in the smart rotating machinery.

## CONCLUSIONS

The reliability of the propulsion, protection and life support power systems in an Integrated Electric Power System needs careful evaluation during the design and operational phases, as the ramifications of non-operation or mal-function could be catastrophic.

Hence, safety-centered system engineering with a reasonable reliability, safety and efficiency trade-off is essential for multi-megawatt vessel power systems. The first part of the article discussed the maturity of marine power system components, importance of RAMS-centered system engineering and developments in the RAMS computation tools.

*Active Magnetic Bearings (AMB) are reliable as there are no frictional components in the system demanding periodic maintenance*

The second part discussed on the integrated approach to RAMS estimation, power system protection coordination based on current-time characteristics and methods for determining SIL-compliant circuit breaking based on numerical tools with field-failure data as inputs.

This part of the article discusses the methodologies for determining the proof test intervals for emergency diesel generator sets and uninterrupted power supplies. Various possible induction motor failure modes, winding and rotor fault detection methods and bearing failures are detailed. The importance of off-line and on-line condition assessment methods for motors and transformers were discussed. The developments in the active magnetic bearings and its reliability are presented.

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**Dr. N. Vedachalam** is currently a Senior Scientist with NIOT, Chennai. His 26 years of experience includes industrial power, process, offshore, and subsea domains at Aditya Birla Group and GE Power Conversion & Alstom-Converteam in France. His technical exposure includes development of multi-megawatt power and control systems for deep-water enhanced hydrocarbon recovery systems of Ormen Lange subsea compression pilot with GE; Ocean renewable energy systems including ocean thermal energy conversion, wave energy systems & remotely operated vehicles with NIOT; subsea grids for tidal energy farms for Paimpol Brehat, France and industrial power generation, utilization and boiler control systems in process industries. He has more than 90 publications in indexed journals, holds an international and two national patents in subsea robotics and subsea process. He is a recipient of the National Meritorious Invention Award in 2019 for the development and usage of underwater robotic vehicles. He is presently a Member of Bureau of Indian Standards and was the Secretary of IEEE Ocean Engineering Society- India Chapter and Executive Member of Marine Technology Society-India Section. He is a regular contributor to MER.

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# AUTOMATION OF FRAMO CARGO PUMP PURGING WITH IoT

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V. Ajantha Devi

## ABSTRACT

Liquid cargo tankers of variable size can preferably choose FRAMO system for their cargo transfer requirements. FRAMO [1] system has been proved as a reliable technology with maker recommended human supervision. The reliability of the pump is mainly depending upon the seals fitted on both cargo and hydraulic oil sides. The major damage of these seals makes the pump completely inoperable or minor damage leads to the maintenance requirement to bring the pump back to normal. To determine the condition of seals, FRAMO recommends to perform purging operations of cargo pumps whenever the tanker is loaded with cargo on daily basis. This procedure will help us to decide the choice of the particular pump for cargo discharging operations. On today's on-board practices the complete purging procedure is performed manually. The pressurised air supply through the cofferdam forcefully removes the content in that space and it helps the crew member to identify any failure of seals and the extent to which the failure is. This paper discusses about automating the purging process under unmanned environment and communicating the test results to the control centre for the decision making on the use of the particular pump. In this paper details of electronic control circuit to automate the purging procedure is described. Added with the above, the detailed testing methods to determine the cofferdam space content and the data transmission of collected test results to control centre also explained.

**Keywords**: FRAMO, Autonomous Ship, IoT, Automation

## 1. INTRODUCTION

Today's big issue is autonomous and remote-controlled vessels. It's no surprise that people believe this is the next stage in the evolution of marine technology in an era where artificial intelligence is closer to reality than it has ever been. Unmanned aerial vehicles and self-driving automobiles are now available, but there are no unmanned vessels in use till date.

The future of maritime technology may be autonomous technology [2], but in what form remains to be seen. There is still need of crew on some cases, no matter how interesting or cool new developments are. New technology must not only substitute but also build upon what came before, and this is also true in the case of autonomy. There are a variety of ways to operate an autonomous vessel, one among them is without any on-board computing system and all command and control from shore [3]. Because of more cargo space available due to replacing the crew (at least some of them), with autonomous or remote-controlled technology could reduce operating expenses and save money. The creators of this technology claim that it would create safe environment with less or nil incidents. Human error is the leading cause of maritime incidents [4] today, so reducing this element could help the industry.

Autonomy can be applied in tiny chunks to make it simpler for a ship's crew, for example, assisting them with docking the vessel. While both autonomous and remote-controlled vessels are unmanned, there is a distinction. Remotely operated vessels [5] are piloted from a control station on shore, while autonomous vessels use computers, algorithms, and sensors to navigate and operate. These two types of unmanned vessels are often discussed in the same breath as a potential solution for sea voyages, implying that they are not mutually exclusive. Both would almost certainly be present in vessels that employ these technologies. There have already been a few real-world examples of autonomy and remote control [6], and more are on the way.

### 1.1. Various Degree of Autonomy

A seaborne vessel that navigates the seas without human intervention is described as an autonomous vessel

[7], but as previously mentioned, this is not always the case. When it comes to MASS [8], there are various levels of autonomy. Companies, organisations, and individuals all have their own definitions of autonomy and degrees of autonomy, which may lead to some misunderstanding. In order for MASS to be implemented on a global scale, clear definitions of the various levels of autonomy are needed. MSC had their 100th meeting in December 2018, and they made progress on the regulatory scoping exercise for MASS. The current set of MASS rules and regulations must be differentiated based on the degree of autonomy of a vessel.

Degree 1: The crew is present and running the vessel with the help of automated systems: In some conditions, certain tasks can be automated and unmonitored. If required, the crew is prepared to take command.

Degree 2: Ship with seafarers on board that is controlled remotely: The vessel is controlled remotely. The crew stay on board and is prepared to take command if necessary.

Degree 3: Remotely controlled ship with no on-board seafarers: The vessel is controlled from shore.

Degree 4: The vessel is totally self-contained and runs on its own. In all cases, the vessel will decide the best approach and make the necessary decision.

### 1.2. Maritime Autonomy vs Industry 4.0

In Industry 4.0, data and machine learning will be used to construct smart and autonomous systems. As the use of cyber-physical systems, cloud technology and the Internet of Things (IoT) rises in manufacturing, so does the demand for cyber security. Autonomous automobiles have already been deployed. Ships, without a doubt, have different challenges than autos, and the maritime industry [9] is known for its slow adaptability to change.

Number of autonomous functions in maritime vessels on specific applications are growing for example, Automated fire safety systems and Automated energy optimisation technics. Still, it is lagging behind the trajectory of other industry including aviation. Even though same basic elements such as motors, pumps, and fans are used in the ships too, they are not connected with Information Technology, communication, or data. New evolution in this area needs, a range of networked gadgets and ICT systems.

Cyber vulnerabilities [10] have also been discovered in planes and Automated avionic vessels are in use. There's no reason to expect that ships will not be more secure, which are one among our vital infrastructure in the maritime industry.

## 2. REVIEW OF EXISTING MARITIME AUTONOMY

MUNIN [11] is a cooperative research venture financed by the European Commission. Maritime Unmanned Navigation with Network Intelligence is what it stands for. This was the first study to investigate whether and how autonomous applications in big commercial ships might reach the same levels of safety as conventional ships [11,12]. The goal is that a ship constructed in this project will deliver goods to its destination autonomously, safely, and independently. The world's first remotely operated commercial vessel has been developed by Rolls-Royce Commercial Marine [6] and global towage operator Svitzer. A demonstration was held in Copenhagen port in Denmark in early 2017 [13], and the development is part of the SISU project. The tug Svitzer Hermod successfully completed a number of remotely controlled manoeuvres.

Kongsberg Maritime [14], or KM for short, is developing a new self-driving ship. AutoBarge is the name of the vessel they're working on, and it's a collaboration with Asko. The project will conclude in two autonomous, electric, and zero-emission vessels crossing the Oslo fjord. AutoBarge will suit 16 semitrailers and replace 150 truck journeys between Moss in Stfold and Holmestrand in Vestfold [15] every day. It will reduce $CO_2$ emissions while also improving traffic congestion and safety. Each of the ships is equipped with a standard bridge, however they will be supervised from a shore control centre, just like Yara Birkeland [16]. The idea is to have Kalmar's autonomous and electric tractors drive semitrailers on and off the ships. Asko wants to be able to drive the trailers from the ports to his storage facility using electricity. The goal is to begin testing in 2021 and to be self-driving, electric, and emission-free by 2024.

Autonomous ships must function at least as safely and reliably as modern ships operated by on-board people in order for their development to be beneficial [17-20]. While algorithm-based decision making can eliminate certain human errors [20], new risks and concerns, such as cybersecurity for autonomous ships, will undoubtedly develop. The simplest remote operation of a ship necessitates a reliable means of monitoring its health and precisely observing the ship's environment without substantial delays. Adopting and further development on existing sensor technology and computer vision to work precisely in the maritime environment, where climatic conditions might be vastly different from those on land. This is one of the first stage in achieving this reality. The findings of vision-based tracking of marine traffic ships [18] and collision avoidance have proven promising in recent investigations. As a result, successful sensory data interpretation is critical for autonomous ships to perform the appropriate action at the right time. As a result, smart decision algorithms must be thoroughly created and validated.

## 3. FRAMO SUBMERGED CARGO PUMPS

FRAMO Cargo pumps as shown in the Figure 1 are vertical, single-stage centrifugal pumps that operate safely and efficiently with hydraulic motors. FRAMO cargo pumps are composed of stainless steel and restricted number of flanges to improve its efficiency to pump any liquid. These pumps are widely used in product carriers and on the introductory phase in large crude carriers.

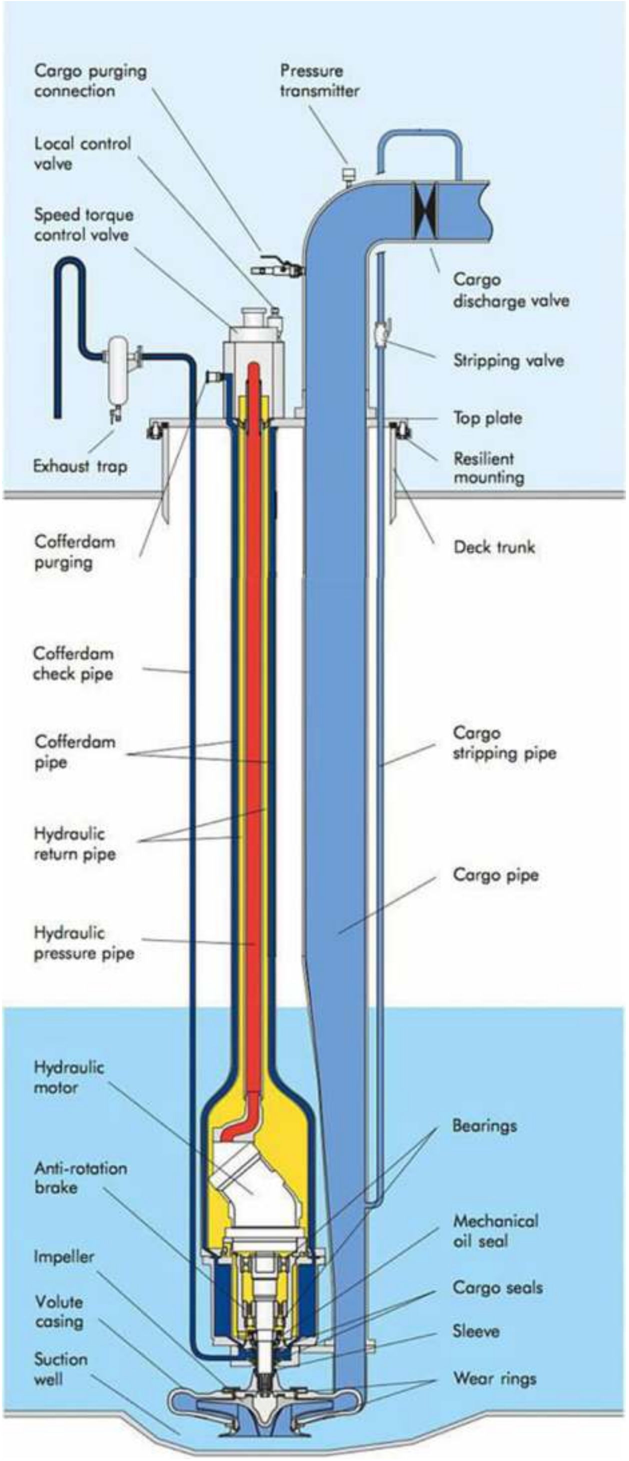


Figure 1. FRAMO PUMP [1]

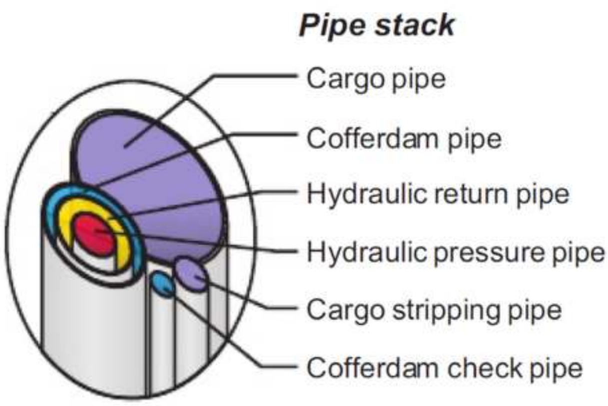


Figure 2a.


Figure 2b.

## 3.1. FRAMO Pump Operation

Hydraulic motor drives the FRAMO pump [21], which receives pressurised hydraulic oil from the power packs. The high-pressure hydraulic oil goes into the hydraulic motor in the red area as in the Figure 2a, and the hydraulic oil returns in the yellow area. Both of these pipes are in a circle around each other.

As this pump is located within the cargo tank, two liquids (hydraulic oil and cargo) must not come into contact. The cargo may be contaminated if hydraulic oil leaks into tank. The hydraulic system will be contaminated if cargo gets into the hydraulic system. The FRAMO pump has a feature that prevents this, Hydraulic oil leaking to the cargo side is prevented with a hydraulic seal. There's also a cargo seal as shown in Figure 2b to keep cargo from seeping into the hydraulic side. As a steel cup with a cargo seal at the bottom, a cofferdam will collect any hydraulic oil or cargo leaks.

## 3.2. On board Condition based Maintenance

Monitoring the condition of seals regularly ensure the trouble-free operation of cargo pumps. Seal monitoring is done by purging the cofferdam from the cargo pump top plate. On the use of FRAMO submerged Cargo pump, one of the most critical preventive maintenance routines is to purge the cofferdam. This is one kind of method to inspect the pumps' seals, and hence their condition, without having to enter the cargo tanks. Any leakage through the seals will accumulate in the cofferdam. By regularly purging the cofferdam, the leakage rates may be assessed, and action (if necessary) may be planned to ensure the cargo pump's safe and efficient functioning.

The cargo pump cofferdam must be purged on a regular basis in line with the FRAMO Purging Instruction, which may be found in Ship's Service Manual. The ship's crew bears primary responsibility for purging, logging results, and any further actions. They are familiar with the actual operating circumstances on board and are entrusted with the proper operation and maintenance of the equipment on a regular basis. If the purging findings suggest that maintenance is required, the ship's crew must take action as soon as possible.

## 4. PROPOSED METHODOLOGY

To automate this purging operation, this paper describes the Proposed methodology as shown in Figure 3 and consist of the following:

1. Initiation of this purging operation triggered either by delay timer or command signal through IoT from shore control station.
2. Automating the purging process under unmanned environment [22] and collect the leakage content if any.
3. Analyse the physical properties of the leakage content with different electronic sensors.
4. Compare the physical property data measured with the sensors and pre-defined database stored to identify the leakage content.
5. Identified result will be notified to the shore control centre using IoT communication [23].

### 4.1. Purging Automation

When the pump is idle at sea, the purging procedure is started by a delay timer or a command signal from the control station. The cofferdam pipe (Dark blue in colour as depicted in the Figure 1) is pressurised by air or nitrogen depending on the cargo type carried, by opening the cofferdam purging supply control valve (Figure 4) located in the main deck.

Through the cofferdam check pipe, pressurised air forces the content gathered in the cofferdam to the exhaust trap in the main deck (Dark blue in colour as shown in the Figure 1). The exhaust trap's drain control valve (Figure 4) opens, and the contents are emptied into the sample container. In each operations sample will be collected in a new container to ensure that the test sample is clean. This complete sequence of operation is accomplished by Automation using Arduino UNO system.

### 4.2. Data Acquisition:

Basis on the sample content following results are derived

- The cofferdam is empty if simply get air into the purging line's exit. There is no hydraulic oil or cargo leakage, and both seals are intact.
- If cargo is detected in the cofferdam, that means the FRAMO pump's cargo seal is leaking.
- If hydraulic oil is detected in the cofferdam, that means the FRAMO pump's hydraulic oil seal is leaking.

The sample content is analysed on its physical properties to conclude weather the content is cargo or hydraulic oil.

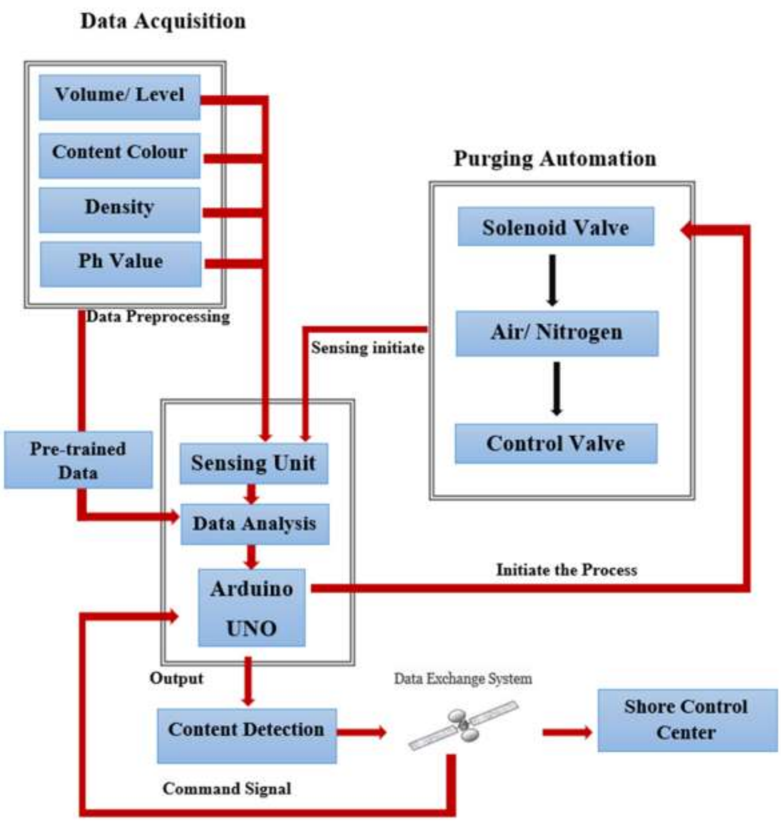


Figure 3. Proposed Methodology on Automation of Purging

- The ship is equipped with various sensors for short and long-range proximity measurements, as well as software for the control unit and sensors, which is run on an Arduino. The control unit runs on the on-board edge cloud, which is an Arduino in this case, and the edge device connects with other components.
- The information acquired from the ship's sensors has to be saved as attributes in Data base. We propose to use larger data sets for simple debugging and test data collection, which necessitated a more robust design.

### 4.3. Control Unit:

Control unit in this proposal perform the following activities,

- Initiating the cargo pump purging operation either of the two conditions.
  1. Pre-defined interval from Timer
  2. Command signal from Shore control station

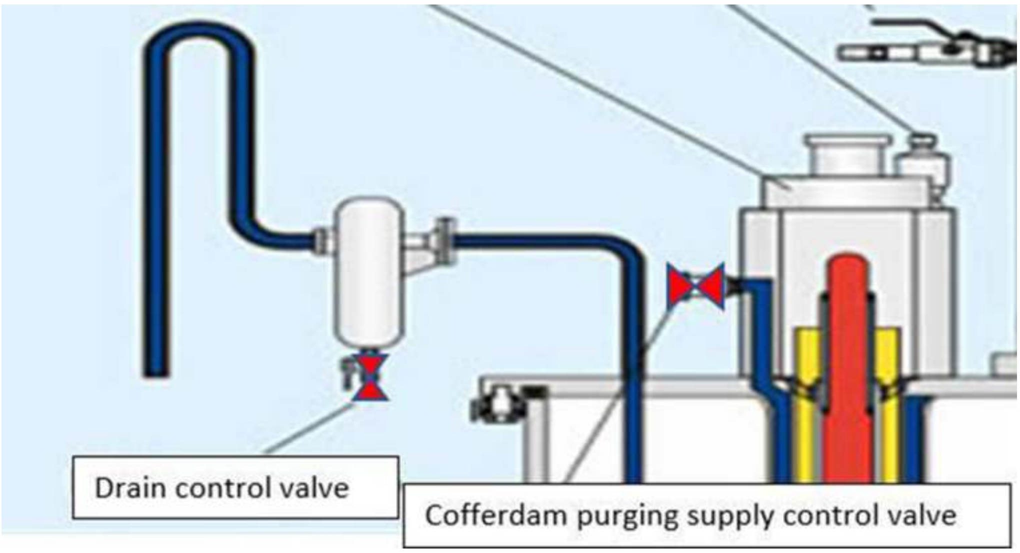


**Figure 4. Purging Automation**

- Supervision of purging sequence and alarming if any faults in the sequence
- Operate and monitor the Sequential flow of sample containers to different sensing devices
- Data acquisition from different measuring sensors
- Comparative study of both the measured value and stored database
- Detect the sample content
- Communication exchanges info based on events
- The shore control centre (SCC) ensures that the ship is operating safely and, if necessary, acknowledges the decision

## 5. FEASIBILITY OF THE PROPOSAL

As this paper discuss about automation of Purging process on FRAMO cargo pumps, this feasibility study can be tripartite as following sub segments:

### 5.1. Automation of Purging Operation

This is an operation in which the functions of various valves are intertwined with time intervals. All of the valves can be hydraulically powered and controlled by an electronic signal to OPEN/CLOSE. The hydraulic power required can be obtained from the same FRAMO system. The ARDUINO board could be used to programme the signal that controls the sequence.

### 5.2. Analysis of Purged Content

Analysis of the content is based on their physical properties which are measured using different sensors.

*A.* **Volume of leakage**

- Leakage volume estimated using measured liquid level and known container cross sectional area. Capacitive level sensors are used for level measuring.
- This sensor is inserted into the sample container as indicated in the image to measure the liquid level.

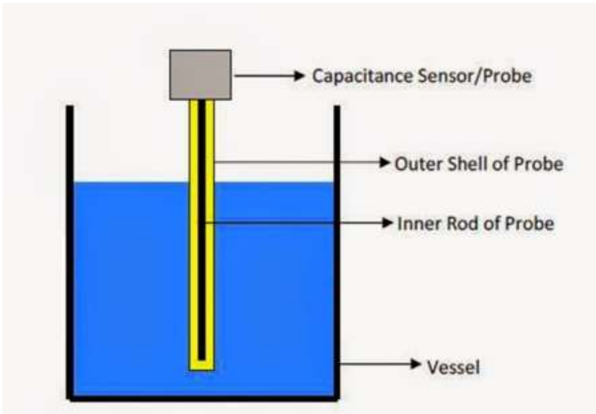


**Figure 5.**

*B.* **PH value of the content**

- The PH value is used to distinguish cargo, particularly if it is chemicals and hydraulic oil. In the sample container, probe type PH metres are used to determine this value.

**Figure 6.**

*C.* **Density of the leakage fluid**

- Because some of the oil cargo and hydraulic oil are generated from the same crude oil source, density is a key criterion for distinguishing the two. Density metres with forks are a good choice for this application


**Figure 7.**

### *D.* Appearance of the liquid

- The colour of the liquid is another useful physical parameter for determining the content. The identification of content liquid can be sped up by colour comparision. Using a high-definition camera to capture the image of sample content and comparing it to a database helps to attain this task.

**Figure 8.**

### 5.3. Data Transmission

As ship is always floats distance away from the shore, the communication system gets much more priority in the maritime industry. With today's developments in the efficient satellite communication and real time data transfers [24] between ship and shore ensures un-interrupted service in the proposed automated process.

The existing available data communication used for the vessel operation eliminates the vessel identification (Address) during the data communication with multiple vessels [25]. We will use Arduino UNO because the setup needs to be easily scalable and cloud-integrable. Also, Arduino is the right choice due to its size is ideal and it has adequate computational capacity to handle the data processed on the edge cloud under Shore control centre.

Integrated sensors eliminate the need for external components, which speeds up and simplifies the automation of this process. The data exchange system as a bridge between the real-world environment and the control unit embedded with Arduino UNO system. To ensure low latency and consequently proper control unit operation, sensor data is transmitted directly to the control unit via the edge device. The control unit receives raw sensor data, which it can pre-process when the type of data it receives requires to Analysis the content of the sample.

## 6. BARRIERS

With the current study of the proposal, few of the following barriers were identified. By performing additional number of experiments these barriers can be removed.

i. **Accuracy of sensors:** Accurate results of measurements were expected if the volume of sample is considerable in size. If the leakage of the seal is less and the sample volume also less, it affects the accuracy of sensor's result.

ii. **Mixed liquids:** At one scenario, if both cargo and hydraulic seals were leaking, the properties sensed on the sample collected in the container does not match with the properties of either cargo or hydraulic oil. To conclude this situation, additional data such as sensor accuracy and properties related to mixer of both liquid need to be considered.

iii. **Different cargo in different Tanks:** Parcel Tankers loaded with different cargo in different tanks. To identify the leakage content, system required to predefine that what cargo loaded in which tank. By including additional parameters sensing such as vapour pressure, can eliminate this limitation. This can be achievable after adding other suitable parameters also in the database.

iv. **Cyber security:** In order to maintain safe marine operations, cyber security [10] is a crucial factor to consider. Because of the increased information and communication technology (ICT) on-board, different attackers may attempt to exploit the system remotely, causing serious damage or disruption. As a result, illegally manipulating or exploiting the system be possible under any circumstances. To be protected from cyber threats, vulnerabilities in the ICT infrastructure must be addressed. Outsiders should not be able to interfere with communication between a ship and the SCC.

## 7. CONCLUSION

Autonomous ships are very near to reality. The first step towards building autonomous ships is for the ships to be unmanned and operated from a shore control centre [26]. This necessitates a comprehensive ability to remotely monitor the ship's condition in real time, which creates a slew of new issues. To enable correct decision-making, the data gathered from the ship's state must be precise and conveniently available to the operator.

Each and every small operation performed by crewmembers out at sea, which are essential for the operation of the vessel or pre-preparation of vessel for its cargo operation required to be automated. This paper chooses one such an operation. This proposal identified how FRAMO cargo pump purging operation can be automated and can produce the accurate result. This study analysed the feasibility of the proposal along with current hurdles to achieve the same. Overall, the detailed study produced in this paper shows the much confidence on the proposal.

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# NANO TECHNOLOGY: AN INNOVATIVE APPROACH FOR ABATEMENT OF SHIP EMISSION AND ENHANCEMENT OF ENGINE EFFICIENCY

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## ABSTRACT

One of the prominent issues that the world is confronting today is air pollution. Various innovative technologies are used to reduce emission and its harmful effect. The rapid growth of nanotechnology has gained a great deal of interest. Nano technology improves efficiency of the fuel which in turn enables reduced fuel consumption. In this paper various types of available Nano fuel additives and their effective utility to minimise emission from ships are discussed. Use of Nano adsorbent is an effective tool for the removal of NOx. 85% of nitrogen oxide emissions can be reduced using this technique. Some of the other application of Nano materials viz., Nano coating will reduce fuel consumption by 30%. A case study has been discussed in this paper elaborating how Nano fuel is prepared and the same was tested in a research vessel. Emission data collected prior and post utilisation of Nano fuel to the engine was recorded using a portable flue gas analyser and the data was validated by using both empirical method and a web tool emission calculator.

**Keywords:** Nano fuel additives, Emission, Nitrogen oxide, Flue gas analyser

## 1. INTRODUCTION

International shipping is a large and growing source of GHG emissions. These emissions are projected to increase significantly if mitigation measures are not put in place swiftly. Maritime transport, in addition to air transport, has become one of the major sources of emitting sulphur and nitrogen oxide. However, rigorous sulphur emission standards will come into force from 2020 as the International Maritime Organization has initiated stringent emission limits. Maritime transport emits around 940 million tonnes of $CO_2$ annually and is responsible for about 2.5% of global greenhouse gas (GHG) emissions.

## 2. NANO FUEL ADDITIVES – A FUTURE FUEL

With the advancement in Nano technology during the past few years, the scientific community focuses on improvising the combustion behaviour, stability aspects, various engine performance parameters, and emission characteristics of conventional diesel engines, using Nano-particle diesel biodiesel fuel blends [1]. Most recently, a few experimental works using Nano-sized metallic, non-metallic, organic, and mixed particles in the base liquid fuel for diesel engines have appeared in the open literature [2].

The results obtained are very encouraging due to multifold enhancement in the thermo-physical and chemical properties of modified fuels, such as high surface to volume ratio, high reactive medium for combustion, enhanced heat and mass transport properties due to high thermal conductivity, and improvement in the flash point, fire point, pour point, etc., depending on the type of Nano-particles used and their particle size and concentration with base fuels [3]. Further, the experimental results of different researchers have not generalised so far to reach a consensus about this new approach of fuel modification.

## 2.1 Types of Nano fuel additives for Diesel Engine

Nano size material includes metals like, Al, Mg, Zr, Ti, Ni, boron (a metalloid), and metal oxides [4]. Recently, Nano sized silicon powders and Nano porous silicon wafers were considered for various applications. Major types of Nano fuel additives are discussed below.

### 2.1.1 Cerium Oxide Nanoparticles

Cerium oxide has the ability to catalyse combustion reactions by donating oxygen atoms from its lattice structure. This catalytic activity is dependent on surface area; therefore, using nanoscale cerium oxide particles can offer distinct advantages over bulk material or larger particles [5]. **Figure 1** depicts the Transmission Electron Microscope images of cerium oxide nanoparticles and $CeO_2$ dispersed in fuel.

**Figure 2** shows how the hydrocarbon is left unburnt in the fuel. Adding cerium oxide nanoparticles to fuel can help assist in the decomposition of unburnt hydrocarbons and soot, thereby reducing the emission of these pollutants from the exhaust while simultaneously reducing the amount of fuel used as shown in **Figure 3**. It was also noted that cerium oxide decreases the pressure in the combustion chamber, which reduces the production of NOx and makes combustion reactions more efficient [6].

Cerium oxide nanoparticles can also be used as a short-term treatment for particulate filters in diesel engines [7]. These nanoparticles help to clear away soot, which clogs up the filters, in an effort to drastically improve the performance of the filters and the overall cleanliness of the exhaust emissions. REDOX properties [8] of Cerium Oxide promote combustion and reduce NOx as shown below:

NOx reduction: $xCe_2O_3 + NO_x \rightarrow 2xCeO_2 + N_2$ (1)

Soot Burning: $4CeO_2 + C_{soot} \rightarrow 2Ce_2O_3 + CO_2$ (2)

Hydrocarbon Combustion:

$(2x+y)CeO_2 + C_xH_y \rightarrow (2x+y)Ce_2O_3/2 + CO_2 + H_2O$ (3)

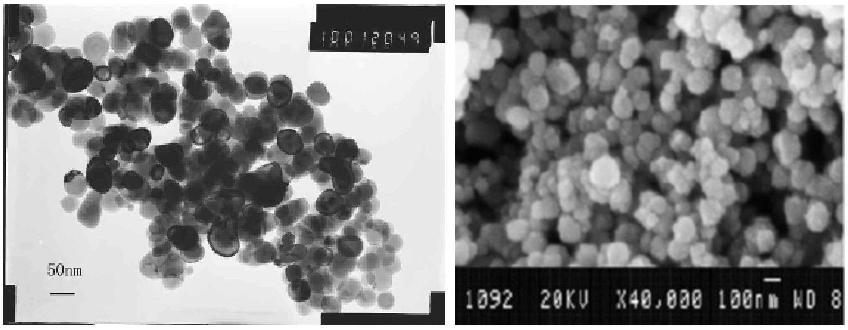


**Figure 1. TEM image of CeO2 nanoparticles & CeO2 dispersed in fuel**

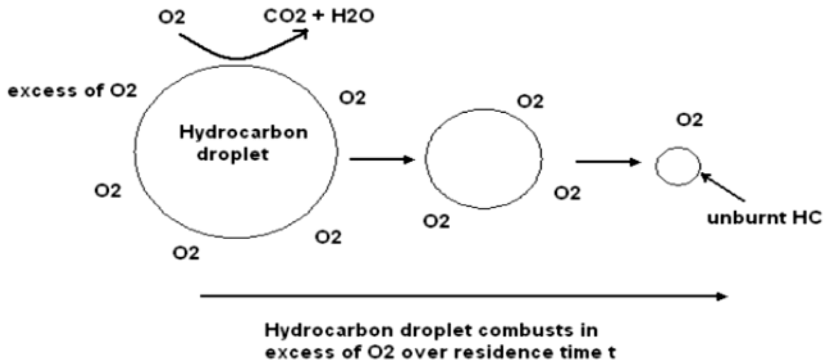


**Figure 2. Fuel oil without Cerium oxide Nano particles**

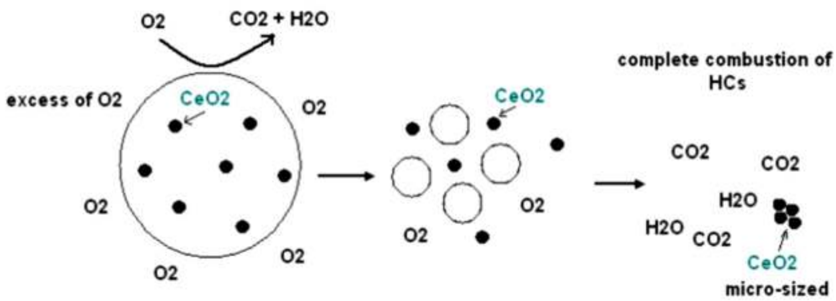


**Figure 3. Fuel oil with Cerium oxide Nano particles**

### 2.1.2 Aluminium Nanoparticles

Nanoparticles and micro particles of aluminum have also been extensively investigated as potential fuel additives. The main reason for this is because of aluminum's ability to increase the power output of engines as a result of its high combustion energy. Recent advances in the fabrication and characterisation of nanoparticles have provided researchers with a more detailed understanding into the relationship that exists between particle size and structure with performance benefit, thereby supporting research into aluminum nanoparticle fuel additives.

In addition, the aluminum nanoparticle suspensions in ethanol-based fuels were much better than those in model hydrocarbons, suggesting that nano-aluminum

**It was also noted that cerium oxide decreases the pressure in the combustion chamber, which reduces the production of NOx and makes combustion reactions more efficient**

could be effective in additive packs for bio-ethanol fuels [9]. In fact, a 2018 study found that incorporating aluminum oxide ($Al_2O_3$) nanoparticles into Jojoba biodiesel-diesel fuel significantly improved engine performance while simultaneously reducing the NOx emissions by 70%, carbon monoxide (CO) emissions by 80% and smoke opacity by 35% [10].

### 2.1.3 Magnesium-Aluminium and Cobalt Oxide Nanoparticles

Ganesh *et al.*, (2011) suggested that India had investigate the potential of cobalt oxide ($CO_3O_4$) and magnesium-aluminum (magnalium) nanoparticles as additives for biodiesel fuels [11]. The oxygen atoms in $CO_3O_4$ particles can moderate the combustion reactions in a similar mechanism as to how cerium oxide Nano additives function. As a result, when $CO_3O_4$ nanoparticles were applied to the fuel, the combustion was cleaner and both CO and unburnt hydrocarbon emission were significantly reduced.

The cobalt Nano additives were also shown to reduce $NO_x$ production. This is especially significant with biodiesel combustion, since biodiesel fuels are often prone to high $NO_x$ emissions as compared to regular petrochemical diesel. Magnalium nanoparticles serve a similar function as fuel additives as compared to aluminium nanoparticles, in that these nanoparticles exhibit a high energy combustion that produces micro explosions. These micro explosions ultimately improve combustion efficiency to help improve fuel efficiency and increase power output.

## 3. NANO FUEL PREPARATION

For this study, a mixture of Cerium oxide and Aluminum Nano particle soaked in Ethanol is being analysed. Material existing in Nano scale (1-100 nm) is easier to disperse in a fuel and they are highly reactive as compared with conventional particle size [12]. Due to higher specific surface area, strong interaction is developed between fuel and particles. Particle will suspend in a stabilised condition for a longer period. A charged layer is formed as a result of absorption of ionic groups of a fuel by Nano particle [13]. Due to the repulsive forces, particle agglomeration will be minimised. Nanoparticles of 5 nm and 10 nm are

*Material existing in Nano scale (1-100 nm) is easier to disperse in a fuel and they are highly reactive as compared with conventional particle size*

considered for the experiment. These particles are spherical in shape with smooth surface.

Ethanol soaked Nano-particles are mixed thoroughly with a mixture of fuel and surfactant. Special mixing technique sonication (pressure induced through ultrasound waves) is used in order to have a homogeneous, stable, long term suspension and very less agglomeration of Nano particle. Constant temperature for the mixture was maintained.

There are different Nano additives available and being developed for different applications. Laboratory experimentation works are being carried out with the combination of different base fuels and oxygenated fuels. Our study stood apart from others in matter of blending of different oxygenated fuel additives. In our study, we are using surfactants along with Nano fuel additives and oxygenated fuel additives added to base marine fuel. Using a surfactant, blending both Nano additives and oxygenated fuel additives to a base marine fuel is a novel technique which has been developed.

### 3.1 Case study

For this study, prepared Nano fuel was tested on-board a research vessel engaged in a suitable cruise. The emissions from the exhaust of the ship before adding Nano fuel additives are recorded with a portable flue gas analyser - Testo 350 as shown in **Figure 4**. The TESTO 350 MARITIME Exhaust Gas Analyser is a certified instrument for measuring emissions at ship diesel engines, specifically for measuring gaseous exhaust concentrations of $O_2$, CO, $CO_2$, NOx, and $SO_2$.

A schematic diagram showing the conventional fuel oil supply arrangement and modified setup for Nano fuel additive supply is shown in **Figure 5**.

Cerium oxide and aluminium nanoparticles are thermally stable oxidation catalysts for promoting oxidation of

*Ship emission measurements taken onboard research vessels* *AIS installed onboard*

**Figure 4. Emission data collected using Portable flue gas analyser – Testo 350**

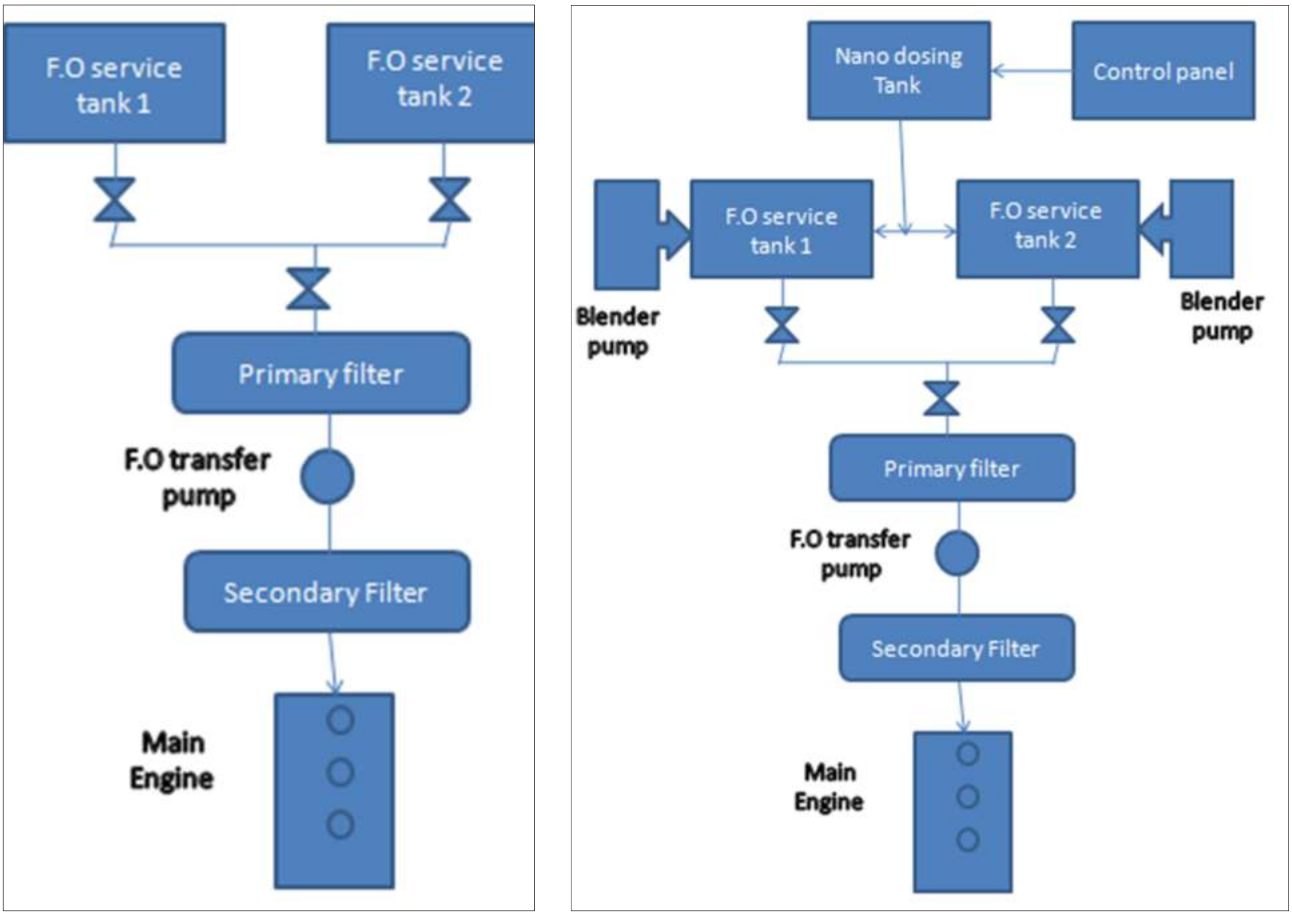


**Figure 5. Schematic diagram of Conventional and modified nano fuel dosing systems on board the Research vessel**

**Table 1. Data collected using portable flu gas analyser (Testo 350) before adding Nano fuel additives**

| S. No | Date & hrs | $O_2$ (%) | $CO_2$ (%) | NO (ppm) | CO (ppm) | $SO_2$ (ppm) | $NO_2$ (ppm) | Temp. (°C) | | Reading From | | | | $P_G$ (kW) | Gen. Running | | | | $P_T$ (kW) | Mode | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Amb.* | *Exh.* | G1 | G2 | G3 | G4 | | G1 | G2 | G3 | G4 | | | |
| 1 | 22-9-19 00.00 | 18.77 | 1.72 | 74 | 237 | 7 | 45.4 | 28.2 | 87.4 | | | | | | | | | | | NA | Emer. Gen. |
| 2 | 22-9-19 13.00 | 13.30 | 5.7 | 580 | 114 | 20 | 6.9 | 30.2 | 326.1 | • | | | | 593 | • | | | | | Drift | NA |
| 3 | 23-9-19 00.00 | 14.96 | 4.53 | 319 | 243 | 15 | 13.6 | 30.9 | 233 | | | | • | 178 | • | • | • | • | 831 | DP | NA |
| 4 | 23-9-19 13.00 | 14.52 | 4.84 | 347 | 251 | 16 | 6.3 | 28.8 | 264.9 | | • | | | 217 | • | • | • | • | 792 | DP | NA |

**Table 2. Data collected using portable flu gas analyser (Testo 350) after adding Nano fuel additives**

| S.No | Date & hrs | $O_2$ (%) | $CO_2$ (%) | NO (ppm) | CO (ppm) | $SO_2$ (ppm) | $NO_2$ (ppm) | Temp. (°C) | | Reading From | | | | $P_G$ (kW) | Gen. Running | | | | $P_T$ (kW) | Mode | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Amb.* | *Exh.* | G1 | G2 | G3 | G4 | | G1 | G2 | G3 | G4 | | | |
| 1 | 22-9-19 00.00 | 17.07 | 0.98 | 60 | 200 | 6 | 32.9 | 28.2 | 87.4 | | | | | | | | | | | NA | Emer. Gen |
| 2 | 22-9-19 13.00 | 11.90 | 2.24 | 560 | 109 | 17 | 2.6 | 30.2 | 326.1 | • | | | | 593 | • | | | | | Drift | NA |
| 3 | 23-9-19 00.00 | 12.87 | 1.68 | 300 | 221 | 12 | 7.9 | 30.9 | 233 | | | | • | 178 | • | • | • | • | 831 | DP | NA |
| 4 | 23-9-19 13.00 | 12.06 | 1.87 | 328 | 207 | 14 | 3.1 | 28.8 | 264.9 | | • | | | 217 | • | • | • | • | 792 | DP | NA |

hydrocarbon fuel [14]. When the combined Nano fuel is used as an additive in CI engine, it reduces NOx emission [15]. After blending the Nano additives in the fuel oil service tank, again emissions are recorded from the exhaust by the portable flue gas analyser. By comparing the data recorded before and after adding Nano fuel additives, it was observed that the NOx emission was reduced by 20%. CO and $CO_2$ showed a reduction of 10% for alumina and cerium oxide Nano particles due to fast evaporation rate. The recorded emission data is validated using an online ship emission calculator by Laboratory for Maritime Transport, National Technical University of Athens and also by using empirical formulae. **Table 1** and **Table 2** show the data recorded using a portable flue gas analyser before and after adding Nano fuel additives.

## 3.2 Ship emission Calculator

It is an open source web-based tool created by the National Technical University of Athens, Laboratory for Maritime Transport for calculating the exhaust gas emissions ($CO_2$, $SO_2$ and NOx) of specific types of ships under a variety of operational scenarios. By feeding the details of the ship and ship's voyage plan in the specified fields, emission data shall be obtained using an inbuilt algorithm. A sample data is shown in **Table 3**.

**Table 3. Emission data obtained from Web tool**

| S.No | Date | $CO_2$ (g/km) | NOx (g/km) | Mode | Remarks |
|---|---|---|---|---|---|
| 1. | 22-9-19 | 161.974 | 1.72 | NA | Emer. Gen. |
| 2. | 22-9-19 | 374.2 | 15.89 | Drift | NA |
| 3. | 23-9-19 | 278.7 | 8.51 | DP | NA |
| 4. | 23-9-19 | 310.6 | 9.30 | DP | NA |

**Table 4. Validation between ship emission calculator and empirical formulae**

| $CO_2$ (g/km) | | NOx (g/km) | |
|---|---|---|---|
| Ship emission calculator | Empirical values | Ship emission calculator | Empirical values |
| 161.974 | 162.974 | 1.72 | 1.713 |
| 374.2 | 372.512 | 15.89 | 15.99 |
| 278.7 | 279.38 | 8.51 | 8.56 |
| 310.6 | 310.98 | 9.30 | 9.36 |

## 3.3 Validation of the data

The Testo 350 values recorded are in ppm. Using the empirical formula conversions, it is converted to g/km. Previous research conducted in this field has established the relationship between the emission gas concentration (ppm) and specific fuel consumption. To compare the EU standard in g/km to the results obtained in ppm, the conversion employed (equations 4-6) was based on the assumptions of Alkama et al., [16] and conversions adopted by Pilusa et al., [17]. The results of this work have proven that 1 ppm of a specific pollutant gas is 8.4 times its density in milligrams per kilometre.

$$CO\ (g/km) = 9.66 * 10^{-3} * CO\ (ppm) \quad (4)$$

$$CO_2\ (g/km) = 166.3 * CO_2\ (vol.\ \%) \quad (5)$$

$$NOx\ (g/km) = 28.56 * 10^{-3} * NOx\ (ppm) \quad (6)$$

**Table 4** shows the values obtained from the ship emission calculator and also the values calculated using the empirical formulas. **Figure 6** shows the $CO_2$ and NOx values got from the ship emission calculator and empirical formulas with a variation of ± 2%.

$$CO_2\ (g/km) = 166.3 * CO_2\ (vole\ \%) = 166.3 * 0.98 = 162.974$$

$$NOx\ (g/km) = 28.56 * 10^{-3} * NOx\ (ppm) = 28.56 * 10^{-3} * 60 = 1.713$$

## 4. CONCLUSION

A good range of Nano fuel additives can be used as additives in diesel and biodiesel fuels. The advantages include increased surface area to volume ratio and increased catalytic activity in Nano size metal oxides and metals. Nano fuel increases better combustion due micro explosion phenomenon. The results of the study may be summarised as follows:

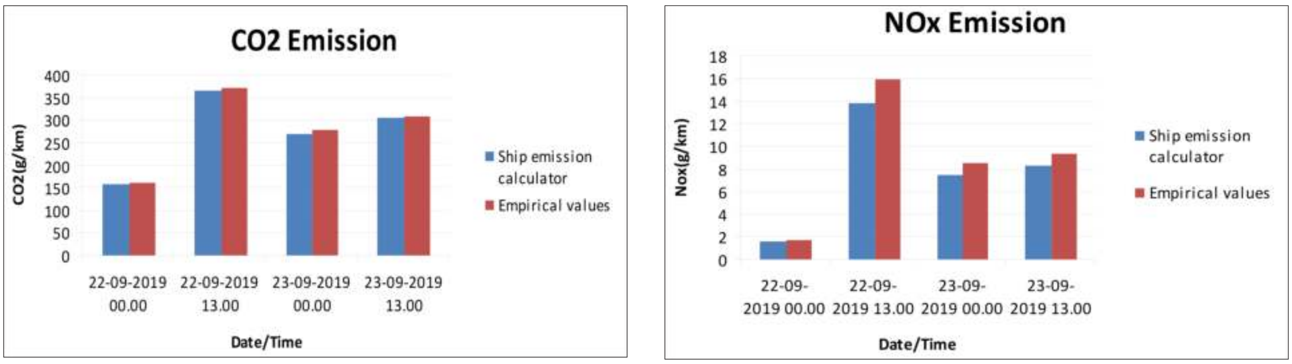


**Figure 6. $CO_2$ and NOx emissions: Validation using Ship emission calculator and Empirical formulae**

- Most of the additives showed reduction in NOx and SOx due to higher cetane number and reduction in HC due to higher evaporation rate and catalytic oxidation
- Lower smoke emission was observed due to higher evaporation rate, reduced ignition delay.
- There is a decrease in CO emission due to improved ignition characteristics with Nano fuel additives.

The use of nanoparticles has been shown to encourage cleaner combustion; fuels mix better with air in the combustion engine burn better and more completely, leading to fewer polluting emissions. They also enhance the efficiency, which means that the engine requires less fuel with reduced running costs.

Thus a novel approach of implementing Nano technology i.e., Nano fuel additives has been proven to be a promising technique for abatement of emissions from ships and enhancement of engine efficiency.

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TECHNICAL NOTES

# LUBE MATTERS # 7

## CYLINDER SCRAPE-DOWN ANALYSIS

Sanjiv Wazir

### Introduction

Traditionally, calibration of piston rings, grooves and liners was used to measure wear of the combustion space components. In slow speed two-stroke crosshead engines monitoring the physio-chemical properties and elemental analysis of the scavenge drain oil/cylinder scrape-down oil can also help monitor wear, give insight about the combustion, wear mechanisms and overall condition prevailing in each unit. It can also help in choosing the right BN and optimising the feed-rate of the cylinder oil.

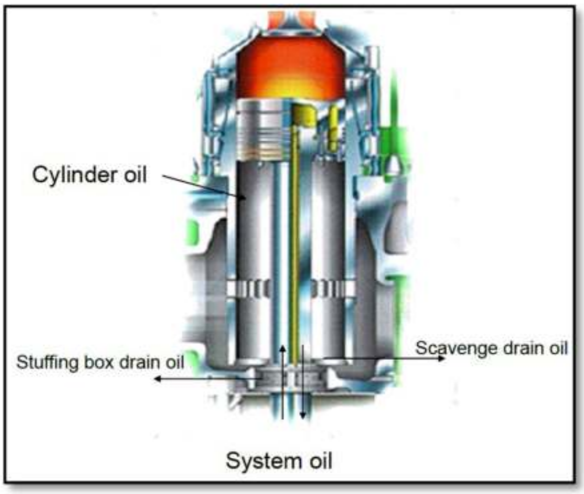



**Figure 1. Cylinder Scrape-down/Scavenge drain oil (1)**

### Cylinder Scrape-down Analysis (CSA)

Many factors can affect the different parameters of cylinder scrape-down oil, such as the cylinder oil feed-rate and BN, the fuel Sulphur content, engine load, fuel injection and combustion efficacy, system oil leakage past the stuffing box seals, etc. Hence drawing valid inferences from the CSA test result is only possible with detailed information on all these key factors.

### System Oil Dilution

Cylinder lubrication is a once-through process. The fresh oil is injected into the liner through the lubricators and the residual oil is continually scraped down by the piston rings. The excess used oil along with any fuel/combustion products and wear particles collects in the under-piston space, from where it drains out. CSA samples are collected from a sample point on the drainpipe.

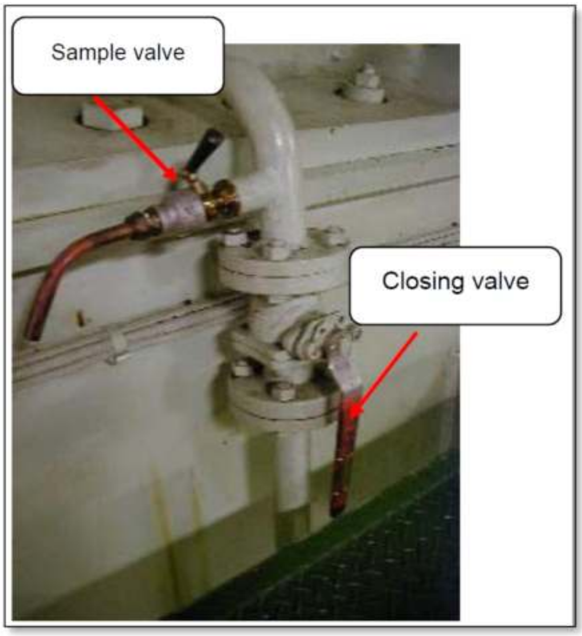



**Figure.2: CSA sample point (2)**

If the stuffing box sealing is not effective, some of the scrape-down oil can travel down and contaminate the system oil in the crankcase. Some system oil can also travel up into to the scavenge space via the stuffing box and contaminate (dilute) the scrape-down oil and greatly influence CSA interpretation.

Hence, LUKOIL recommends vessels to take a sample of the system oil along with the CSA samples to estimate system oil dilution and account for such dilution when reporting important parameters such as Iron (Fe), Particulate Quantifier (PQ), Base Number (BN), Kinematic Viscosity (KV), etc. It also helps to get an estimate of stuffing box cleaning efficacy in the unit.

## Impact of Fuel & Combustion

The ratio of fuel consumption (specific fuel oil consumption) to cylinder oil consumption (specific lube oil consumption) can be > 150:1. Various parameters of the combusted fuel, such as sulphur content, ignition and combustion qualities, cat fines, fuel treatment, temperature, spray, drip, etc have a huge impact on CSA results. Hence, LUKOIL recommends taking a sample of the in-use fuel along with the CSA samples for better interpretation of the CSA results.

## Collecting CSA samples

As with any other oil analysis, collecting representative samples is the heart of meaningful analysis. OEMs and Lube suppliers provide instructions for collecting samples. To avoid long settled sludge and debris distort current

**OIL RATING**

Remaining reserve of alkalinity (BN) in the oil is adequate.

**UNIT RATING**

PQ and elemental Fe results suggest that the Iron level is within the acceptable limit. Fuel valve hrs data missing on the labels; please always report the entire data asked on the sample submission form to make the best possible assessment/recommendation. PUS cleaning hrs reported as 492 hrs after correction, which was mentioned as 30066 hrs (ME Hours when Scav. Space last cleaned) on the labels.

**Figure 3. Overall Oil & unit Rating (3)**

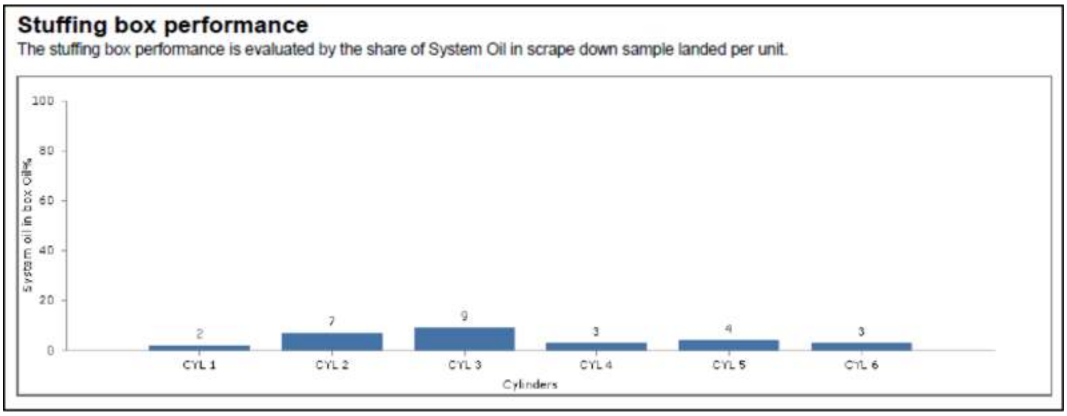



**Figure 4. Unit-wise stuffing box efficacy estimated based on system oil ingress in the scrape-down oil (3)**

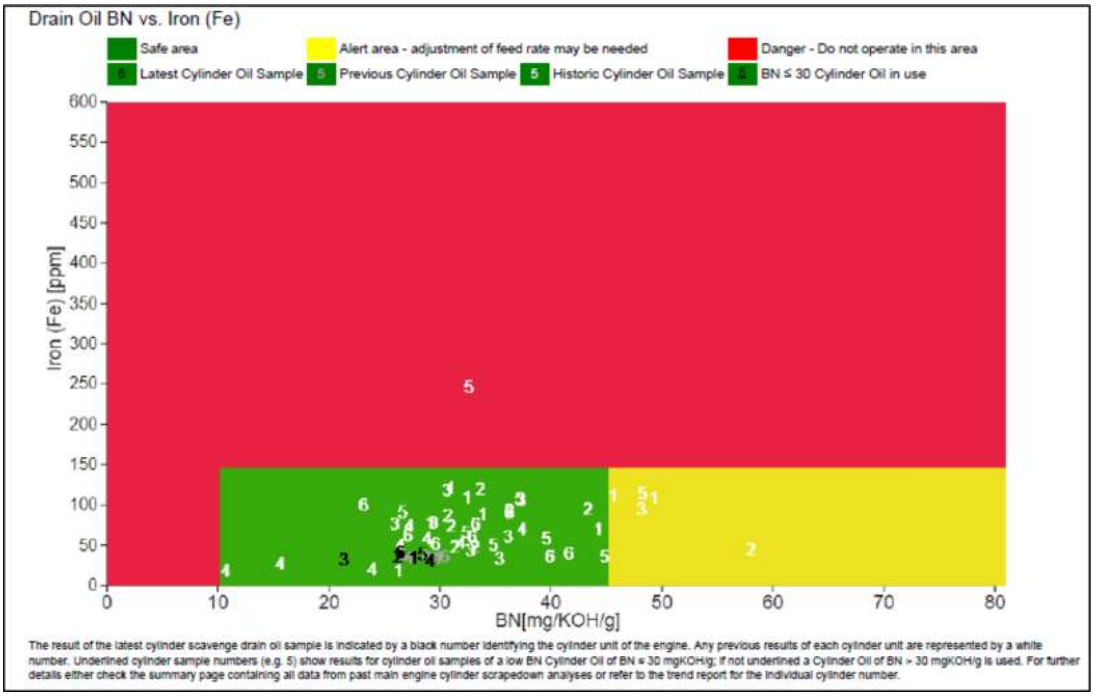



**Figure 5. Residual BN vs Fe, latest and historical data (3)**

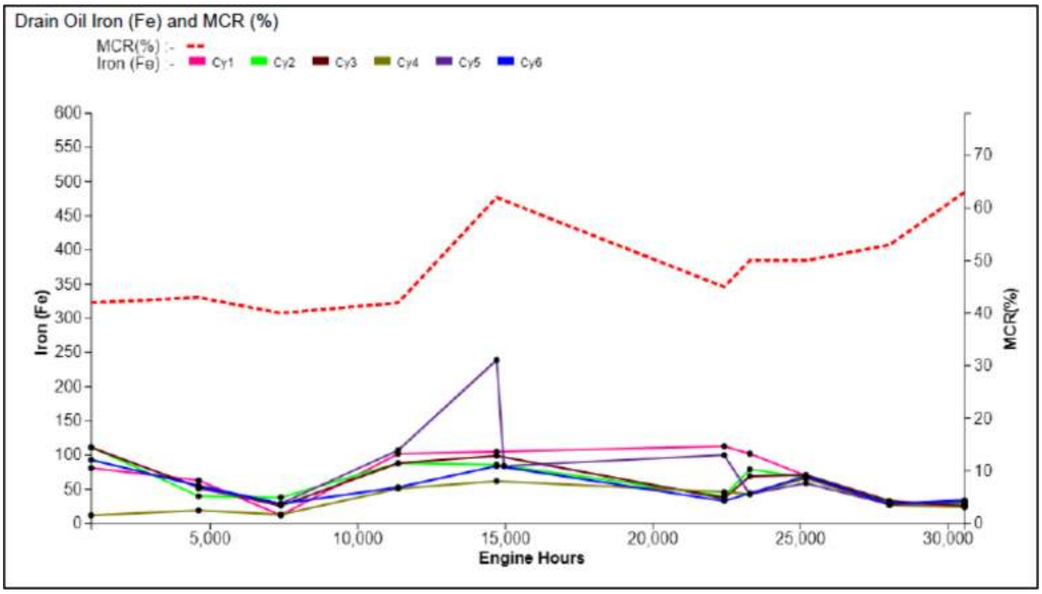
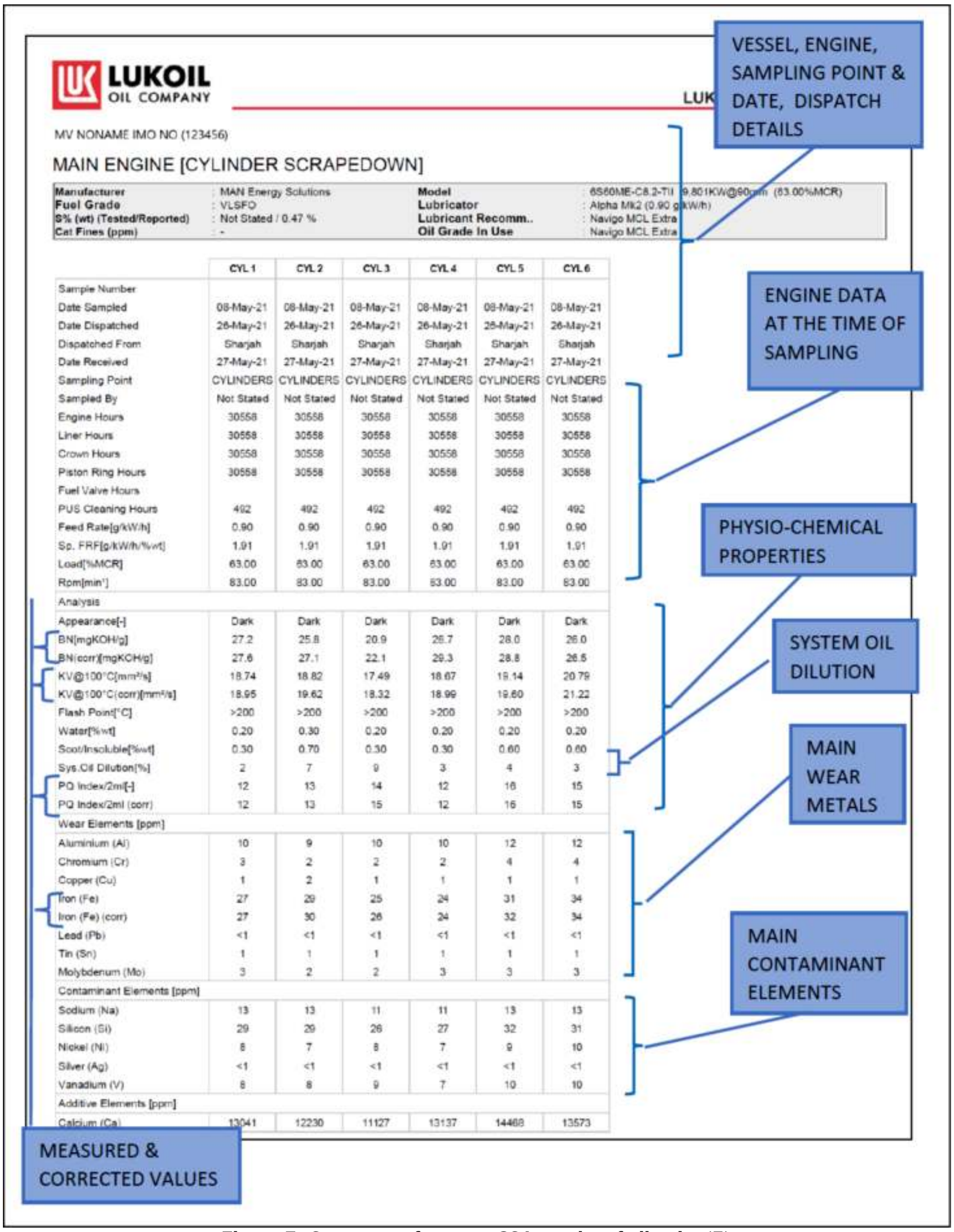



Figure 6. Unit-wise Fe vs Engine load, historical data (3)




LUKOIL OIL COMPANY

MV NONAME IMO NO (123456)

MAIN ENGINE [CYLINDER SCRAPEDOWN]

| | | | |
|---|---|---|---|
| **Manufacturer** | : MAN Energy Solutions | **Model** | : 6S60ME-C8.2-TII 9,801KW@90rpm (63.00%MCR) |
| **Fuel Grade** | : VLSFO | **Lubricator** | : Alpha Mk2 (0.90 g/kW/h) |
| **S% (wt) (Tested/Reported)** | : Not Stated / 0.47 % | **Lubricant Recomm..** | : Navigo MCL Extra |
| **Cat Fines (ppm)** | : - | **Oil Grade In Use** | : Navigo MCL Extra |

| | CYL 1 | CYL 2 | CYL 3 | CYL 4 | CYL 5 | CYL 6 |
|---|---|---|---|---|---|---|
| Sample Number | | | | | | |
| Date Sampled | 08-May-21 | 08-May-21 | 08-May-21 | 08-May-21 | 08-May-21 | 08-May-21 |
| Date Dispatched | 26-May-21 | 26-May-21 | 26-May-21 | 26-May-21 | 26-May-21 | 26-May-21 |
| Dispatched From | Sharjah | Sharjah | Sharjah | Sharjah | Sharjah | Sharjah |
| Date Received | 27-May-21 | 27-May-21 | 27-May-21 | 27-May-21 | 27-May-21 | 27-May-21 |
| Sampling Point | CYLINDERS | CYLINDERS | CYLINDERS | CYLINDERS | CYLINDERS | CYLINDERS |
| Sampled By | Not Stated | Not Stated | Not Stated | Not Stated | Not Stated | Not Stated |
| Engine Hours | 30558 | 30558 | 30558 | 30558 | 30558 | 30558 |
| Liner Hours | 30558 | 30558 | 30558 | 30558 | 30558 | 30558 |
| Crown Hours | 30558 | 30558 | 30558 | 30558 | 30558 | 30558 |
| Piston Ring Hours | 30558 | 30558 | 30558 | 30558 | 30558 | 30558 |
| Fuel Valve Hours | | | | | | |
| PUS Cleaning Hours | 492 | 492 | 492 | 492 | 492 | 492 |
| Feed Rate[g/kW/h] | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| Sp. FRF[g/kW/h/%wt] | 1.91 | 1.91 | 1.91 | 1.91 | 1.91 | 1.91 |
| Load[%MCR] | 63.00 | 63.00 | 63.00 | 63.00 | 63.00 | 63.00 |
| Rpm[min⁻¹] | 83.00 | 83.00 | 83.00 | 83.00 | 83.00 | 83.00 |
| Analysis | | | | | | |
| Appearance[-] | Dark | Dark | Dark | Dark | Dark | Dark |
| BN[mgKOH/g] | 27.2 | 25.8 | 20.9 | 26.7 | 28.0 | 26.0 |
| BN(corr)[mgKOH/g] | 27.6 | 27.1 | 22.1 | 29.3 | 28.8 | 26.5 |
| KV@100°C[mm²/s] | 18.74 | 18.82 | 17.49 | 18.67 | 19.14 | 20.79 |
| KV@100°C(corr)[mm²/s] | 18.95 | 19.62 | 18.32 | 18.99 | 19.60 | 21.22 |
| Flash Point[°C] | >200 | >200 | >200 | >200 | >200 | >200 |
| Water[%wt] | 0.20 | 0.30 | 0.20 | 0.20 | 0.20 | 0.20 |
| Soot/Insoluble[%wt] | 0.30 | 0.70 | 0.30 | 0.30 | 0.60 | 0.60 |
| Sys.Oil Dilution[%] | 2 | 7 | 9 | 3 | 4 | 3 |
| PQ Index/2ml[-] | 12 | 13 | 14 | 12 | 16 | 15 |
| PQ Index/2ml (corr) | 12 | 13 | 15 | 12 | 16 | 15 |
| Wear Elements [ppm] | | | | | | |
| Aluminium (Al) | 10 | 9 | 10 | 10 | 12 | 12 |
| Chromium (Cr) | 3 | 2 | 2 | 2 | 4 | 4 |
| Copper (Cu) | 1 | 2 | 1 | 1 | 1 | 1 |
| Iron (Fe) | 27 | 29 | 25 | 24 | 31 | 34 |
| Iron (Fe) (corr) | 27 | 30 | 26 | 24 | 32 | 34 |
| Lead (Pb) | <1 | <1 | <1 | <1 | <1 | <1 |
| Tin (Sn) | 1 | 1 | 1 | 1 | 1 | 1 |
| Molybdenum (Mo) | 3 | 2 | 2 | 3 | 3 | 3 |
| Contaminant Elements [ppm] | | | | | | |
| Sodium (Na) | 13 | 13 | 11 | 11 | 13 | 13 |
| Silicon (Si) | 29 | 29 | 26 | 27 | 32 | 31 |
| Nickel (Ni) | 8 | 7 | 8 | 7 | 9 | 10 |
| Silver (Ag) | <1 | <1 | <1 | <1 | <1 | <1 |
| Vanadium (V) | 8 | 8 | 9 | 7 | 10 | 10 |
| Additive Elements [ppm] | | | | | | |
| Calcium (Ca) | 13041 | 12230 | 11127 | 13137 | 14468 | 13573 |

Figure 7. Summary of current CSA results of all units (3)

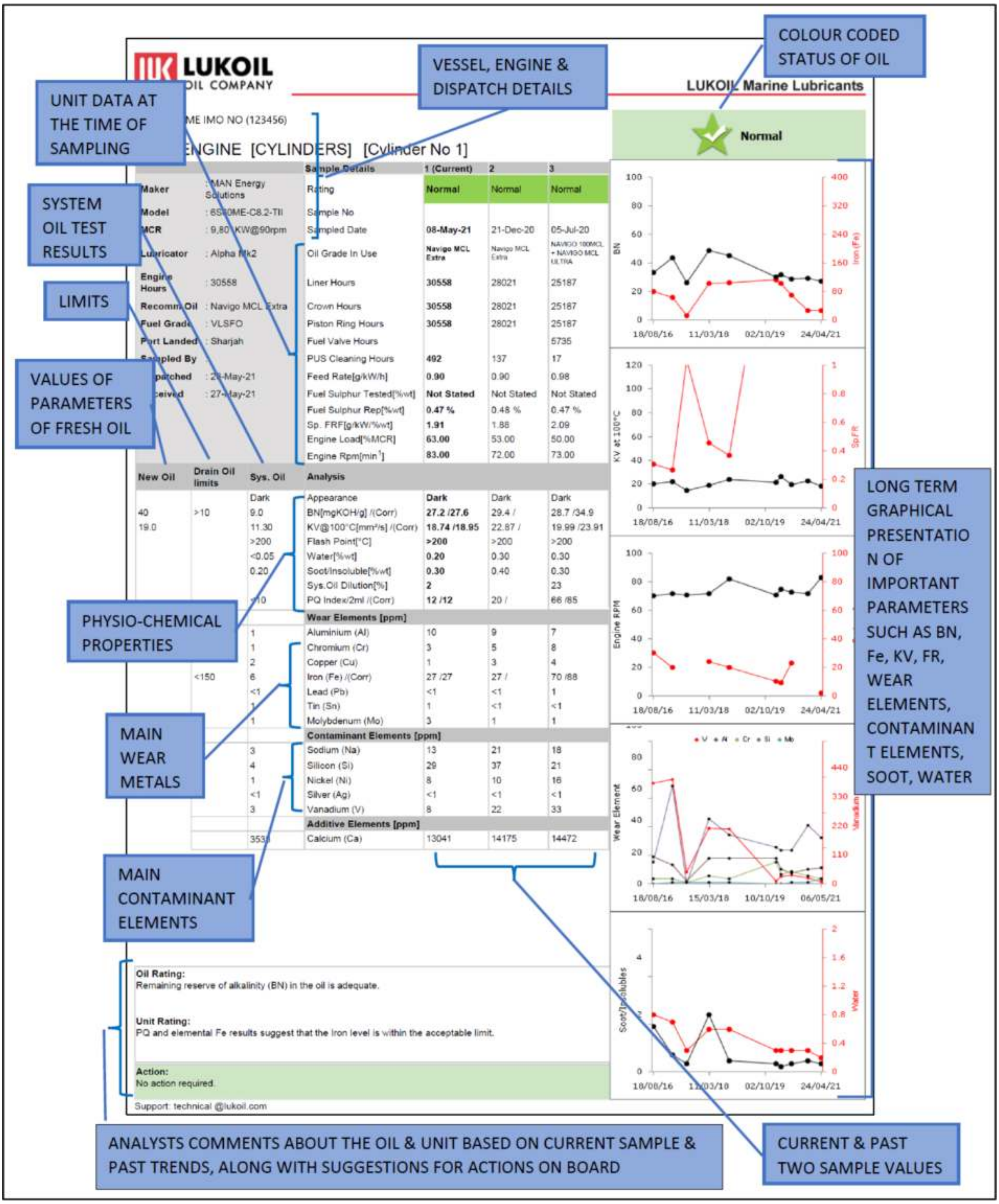



**Figure 8. CSA report for a unit, current and historical data (3)**

results, clean the scavenge spaces of all the units and carry out scavenge space inspection at the last port before sampling. Collect samples within about 150 hrs of cleaning. Sufficient oil from the sampling cock should be drained away before collecting the sample.

Fill all the required information in the sample label, including engine and unit information, and dispatch to the lab from the earliest port.

## CSA Report

The CSA report can give a detailed picture of the overall engine condition. Examples from various sections of a LUKOIL CSA report are shown in Figure 8.

## CSA Report: What Does It Tell Us?

Despite cylinder lubrication being a once-through type of lubrication, full benefits of CSA can be obtained only if

**Table 1 A Ready Reckoner**

| Property | |
|---|---|
| BN | The residual BN is an indication of the remaining ability of the oil to neutralize acids. It is mainly influenced by fuel sulphur content, cylinder oil BN and feed-rate.<br>If the residual BN is too low, the oil film may not be able to protect the liner from corrosive wear. Increase in cylinder oil feed-rate or BN or both may be needed.<br>If the residual BN is too high, the risk of deposits of un-neutralised alkaline additive rises, increasing the possibility of abrasive wear causing bore-polishing. Reduction in cylinder oil feed-rate or BN or both may need to be considered.<br>Also refer to Figure 9. |
| Kinematic Viscosity (KV) | Too low KV may indicate ingress of system oil (stuffing box leakage or piston cooling oil leakage)<br>Too high KV may be indicative of blow-by of unburned/partly burned fuel, poor combustion. This may be accompanied by rise in Soot & elements from Fuel (V, Ni, Na) |
| Flash Point | A drop of the flash point is indicative of ingress of fuel or fuel components |
| Soot/Insoluble | A rise in the soot/insoluble concentration is indicative of poor combustion |
| Water | Mainly originating from excessive moisture in the scavenge air.<br>Cooling water leakage is also a possibility. |
| Wear and contaminant elements (by spectrometry) | Many metal alloys and coatings are used in combustion space components. An increase of these elements can indicate that abnormal wear has set in. Scrape-down oil can also indicate signs of contamination by fuel components, water and air borne dirt. |
| Iron (Fe) & PQ | Fe is a major constituent in all engine components. Hence, besides residual BN, Fe is the most important parameter considered while evaluating the CSA results. In the scrape-down oil, it is usually originating from corrosive wear due to acid attack on the liner/rings or abrasive wear on or between liners and piston rings, caused by micro-seizure or cat fines. Frequent inspections to monitor the wear and determine causes should be initiated.<br>Different wear mechanisms result in different forms of Fe. For example, abrasive wear usually results in larger and magnetic iron particles, while corrosive wear usually results in smaller and non-magnetic particles.<br>Hence, for a meaningful evaluation it is important to consider levels of both, Fe (by spectrometry) and PQ. |
| Aluminium | An increase of aluminium in conjunction with Si is indicative of cat fine ingress. Likely to be accompanied by rise in Fe and PQ.<br>Running in of Alu-coated piston rings can also cause a rise in Al. |
| Chromium | An increase of chromium is indicative of wear of piston ring grooves and piston ring coatings. Inspect for micro-wear & ring pack cleanliness |
| Copper | A small increase of copper can be expected during running in of new piston skirt. A large increase is indicative of abnormal wear of piston skirt bronze wear band and/or stuffing box seals. |
| Tin | Low levels of tin can be expected during running in, higher values may be indicative of piston-alignment issues. |
| Molybdenum | Constituent of some liner materials & piston skirt wear band |
| Vanadium & Nickel | Constituents of residual fuels. Increase is indicative of ingress of fuel components due to blow-by. Usually accompanied by a rise in KV. |
| Sodium | Sodium is sometimes a contaminant in fuel (from sea water). Sodium can also be a constituent of fuel (like V & Ni).<br>Na-based chemicals are often used for cooling water treatment, so increase could indicate cooling water ingress.<br>Na-based chemicals are sometimes constituents of tank cleaning chemicals.<br>If the air cooler is sea water cooled and water ingress is high, possibility of water leakage from air cooler should be considered |
| Silicon | Multiple possible sources:<br>If there is a large increase in silicon: Airborne dust/dirt/sand.<br>If the Si level rising along with Al: Cat Fines.<br>If small variation: Oil additive |

**Guiding drain oil levels**

| Engine bore size | Max. Fe content (ppm) |
|---|---|
| 26-50 | 100 |
| 60-70 | 150 |
| 80-98 | 200 |

NB: Cylinder oil BN levels in drain oil samples may vary depending on engine and oil type. For guidance, the BN in the drain oil should be kept above 25% of the original BN value.

**Figure 9. MAN guidance values for Fe (max) and BN (min) for engines burning VLSFO (<0.5% S) (4)**

testing is done regularly to establish a trend. Since many factors can influence the combustion process and liner/piston ring interface, variations in any parameter should be cross-checked with results of other parameters before drawing definitive conclusions.

## ABOUT THE AUTHOR

**Sanjiv Wazir** is a Technical Adviser with LUKOIL Marine Lubricants. He is a mechanical engineer from IIT-Bombay. He is a marine engineer and a member of the Institute of Marine Engineers. He is a Certified Lubrication Specialist from the Society of Tribologists & Lubrication Engineers (STLE), USA and is a member of the Tribological Society of India. He has contributed to MER on marine lubrication developments in the past, and on oil contamination issues under "Lube Matters", earlier.

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## Scavenge Port Inspections & Wear Measurements

Besides CSA and on-board tests, scavenge port inspection of pistons, rings, grooves, top-land and ring-lands, crown, liners, ports, scavenge spaces, air coolers, water-catchers and drains are extremely important. These should be undertaken frequently to detect any condition changes. Measurement of liner, piston ring and groove wear as well as wear of ring coatings should also be carried out. The obtained information should be stored in the vessels maintenance system. CSA results should be correlated with inspection findings. Collecting good photographic evidence for records helps comparing and monitoring changing conditions over time. OEMs provide detailed instruction for such inspections.

## Conclusion

CSA has become an important tool to understand oil condition, wear condition, oil contamination and to optimise cylinder oil selection and feed-rate. It can provide early indication of changes in unit condition.

## References

1. CIMAC No. 31, April 2017: The Lubrication of Two-Stroke Crosshead Engines
2. CIMAC No. 30, 2011: Used Engine Oil Analysis-User Interpretation Guide
3. LUKOIL CSA Reports
4. MAN Service Letter SL2019-671/JAP, April 2019: Cylinder Lubrication update for 0 to 0.5% sulphur fuels

# MODEL STUDY ON DAMAGE AND ACCIDENTAL OVERFLOW OF CARGO OIL

Agaram Ramanujan

## 1. INTRODUCTION

This paper is the continuation of the previous paper titled MODEL STUDY ON DAMAGE AND DAMAGE STABILITY OF TANKERS. In this paper, cause for grounding damage, damage calculations and accidental cargo oil outflow will be explained with the same tanker model for easy comprehension.

Grounding is most likely to happen when the ship enters shallow waters and is influenced by the effect of squatting which commonly occurs in shallow waters when the clearance between seabed and ship's bottom is critical.

## 2. REASONS FOR GROUNDING

The squat effect is the hydrodynamic phenomenon by which a vessel moving quickly through shallow water creates an area of lowered pressure that causes the ship to be closer to the seabed than would otherwise be expected. This phenomenon is caused when water that should normally flow under the hull encounters resistance due to the close proximity of the hull to the seabed. The small clearance causes the water to move faster. In water level ,where the section is smaller (according to Bernoullì's theorem), a velocity increase creates a low-pressure area and the ship is pulled down. This squat effect results from a combination of vertical sinkage and a change of trim that may cause the vessel to dip towards the stern or towards the bow.

Squat effect is approximately proportional to the square of the speed of the ship. Thus, by reducing speed by half, the squat effect is reduced by a factor of four. Squat effect is usually felt more when the depth/draft ratio is less than four or when sailing close to a bank. It can lead to unexpected groundings and handling difficulties. For ease of understanding, the buoyancy/upthrust and weight effects are shown in **Figure 1**.

Together with squat effect, the ship undergoes vertical vibration due to the variation of the buoyancy pressure under the ship. This can lead to contact between the ship's bottom and the ground and can cause impact damage to the bottom.

If grounding happens on a sand or mud bank at low tide, the vessel can float during high water and proceed.

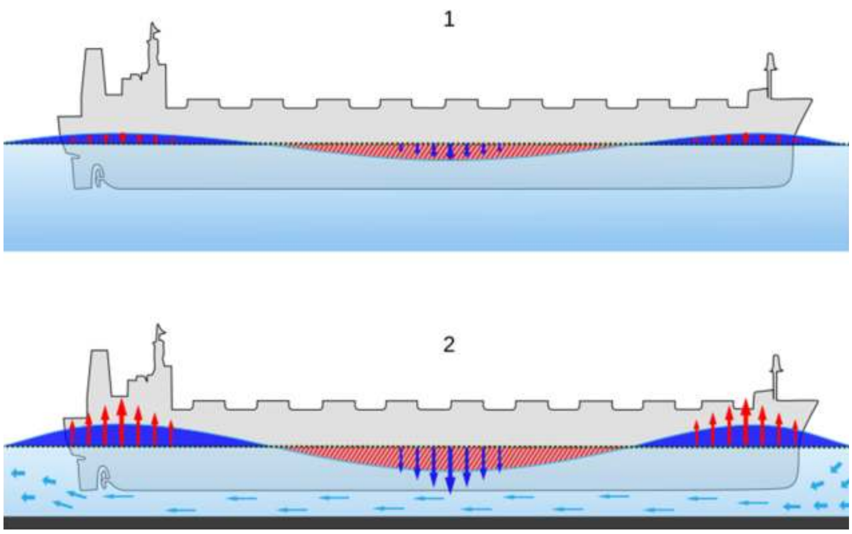


**Figure 1.**

However, if the bottom is pierced or torn, it cannot refloat since the available buoyancy will be less than the displacement of the ship and this situation is called stranding.

Bottom damage occurs if the seabed is rough and hard, especially if it is a rocky reef or coral reef. In this case, the bottom gets pierced.

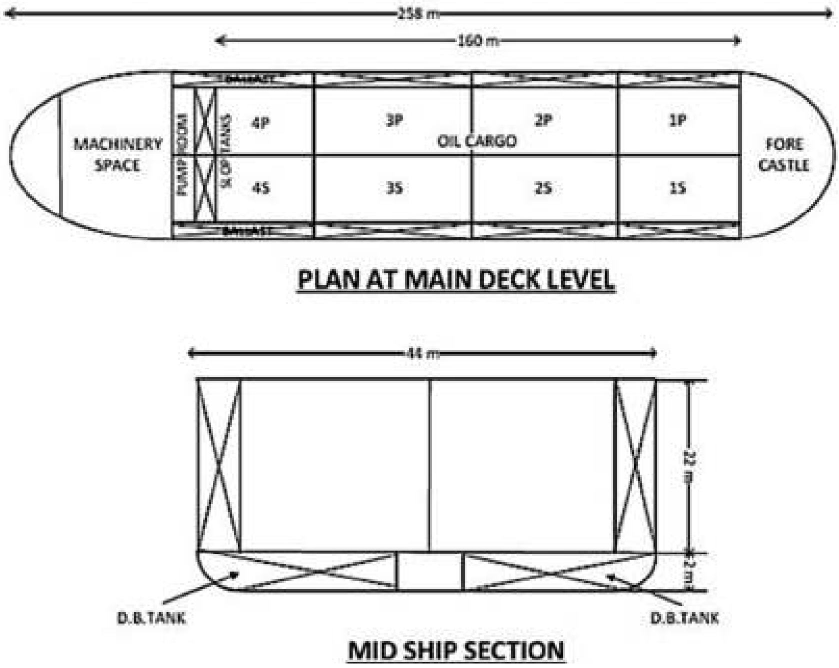


FIGURE 2.

## 3. TANKER MODEL MAIN DIMENSIONS AND DESCRIPTION

**LENGTH (L) = 250m, LOA = 258m, BREADTH (B) =44m, DEPTH (D) =22m, DRAUGHT (d) =20m**

The Freeboard calculated using the freeboard formula is 3m. The plan view at main deck level and midship section is given in **Figure 2**.

The cargo is loaded in 8 tanks as 4 longitudinal x 2 transversal. All tanks are of same capacity and their dimensions are length 40m, breadth 20m and depth20m. The load water plane area is 7200m$^2$ as given in part1.

At full capacity of 98 percent (MARPOL requirement) the volume is 16000m$^3$ and with car goof 0, 9sp go the load is 112896 tons.

The tanker is double hulled with ballast loaded in the space between the inner and outer skins as well as the DB space. The DB space is transversely subdivided by a central duct keel at the bottom extending throughout the cargo space including the pump room. The ballast space is further divided transversely as per the cargo tanks arrangement, i.e., the transverse WT bulk heads of the cargo tanks also form the transverse bulkheads for the bulk heads at the sides.

The Fore peak and after peak tanks are also ballast tanks. The mean height and width of the DB tanks and side ballast tanks is 2m.

## 4. HYPOTHETICAL GROUNDING CASE WITH DAMAGE CALCULATIONS

Assuming that the loaded tanker is passing through the straits of Sumatra on her way to Australia, when due to an operational error in navigation, the tanker passes over a rocky shoal where the sea is shallow and is about 21 meters at low water and the vessel experiences squat with the amplitude of vertical vibration about. The speed of the ship was not reduced and is 15 knots.

The ship has grounded with no 3 starboard cargo tanks being pierced. The extent of the damage is in accordance with Reg 24.2 of MARPOL ANNEX 1 CH4 and has the following rough dimensions: longitudinal shear of 5m, transverse shear of 5m and vertical penetration into the inner bottom or bottom of tank plating. The inner bottom plating shear dimensions are similar to the outer bottom plating dimensions and both sheared portions are bent to allow oil leakage from the tank into the sea and entry of water into the tank. Let us verify if such an extensive damage is possible from the stated conditions.

Referring to the squatting effect in **Figure 3**, the relevant particulars is Displacement = $\Delta$, h = instantaneous vertical movement, $\rho$ = density of sea water and A= the water plane area which is constant for small vertical distances

The disturbing force= $\Delta$*instantaneous acceleration (1)

The controlling force=A*h* $\rho$*g Newton's (2)

Equating (1) and (2) we have

Instantaneous Acceleration/h = Instantaneous Acceleration / Instantaneous displacement

=A* $\rho$*g/$\Delta$ = a constant = $\rho^2$ (square of angular velocity)

Assuming effective amplitude of 1m caused both by the natural vertical vibration of the ship combined with the water pressure variation under the ship as a partial resonant condition.

The value for amplitude chosen may sound exaggerated but it is not so. To prove it is a modest value, the relevant

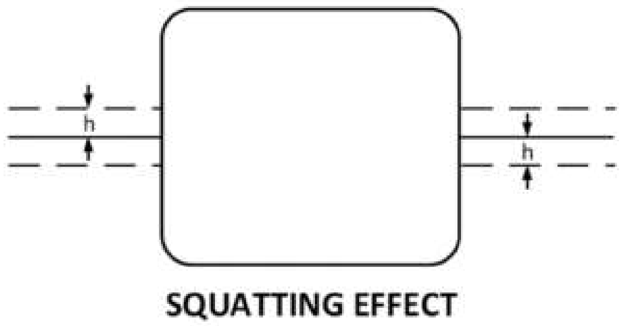


Figure 3.

findings of the enquiry of the luxury passenger ship Queen Elizabeth 2 in August 1992 are provided.

It was a cause of the 7 August 1992 grounding of the Queen Elizabeth 2 (QE2) off Cuttyhunk Island, near Martha›s Vineyard. The liner›s speed at the time was 24 knots (12 m/s) and the draft was 32 feet (9.8 m). The rock upon which the vessel grounded was an uncharted shoal later determined to be 34.5 feet (10.5 m), which should have given her room to spare, were it not for the «squat effect.» U.S. National Transportation Safety Board investigators found that the QE2›s officers had significantly underestimated the amount the increase in speed which would have increased the ship's squat. The officers allowed for 2 feet (0.61 m) of squat in their calculations, but the NTSB concluded that squat at that speed and depth would have been between 4.5 and 8 feet (1.4 and 2.4 m).

We have the total damage energy caused by the vibrating ship as Δ* 12 *7200*1025*9.81/Δ* ½ =36199 KJ.

**The damage energy utilised on the tanker for bottom plating:**

The outer bottom thickness is 33mm and inner bottom thickness is 28 mm as per the ships structural plans. Assuming an UTS value of 480 Newton's per $mm^2$, the energy utilised will be

1 For bottom plate damage:

(10*1000*33*480*33/1000)/1000 KJ

= 5227KJ

2 For inner bottom plate damage:

(10*1000*28*480*28/1000)/1000KJ =3763 KJ

Add 30 percent for bending both plates

= (5227+3763)1.3 = 11687 KJ.

The above damage calculations prove that the extent of damage is possible

## 5. RELEVANT REGULATIONS FROM MARPOL ANNEX1 CHAPTER 4

The probability $P_B$ of breaching a compartment from bottom damage shall be calculated as follows:

1. $P_B = P_{BL} P_{BT} P_{BV}$

$P_{BL} = 1 - P_{BF} - P_{BA}$ = Probability the damage will extend into the longitudinal zone bounded by $X_a$ and $X_f$

$P_{BT} = 1 - P_{BP} - P_{BS}$ = Probability the damage will extend into the transverse zone bounded by $Y_p$ and $Y_s$; and

$P_{BV} = 1 - P_{BZ}$ = Probability the damage will extend vertically above the boundar defined by z

2. $P_{Ba}$, $P_{Bf}$, $P_{Bp}$ $P_{Bs}$ and $P_{Bz}$ shall be determined by linear interpolation from the table of probabilities for bottom damage provided in paragraph 9.3 of this regulation where,

$P_{Ba}$ = the probability the damage will lie entirely aft of location $X_a$/ L;

$P_{Bf}$ = the probability the damage will lie entirely forward of location Xf/L;

$P_{Bp}$ = probability the damage will lie entirely to port of the tank;

$P_{Bs}$ = probability the damage will lie entirely to starboard the tank; and

$P_{Bz}$ = probability the damage will lie entirely below the tank.

Compartment boundaries $X_a$, $X_f$, $Y_p$, $Y_s$ and z shall be developed as follows:

$X_a$ and $X_f$ as defined in paragraph 8.2 of this regulation;

$Y_p$ = the transverse distance from the port-most point on the compartment located at or below the waterline $d_B$, to a vertical plane located $B_B$/2 to starboard of the ship's centre line;

$Y_s$ = the transverse distance from the starboard-most point on the compartment located at or below the waterline $d_B$, to a vertical plane located $B_B$/2 to starboard of the ship's centre line;

z = the minimum value of z over the length of the compartment, where, at any given longitudinal location, z is the vertical distance from the lower point of the bottom shell at that longitudinal location to the lower point of the compartment at that longitudinal location.

**Table 1.**

| 2.0 | Bottom damage: | For 0.3L from the Forward perpendicular Of the ship | Any other part of the ship. |
|---|---|---|---|
| 2.1 | Longitudinal extent($l_s$) | L/10 | L/10 or 5m, Whichever is less |
| 2.2 | Transverse extent($t_s$) | B/6 or 10m, Whichever is less, but not Less than 5m | 5m |
| 2.3 | Vertical extent from the baseline($v_s$) | B/15 or 6m, whichever is less. | |

3. Table of probabilities for bottom damage

$P_{Bz}$ shall be calculated as follows:

$P_{Bz} = (14.5 - 67\ z/D_S)\ (z/D_S)$ for $z/D_S = 0.1$.

$P_{Bz} = 0.78 + 1.1\ \{(z/D_S - 0.1)\}$ for $z/D_S > 0.1$

$P_{Bz}$ is not to be taken greater than 1.

4. The following assumptions shall be used when combining the oil outflow parameters:

a) The mean oil outflow shall be calculated independently for side damage and for bottom damage and then combined into a non-dimensional oil outflow parameter $O_M$, as follows:

$O_M = (0.4\ O_{MS} + 0.6\ O_{MB}) / C$

Where:

$O_{MS}$ = mean outflow for side damage, in $m^3$

$O_{MB}$ = mean outflow for bottom damage, in $m^3$

C = total oil fuel volume.

b) For bottom damage, independent calculations for mean outflow shall be done for 0 m and 2.5 m tide conditions, and then combined as follows:

Where:

$O_{MB} = 0.7\ O_{MB}\ (0) + 0.3\ O_{MB}\ (2.5)$

$O_{MB(0)}$ = mean outflow for 0 m tide condition, and

$O_{MB(2.5)}$ = mean outflow for minus 2.5 m tide condition, in $m^3$

c) The mean outflow for side damage $O_{MS}$ shall be calculated as follows:

where

i = represents each cargo tank under consideration;

n = total number of cargo tanks;

$P_{S\ (i)}$ = the probability of penetrating cargo tank i from side damage, calculated in accordance with paragraph 8.1 of this regulation;

$O_{S(i)}$ = the outflow, in $m^3$, from side damage to cargo tank i, which is assumed equal to the total volume in cargo tank i at 98% filling, unless it is proven through the application of the Guidelines referred to in the regulation 19.5 that any significant cargo volume will be retained; and

$C_3$ = 0.77 for the ships having two longitudinal bulkheads inside the cargo tanks, provided these bulkheads are continuous over the cargo block and $P_{s(i)}$ is developed in accordance with this Regulation; $C_3$ equals 1.0 for all other ships or when $p_{s(I)}$ is developed in accordance with paragraph 10 of this regulation.

**Table 2.**

| $X_a/L$ | PBa | | $X_f/L$ | PBf | | $Y_p/B_B$ | PBp | | $Y_s/B_B$ | PBs |
|---|---|---|---|---|---|---|---|---|---|---|
| 0,00 | 0,000 | | 0,00 | 0,969 | | 0,00 | 0,844 | | 0,00 | 0,000 |
| 0,05 | 0,002 | | 0,05 | 0,953 | | 0,05 | 0,794 | | 0,05 | 0,009 |
| 0,10 | 0,008 | | 0,10 | 0,936 | | 0,10 | 0,744 | | 0,10 | 0,032 |
| 0,15 | 0,017 | | 0,15 | 0,916 | | 0,15 | 0,694 | | 0,15 | 0,063 |
| 0,20 | 0,029 | | 0,20 | 0,894 | | 0,20 | 0,644 | | 0,20 | 0,097 |
| 0,25 | 0,042 | | 0,25 | 0,870 | | 0,25 | 0,594 | | 0,25 | 0,133 |
| 0,30 | 0,058 | | 0,30 | 0,842 | | 0,30 | 0,544 | | 0,30 | 0,171 |
| 0,35 | 0,076 | | 0,35 | 0,810 | | 0,35 | 0,494 | | 0,35 | 0,211 |
| 0,40 | 0,096 | | 0,40 | 0,775 | | 0,40 | 0,444 | | 0,40 | 0,253 |
| 0,45 | 0,119 | | 0,45 | 0,734 | | 0,45 | 0,394 | | 0,45 | 0,297 |
| 0,50 | 0,143 | | 0,50 | 0,687 | | 0,50 | 0,344 | | 0,50 | 0,344 |
| 0,55 | 0,171 | | 0,55 | 0,630 | | 0,55 | 0,297 | | 0,55 | 0,394 |
| 0,60 | 0,203 | | 0,60 | 0,563 | | **0,60** | **0,253** | | 0,60 | 0,444 |
| 0,65 | 0,242 | | 0,65 | 0,489 | | **0,65** | **0,211** | | 0,65 | 0,494 |
| 0,70 | 0,289 | | 0,70 | 0,413 | | 0,70 | 0,171 | | 0,70 | 0,544 |
| 0,75 | 0,344 | | 0,75 | 0,333 | | 0,75 | 0,133 | | 0,75 | 0,594 |
| 0,80 | 0,409 | | 0,80 | 0,252 | | 0,80 | 0,097 | | 0,80 | 0,644 |
| 0,85 | 0,482 | | 0,85 | 0,170 | | 0,85 | 0,063 | | 0,85 | 0,694 |
| 0,90 | 0,565 | | 0,90 | 0,089 | | 0,90 | 0,032 | | 0,90 | 0,744 |
| 0,95 | 0,658 | | 0,95 | 0,026 | | 0,95 | 0,009 | | 0,95 | 0,794 |
| 1,00 | 0,761 | | 1,00 | 0,000 | | 1,00 | 0,000 | | 1,00 | 0,844 |

The following assumptions shall be used when combining the oil outflow parameters:

1. The mean oil outflow shall be calculated independently for side damage and for bottom damage and then combined into the non-dimensional oil outflow parameter $O_M$, as follows:

   $O_M = (0.4O_{MS} + 0.6O_{MB})/C$

Where:

$O_{MS}$ = mean outflow for side damage, in $m^3$; and

$O_{MB}$ = mean outflow for bottom damage, in $m^3$.

2. For bottom damage, independent calculations for mean outflow shall be donefor0mandminus2.5mtide conditions, and then combined as follows:

   $O_{MB} = 0.7O_{MB}(0) + 0.3O_{MB}(2.5)$

   Where:

   $O_{MB}(0)$ = mean out flow for 0mtidecondition; and

   $O_{MB}(2.5)$ = mean outflow for minus 2.5 m tide condition, in $m^3$.

The cargo level after damage shall be calculated as follows:

$H_C = \{(d_S + t_C - Z_l)(P_S) - (1000P)/g\}/p_n$

Where:

$h_C$ = the height of the oil fuel surface above $Z_l$, in metres;

$t_C$ = the tidal change, in m. Reductions in tide shall be expressed as negative values;

$Z_l$ = the height of the lowest point in the cargo tank above the baseline, in m;

$P_S$ = density of seawater, to be taken as 1,025 kg/$m^3$; and,

$P_n$ = nominal density of the oil fuel, as defined in 4.4.

$P$ = if an inert gas system in fitted, the normal overpressure in kpa to be taken as not less than 5 kpa; if an inert gas system is not fitted, the overpressure may be taken as 0

$g$ = the acceleration of gravity, to be taken as 9.81 m/$s^2$

For cargo tanks bounded by the bottom shell unless proven otherwise, oil outflow $O_{B(i)}$ shall be taken not less than 1% of the total volume of cargo oil load in cargo tank i, to account for initial exchange losses and dynamic effects due to current and waves.

In the case of bottom damage, a portion from the outflow from a cargo tank may be captures by non-oil compartment. This effect is approximated by application of the facto $C_{DB(i)}$ for each tank, which shall be taken as follows

$C_{DB(i)}$ = 0.6 for cargo tanks bounded from below by non-oil compartments;

$C_{DB}$1.0for cargo tanks bounded by the tank bottom.

## 6. ACCIDENTAL OUTFLOW OF OIL

The vessel runs aground at high water when the depth of water is the loaded draft which is 20 m. immediately following the damage, the oil level in the concerned tank being higher than the level of sea water outside the ship, oil will flow out and water will enter into the damaged tank and the damaged ballast tank. The vessel is grounded on level keel without trim and heel. This is the assumption given in the relevant regulations in CH4.

The tank is over-pressurised to 5 Kpa by inert gas. This gas is occupied in the 2 percent empty space above oil level in the tank and when damage occurs this space does not allow the oil level to increase above the upper datum of the tank which 19.6m from bottom of tank. The equivalent 5 Kpa inert gas pressure is expressed as 5/9.81 m water column = 0.509 m.

Immediately on running aground and when the stated damage takes place, commencement of oil outflow happens and continues till maximum low water and the fall in tide is to be assumed 2.5 m as per the given regulations.

The final height of oil in the damaged tank is calculated as per the stated formula and is given as:

$$H = [(20-2.5--2) *1.025 - 5/9.81]/0.9 \qquad (1)$$

*Where (5/9.81) is 5 K pa inert gas over pressure converted to water column of 5/9.81 m = 0.509m

* 2.5 represents the range of tide in meters and 2 is the height of the DB ballast tank under the cargo tank.

Hence, $H = (15.5*1.025 - 0.509)/0.9 = 17.0872$ m

The corresponding accidental outflow at low water, which is -2.5 m is

$$(19.6-17.0872) *40 *20 = 2010 \text{ m}^3 \qquad (2)$$

The corresponding height of oil in damaged tank when grounding occurs at high water H= (18*1.025 – 0.509)/ 0.9 = 19.934 M.

The corresponding accidental outflow is:

$(19.934-19.6) *40*20 = 267$ $m^3$

Further outflow will not occur provided the following assumptions are accepted:

- The sea condition and weather both are calm.

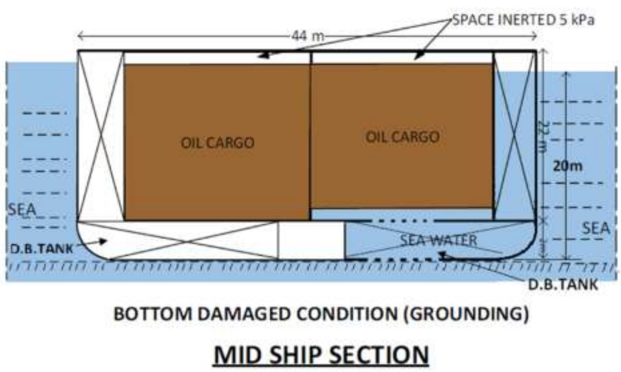


**Figure 4.**

- The oil is not miscible in sea water.
- There is no variation in the stated tidal range of 2.5 m

However, in reality, the above assumptions cannot prevail because the tidal range is never constant in any location and it depends on the net gravitational force on the sea by the sun and the moon according to the phase of the moon and its location with respect to the sun which gives rise to spring tides and neap tides with variable tidal range. The tides are also influenced by the prevailing winds and weather conditions.

One may ask why a statistical mean outflow calculation is prescribed under chapter 4 when the damage condition itself implies a noticeable quantity of oil flow and hence its calculation is not needed.

## 7. THE USE OF STATISTICAL ACCIDENTAL OUTFLOW DATA

To justify the need, the reasons are:

- These calculations are needed to ensure that the tank locations and sizes are in accordance with the limitations of accidental outflow of oil and accordingly these calculations are required to be done and given in the tanker damage stability book of every oil tanker
- These calculations are used by investigators of marine casualty to estimate the quantum of oil outflow from any tanker involved in a collision or grounding
- The calculations are useful in actuarial calculations to be used by the insurance companies and P&I club to determine the annual premiums to be charged for liability cover against oil spillage caused by accidents

## 8. CALCULATION OF ACCIDENTAL MEAN STATISTICAL OUTLOW OF OIL

Using the statistical tables for bottom damage values for the various parameter are selected and given in tabular format against a selected location for each tank.

In order to obtain a good value for the statistical mean accidental outflow, the locations have been chosen differently for each tank.

$P_{BZ}$ is common for all tanks and is given by 0.78

TANK 1P $P_B$ = (1-0.029—0.894) * (1—0.644-- 0.097) * (1—0.78)

= 0.077* 0.259* 0.22 = 0.00439

TANK 2P $P_B$ = (1-0.096-0.775) * (1—0.444-0.253) * (1—0.78)

= 0.129* 0.307*0.22 = 0.0087

TANK 3P $P_B$ = (1—0.203—0.563) *(1—0.253 – 0.444) *(1--.78)

= 0.239* 0.307*0.22 = .01614

**Table 3.**

| TANK | LOCATION | PBa | PBf | PBp | PBs |
|---|---|---|---|---|---|
| 1P | 0.2 | 0,029 | 0,894 | 0,644 | 0,097 |
| 2P | 0.4 | 0,096 | 0,775 | 0,444 | 0,253 |
| 3P | 0.6 | 0,203 | 0,563 | 0,253 | 0,444 |
| 4P | 0.8 | 0,409 | 0,252 | 0,097 | 0,644 |
| 1S | 0.1 | 0,008 | 0,936 | 0,744 | 0,032 |
| 2S | 0.3 | 0,058 | 0,842 | 0,544 | 0,171 |
| 3S | 0.5 | 0,143 | 0,687 | 0,344 | 0,344 |
| 4S | 0.7 | 0,289 | 0,413 | 0,171 | 0,544 |

TANK 4P $P_B$ = (1- 0.409-0.252) *(1-0.097—0.644) *(1-0.78)

= 0.339* 0.259 * 0.22 = .0193.

TANK 1S $P_B$ = (1--0.008—0.936) *(1—0.744—0.032) *(1-0.78)

= 0.056*0.224*0.22 = .00276

TANK 2S $P_B$ = (1—0.058—0.842) *(1—0.544—0.171) *(1-0.78))

=0.1* 0.285* 0.22 = .00627

TANK 3S $P_B$ = (1—0.143—0.687) * (1—0.344—0.344) * (1—0.78)

= 0.17*0.312*0.22 =.0116

TANK 4S $P_B$ = (1—0.289—0.413) *(1—0.171—0.544) * (1—0.78)

= 0.298* 0.285*0.22 = .0187

Sum of all the above probabilities is

0.00439 + .0087+0.0164 +0.0193 + 0.00276+ 0.00627 +0.0116 +.0187

= **0.08812**

Reg 23.7.4 The mean outflow for bottom damage $O_{MB}$ shall be calculated as follows:

$$O_{MB(0)} = \sum_{1}^{n} P_{B(i)} O_{B(i)} c_{DB(i)} \; (M^3)$$

Where,

i = represents each cargo tank under consideration;

n = total number of cargo tanks;

$P_{B(i)}$ = the probability of penetrating cargo tank i from bottom damage, calculated in accordance with paragraph 9.1 of this regulation;

$O_{B(i)}$ = the outflow, from cargo tank i, in m3, calculated in accordance with paragraph 7.3 of this regulation

$O_{MB(0)}$ = the outflow of bottom damage at 0 tide

$C_{DB\ (i)}$ = factor to account for oil capture as defined in paragraph 7.4 of this regulation n

$$O_{MB(2.5)} = \sum_{1}^{n} P_{B(i)} O_{B(i)} C_{DB(i)} \ (M^3)$$

Where,

i = represents each cargo tank under consideration;

n = total number of cargo tanks;

$P_{B\ (i)}$ = the probability of penetrating cargo tank i from bottom damage, calculated in accordance with paragraph 9.1 of this regulation;

$O_{B\ (i)}$ = the outflow, from cargo tank i, in m3, calculated in accordance with paragraph 7.3 of this regulation

$O_{MB(2.5)}$ = the outflow of bottom damage at -2.5m tide

$C_{DB\ (i)}$ = factor to account for oil capture as defined in paragraph 7.4 of this regulation n

In the case of bottom damage, the intensity of the impact as well as the profile and hardness of the ground can cause penetration into some tanks or even all tanks simultaneously during impact. Accordingly, the mean statistical accidental outflow is multiplied by the number of cargo tanks.

**The accidental mean statistical outflow is given by:**

**$[0.7O_{MB\ (2.5)} + 0.3O_{MB\ (0)}] * N*C_{DB(I)} * P_{BI} = (0.7*267 +0.3*2010) *8*0.08812 *0.6$**

**$= (186.9 + 603) *8*0.08812*0.6 = 334\ m^3$**

In conclusion, it may be stated that in the case of side damage (with the maximum possible side damage assumed due to the intensity of the collision), the entire contents of the tank may be considered to be lost to the sea. In addition, the collision (as a hit) is possible at only one tank location.

## Reference

Chapter 4 MARPOL ANNEX 1

## ABOUT THE AUTHOR

**A. K. Ramanujan** is an octogenarian marine engineer, passed out from DMET in 1955 . He has served in various capacities as surveyor, examiner of engineers and Engineering superintendent of shipping companies. Since 1989 he has taught in various training institutes including I.MAR.E MUMBAI. He holds an EXTRA FIRST CLASS CERTIFICATE OF COMPETENCY, issued by UK MOT.

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STUDENTS' SECTION

# RECYCLING - CHALLENGES AND EFFECTS IN SHIPPING INDUSTRY

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## ABSTRACT

Energy drives everything in the world and so the shipping industry. There are many innovative methods of producing energy but it is much appreciated if the energy could be consistently derived from the ship waste. The waste disposal is an arduous task in shipping industry and hence many researches are in place for effectively disposing the waste. According to the statutory bodies, India has huge source of industrial as well as urban organic waste. The shipping industry demands enormous energy like any other industry. Starting from small crafts to ultra large vessels, there exist huge quantity of waste on daily basis (aerobic as well as anaerobic). Therefore, there is a large potential of harvesting energy from these wastes and the problem of waste disposal as well as depletion of conventional energy sources can be effectively resolved simultaneously. This paper analyses the several methods of producing energy from waste. In addition, the present scenario of Waste-to-Energy (WTE) in our country and world is also deliberated.

**Keywords:** Waste disposal, energy harvest, energy demand, aerobic waste.

## 1. INTRODUCTION

Waste disposal is a major challenge being faced by the world today. Research is being undertaken the world over to find new and effective ways of handling and recycling waste. New methods of converting organic and inorganic waste into useful alternatives are also being developed. One of the best ways to overcome this problem of waste management is to adopt waste-to-energy (WTE) initiatives. This in turn addresses another pressing issue, that of finding alternative energy sources. Research has already found a number of ways of converting waste to energy, but the applications on the field, particularly in India, are very limited. There is huge untapped potential in the waste-to-energy sector and the maritime industry can be an eminent contributor in this.

### 1.1. Waste-To-Energy In India - Current Scenario

India is a large sub-continent with a population of nearly 1.38 billion, as of 2020 [1]. The country generates on an average 450 gm per capita per day of municipal solid waste (MSW) [2]. As of 2017, the gross generation was nearly 1,33,760 tonnes of MSW per day [3], out of which about 91,152 tonnes was collected and only 25, 884 tonnes was treated.

According to the Annual Report on Implementation of Solid Waste Management Rules for 2018-19, published by the Central Pollution Control Board, the MSW collection efficiency lies at 98.4% of generated waste [4]. The report, however, also mentions that most of the waste processing facilities in the majority of the States are not in working conditions. A huge portion of this collected waste is lying around in open dumpsites and landfills, unsegregated, posing environmental and health hazards. Not to mention, they have rendered large stretches of land barren and useless.

As part of India's WTE efforts, the first large scale MSW incinerator was built at Timarpur, New Delhi in 1987 [3]. It had a capacity to process 300 tonnes of waste per day and cost Rs. 250 million. This project, however, failed due to a number of reasons such as poor waste segregation, seasonal variations in waste composition, lack of appropriate technology and operational and maintenance issues.

After the Timarpur plant, 14 other WTE plants with a total capacity of 130 MW have been installed in the country but 7 of these have already become non-functional, that is a loss of nearly 66 MW. Currently only 7 plants remain functional with a combined capacity of approximately 69.2 MW [8]. Most of these projects have faced criticism and resistance from residents and environmentalists for causing pollution and posing health risks.

As of 2018, India had a total capacity of 9.54 GW of grid-connected bio-power installed, which includes 8.73 GW from bagasse cogeneration, 0.68 GW from non-bagasse cogeneration and 0.13 GW from waste to energy [6]. Another 84.3 MW of WTE is said to be under construction [8].

Though the amount of energy being generated from waste in India is very nominal, currently the future of waste-to-energy looks promising for the country. The Ministry of New and Renewable Energy has shown notable interest in the field of waste-to-energy and bio-energy and has revised the guidelines of its waste-to-energy programme to create a more conducive environment for sustaining the WTE plants. Under this revised scheme, the government aims to provide financial assistance in the form of capital subsidy and Grants-in-Aid for installations of a number of waste-to-energy and bio-energy plants as well as for expanding capacity of existing plants [7].

However, some of the major challenges in the generation of energy from waste in India still remain. The first major concern in this regard is the composition of waste. In countries like Sweden and Norway where WTE is a major source of power generation today, the quality of the waste generated is very different from what we find in India.

While the calorific value of the waste generated in these countries ranges from 1,900-3800 kcal/kg, the waste in India has a calorific value of only about 1,411–2,150 kcal/kg [8]. This makes it unsuitable for burning and even when burnt, the energy obtained is very low. This is mostly because the majority of the waste generated in India is organic waste having very high moisture content. Secondly, WTE is more expensive as compared to conventional sources of power despite the subsidies offered by the government. As compared to Rs. 3 to 4 per kWh for coal or solar based plants, electricity generated from WTE plants costs users approximately Rs. 7 per kWh [8].

## 2. INDIA'S POTENTIAL IN THE WASTE-TO-ENERGY SECTOR

The MSW generated in urban areas of India has potential to produce approximately 500 MW of power, which is expected to increase to 1,075 MW by 2031 and to nearly 2,780 MW by 2050 [2]. However, to be able to reach full potential, the authorities have to enforce stricter measures to ensure that the ongoing and future projects are able to sustain.

According to the Solid Waste Management Rules 2016 [7], only segregated, non-recyclable, high calorific waste must be sent to WTE plants. This means that of the total MSW generated in urban areas, only 30,000 tonnes per day can be sent to the WTE plants, which have a gross capacity of 37,000 tonnes per day [8]. Moreover, stringent emission control rules have to be in place to monitor the operations of WTE plants so that environmental pollution from these plants can be kept check.

### 2.1 Waste-to-Energy technologies

#### *2.1.1 Incineration*

Incineration is the most common thermal treatment based WTE technology in use currently. In the incineration process, the waste is fed into the incinerator kiln where it undergoes combustion at high temperatures, >850℃, with sufficient supply of air [9]. The waste is allowed to burn completely to prevent the formation of dioxins or carbon monoxide. The heat of combustion, in the form of flue gases, is used for energy recovery for generating steam in boilers. This high temperature steam can then be used for space heating, electricity generation and other applications. Incineration is best suited for high calorific value wastes [10].

However, incineration does not work well with waste having high moisture content. Also particulate emissions and toxic metal content in the bottom ash, which may be later sent to landfills, are some major concerns with this method.

#### *2.1.2 Gasification*

Another common method for thermal treatment of solid waste is gasification. It is the process of converting carbonaceous substances into carbon dioxide, carbon monoxide and some amount of hydrogen. This is also a high temperature process, but the waste is not allowed to undergo combustion in this method. The temperature range in gasification is generally between 760°C to 1300°C [11].

The gas produced by this process is known as syngas and can be used as fuel for burning. This fuel is also used for generation of electricity and production of steam among multiple other uses. Gasification is better for controlling environmental pollution as compared to incineration as particulate emission here is much less. However, the amount of energy recovered depends largely on the type of waste used.

#### *2.1.3 Pyrolysis*

Pyrolysis is another high temperature procedure in which carbon-based waste matter is made to undergo thermal decomposition in an oxygen deficient, inert environment. The pyrolysis of biomass leads to the production of pyrolysis vapours, which can be condensed into biofuel and biochar.

#### 2.1.4 Landfill gas recovery

Landfill gas recovery is a thermo-chemical process of waste treatment. Landfill gas is generated as a result of thermal, chemical and microbial processes taking place on the waste matter. This gas is produced as a result of anaerobic decomposition of organic waste in landfills. The gas is composed mainly of methane and carbon dioxide along with small quantities of other organic compounds.

In the initial stages of waste deposited in a landfill, aerobic decomposition takes place which generates small amounts of methane. Over time, anaerobic conditions are created and methane-producing bacteria begin to decompose the organic matter to generate large amounts of methane and CO2. This gas can be collected and treated to be used for various applications, as cooking gas, vehicle fuel and even in power generation.

#### 2.1.5 Anaerobic digestion

Anaerobic digestion is a process similar to landfill gas generation. Here the organic content in waste is allowed to be broken down by microorganisms in the absence of oxygen, producing biogas that can be used in multiple applications. The biggest advantage of this method is that it can be done both on a small scale as well as on a large scale.

## 3. RENEWABLE ENERGY OPTIONS AND WTE ON BOARD SHIPS

Shipping, as an energy intensive sector, is certainly in need of more renewable energy options. Renewable energy application on ships can provide sustainable solutions for hybrid, auxiliary or even primary propulsion as well as on board energy requirements.

The shipping industry is already taking up new innovative measures to incorporate renewable energy in the existing fleet and into new shipbuilding and design globally.

The current focus on renewable energy measures in shipping is on a few areas such as wind and solar energy based design modifications. Attempts are being made to tap wind energy by means of specially designed soft-sails, fixed sails and kite sails [12].

Wind turbines have also been tested but there have been no successful prototypes yet. Solar photovoltaic cells, hybrid with other energy sources, are being used on small ships. Biofuels are also finding their way into shipping, with the Meri cargo ship claiming to be the first of its size to run on 100% biofuel.

However, waste-to-energy is still a less explored technology in shipping. Large cruise ships produce enormous amounts of waste. This itself presents a huge potential for WTE as a means of producing renewable energy on board ships. There are very few manufacturers who are venturing into the WTE sector to create energy from waste generated on ships.

Scanship, a Norwegian waste management systems manufacturer for ships, has developed a system that converts carbon-based waste generated on ships into biofuels by microwave-assisted pyrolysis. The system can convert waste material like food, paper, plastic and oils into flammable gas, bio-oil and charcoal [13].

Another Norwegian manufacturer, TECO TECH, has developed a waste management system that uses gasification of waste to achieve heat recovery through proprietary sodium heat pipe economizers [14].

These are some of the pioneers in the application of WTE systems in shipping. Yet waste management on ships can improve by leaps and bounds with the use of WTE. Currently, most of the food waste from ships is discharged at sea, where permitted under MARPOL Annex V, plastics are not being incinerated, sewage is being discharged to the sea under MARPOL Annex V [15].

Processes like gasification, pyrolysis and incineration technologies have already been implemented on board ships. With further advancements in these systems through research and development the shipping industry could become a self-sustaining industry, in terms of energy generation and usage.

## CONCLUSION

WTE is still an emerging sector in India and so far the country hasn't seen much success in this field. However, with new measures being taken and increased interest of the government and MNRE in waste management and WTE, major developments can be expected in the near future.

In the shipping industry as well, WTE is more or less a novel concept.

Countries like Norway, that are successfully running WTE plants on land, are gradually transferring the technology on board and leading the way for others. With more measures like these, the waste let out into the sea from ships can be drastically reduced, creating a more balanced ecosystem for all life forms.

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BRANCH NEWS

KOLKATA BRANCH

# Web Session on Class Surveyor

A web session on the topic **'Life of a Surveyor at Classification Society'** was hosted on **18 December 2021** by IME(I) Kolkata Branch. **Dr. Suman Kumar Jha, Vice President & Head (HR), Indian Register of Shipping**, delivered the lecture on the topic.

Shri. Gautam Sen, Chairman, IME(I) Kolkata Branch, welcomed the speaker and the attendees. He expressed the hope that everyone attending the webinar would be benefited by the presentation, and that young marine engineers would be motivated to consider a career in classification societies.

Shri. Amit Bhatnagar, Vice President, IME(I), gave a brief introduction of the speaker.

Dr. Jha initially explained what prospective employees looked for while looking for or joining a new job. He talked about motivation and job satisfaction. He elaborated on the Job characteristics model by Hackman and Oldham and the Career Anchors Model by Edgar Schein.

Dr. Jha then went on to state that the motivating factors for a classification society job were many, and that the surveyor kept learning new things every day. The job of a classification surveyor was both knowledge and service oriented, which aspect he opined was rare. He said marine engineers working as class surveyors, apart from the scope of rising within the organisation, had the opportunity to work with IACS and / or IMO.

In his concluding remarks, Dr. Jha commented that a class surveyor's job offered a unique value proposition to a marine engineer looking for a job on shore.

The lecture was followed by a lively question-answer session.

Shri. Swapan Kumar Saha, GC Member, Kolkata Branch, gave a vote of thanks to conclude the session.

MUMBAI BRANCH

# WEBINAR ON OUTCOME OF IMO MEPC 77

## CONDUCTED BY TECHNICAL SUB-COMMITTEE IME(I), MUMBAI BRANCH

An event on the outcome of **"MEPC 77"** was held on 22nd December 2021 from 16:00 hrs. to 18:00 hrs. on a web platform in association with Director General of Shipping, Govt. of India. The objective was to discuss the outcome of 77th session of the IMOs Marine Environmental Protection Committee, which was held from 22nd to 26th November 2021. The webinar was attended by over 200 participants.

**Mr. Sunil Kumar, Head - Technical Sub-Committee, IME(I), Mumbai Branch** gave the opening remarks of the event. He offered gratitude to DGS officials, Govt. of India for their wholehearted support in conduct of this event. He further invited **Mr. A K Gupta, Chairman, IME(I) Mumbai Branch & Ex CMD SCI** for giving the welcome address.

**Mr. Gupta,** welcomed **Chief Guest, Mr. S. Barik, Chief Surveyor to Govt. of India** and **Mr. Ajith Kumar Sukumaran, Principal Officer of MMD, Chennai** and also the panelists for participating and contributing in this event.

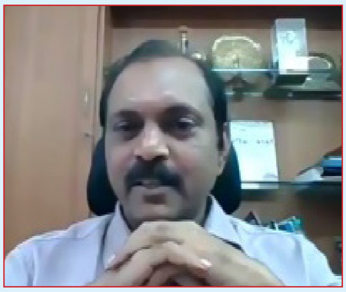
**Chief Guest, Mr. Barik** congratulated all the Indian Delegates for successfully raising all the issues at **MEPC 77.** He mentioned that today's discussion will be of great significance for the maritime industry and without the contribution of each stakeholder the global issue of climate change cannot be addressed. He further invited members of IME(I) to come forward and submit papers on relevant topics for submission to IMO and also announced that top 3 papers out of the submissions will be suitably awarded.

**Mr. S. Barik** *(Chief Guest)*

Mr. Kumar invited **Mr. David Birwadkar, Vice Chairman IME(I) Mumbai Branch** to introduce the moderator of the event **Mr. S M Rai, Member, Technical Sub-Committee IME(I) Mumbai Branch** and invited him to continue with the proceedings with panelists.

Mr. Rai first invited **Leader of Delegation Mr. Sukumaran** highlighted the fundamental aspects on which Indian delegates were focusing at IMO. He further gave a brief framework and said that the panelists will continue with the discussions.

**Mr. Vikrant Rai, E&SS, DG Shipping** gave a general idea of the formation and functioning of shadow committee. He emphasised the need of more and more people from industry to participate in activities related to MEPC. He further mentioned about future strategies for GHG reduction that will be proposed in next MEPC meeting.



**Mr. Sukumaran** *(Leader of Delegation)*

**Mr. P. K. Mishra (Head-Operations, IRS)** spoke on Energy Efficiency Existing Ship Index (EEXI) and outcome of COP 26 meeting in Glasgow, UK.

**Mr. A. Srinivasa Prasad (E&SS, DGS)** mentioned about discussion held at MEPC on GHG9 and GHG10. He also spoke on use of low carbon fuel towards control of GHG emissions.

**Mr. CPK Kashyap (Executive Director – Operations, Sanmar Shipping)** highlighted the outcome of MEPC on Carbon Intensity Index (CII). He also

mentioned about required improvements in SEEMP (Ship Energy Efficiency Management Plan) towards meeting CII requirements.

**Mr. Mudit Mehrotra (AVP-Technical, GESCO)** enlightened the audience on the difference between Net Zero CO2 emissions, Net Zero Emissions and Zero emissions.

**M. B. Prasad (GM-Training, Ambuja Cements)** spoke on Biofuel/ alternative fuel and their availability in the market.

**Mr. Mahesh Subramanian (Manager – Energy Efficiency, AEMS)** shared his views on Ballast Water Management System and the challenges being faced by the industry on the same.

Subsequently, questions from the audience based on the panel discussion were addressed. It was heartening to note many thought provoking questions that the discussion had generated among the audience.

After the panel discussion and Q&A session, Mr. Sukumaran**,** added further insights and his views on the deliberated agenda, while giving the concluding remarks.

Towards the end of session, **Mr. Sanjeev Mehra, Hon. Secy, IME(I) Mumbai Branch** requested Mr. Gupta to present a memento to the Chief Guest Mr. Barik. Then, Mr. Barik presented the mementos to all the panelists as a token of appreciation on behalf of IME(I).

Lastly, **Mr. T S Girish, Member, Technical Sub-Committee IME(I) Mumbai Branch** proposed the Vote of Thanks**.**

The webinar was concluded with the recitation of the National Anthem.

# IN THE WAKE

**Rajoo Balaji**

## Corona Chronicles

(With the Omicron (Oh my God) threat, these bullets can be a reminder of the first-week of December 2021 resolutions at IMO).

- Seafarer to be treated as a 'key worker' (been hearing it often)
- Industry recommended protocols while considering seafarers
- Priority for seafarers (jab the ship-Joiners first)
- Exempt seafarers from C-19 requirements of proof of vaccination for entry; allow free travel between countries
- Provide medical care to seafarers on priority (evacuation and attention)

Wish these evaporate as a vanishing wish list as the year rolls on.

## Shipping Matters

In the MEPC tambola, it is a pair of walking sticks… seven and seven (MEPC 77)!

Some talks and thought from the meet (some ideas already in circulation):

Maritime Research Fund target of US$5 billion to be milked from contributions at US$2/ton of oil consumed: This idea is getting traction.

Resolution + rest: Use of distillates in the Arctic; Guidelines for EG cleaning; BWM discussions (when will this end?)

*Background brief: Dates to remember:*

Amendments to MARPOL (expected to be in force): 1 November 2022

Requirements for EEXI Certification kicks in: 1 January 2023

Terms entering Ship Operations vocabulary: Engine Power Limitation (ELP); Shaft Power Limitation (SHAPOLI) [EEDI and EEXI already in the lexicon].

[Drone Inspection images downloaded from dnvgl.com]

This is expected to have an impact on the Charter Party Clause. Those who are curious and under FOMO, can check out the link below:

https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/2021_eexi_transition_clause

## Tech Talks:

Can you hear them? Can you see them?

The drones have been buzzing like genetically modified locusts and now are to become regular in the ship's tanks and inaccessible sections (enclosed spaces). These will fly on their own and will use the brain of AI based computers.

Food for the computers?

Hyperspectral (Imaging + Data).

What is that?

Inputs of different spectra (visible light to infra and ultra-frequencies) will be captured and analysed to assess the paint condition. Epoxies, polyurethanes... bare steel... can be checked swiftly and safely (and economically?).

What else? Check for cracks, corrosion, do thickness measurements.

Check out the DNV short video clip on the remote controlled drone inside the tank and doing the tricks.

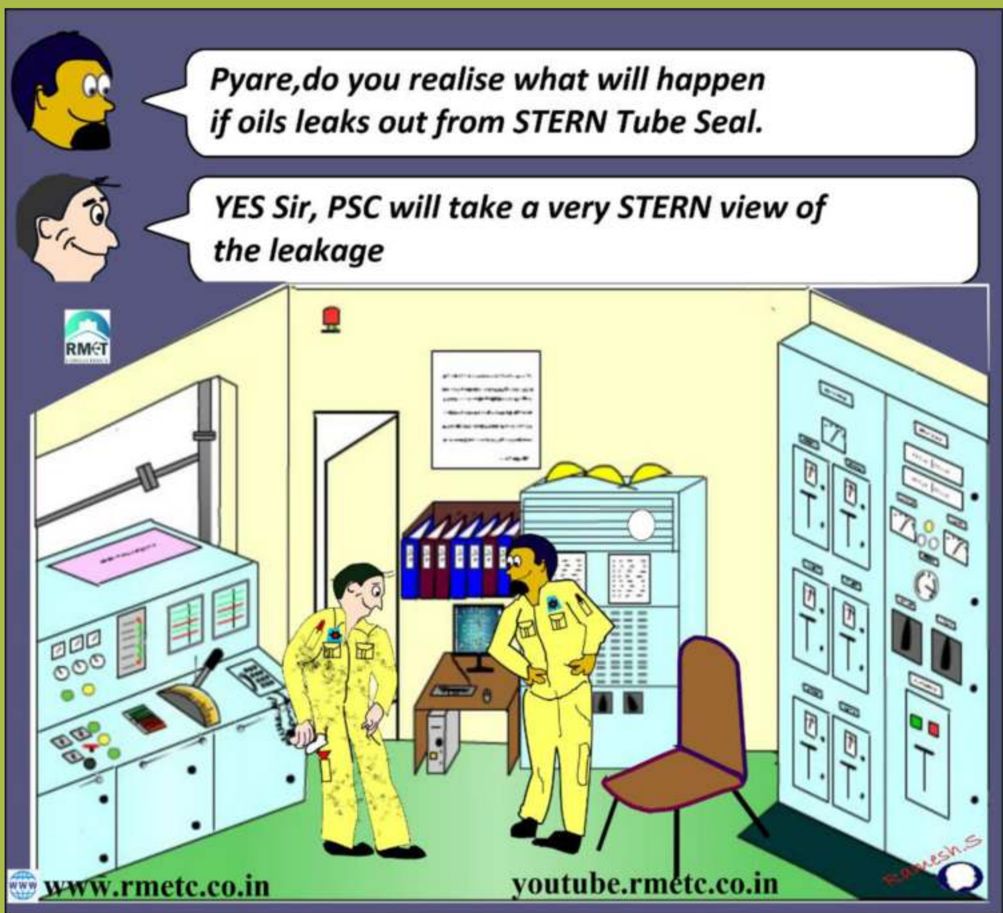
## About January

January has some very inspiring days...

Just a couple of samples: Jan 1: Global Family day; Jan 12: National Youth Day.

Check out the other days and wish well: Indian Army Day (recall and meditate a moment for the Coonoor chopper crash victims); National Girl Child Day (wish the world become safer for all children); National Tourism Day (wish for a tension-free travel this year).

## THE END VIEW

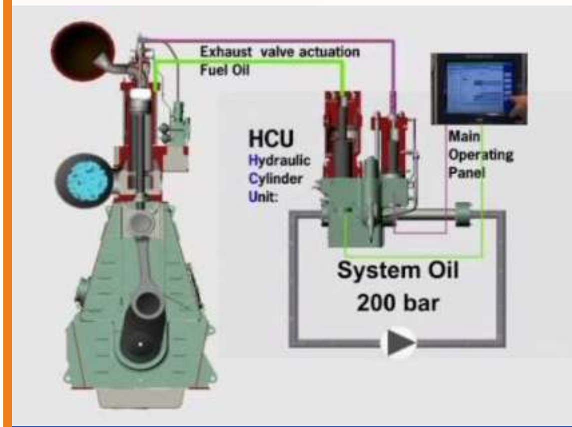



*Idea, Words & Drawing:* **Ramesh Subramanian**

# MASSA Maritime Academy, Chennai

# The Institute of Marine Engineers (India)

# Electronic Engine Familiarisation Course (ME-Type Engine) Delivered online with Cloud access to ME Engine Simulator




This 3 days course is designed for all Ship's Engineer Officers and Electro Technical Officers responsible for the operation of ME Engine. This course consists of technical lessons and practical instructions on the design, principles, operating procedures and maintenance activities for the safe, efficient and optimal performance of the engine system.

## Course Aims and Objectives:

**The course aims to provide practical understanding of the principles, design, operation and maintenance of the ME Engine System, enabling participants to safely and efficiently operate the engine and perform fault-finding in the control system.**

## Coverage / Program Focus:

### This course deals with the following training areas:

- **Introduction to ME Engine**
- **Hydraulic Power Supply (HPS)**
- **Hydraulic Cylinder Unit (HCU)**
- **Engine Control System (ECS)**
- **Main Operating Panel (MOP)**
- **Standard Operation**

## Entry Requirement / Target Group:

**Entry is open to all Ship's Engineers and Electro Technical Officers with basic knowledge of diesel engines.**

**DATE & TIMING** : 18th to 20th **Jan.'22,** 15th to17th **Feb.'22,** 15th to17th **Mar.'22.**
**8:00 am - 4:00 pm IST**

**VENUE** : Web Platform / Zoom**. APPLICATION LINK:** https://forms.gle/e4As7kCucR5xoJBm9

**REGISTRATION & PAYMENT** : Rs. 15,000/- /- per participant – inclusive of taxes.
For IME(I) Members 13,500/- per participant - inclusive of taxes.
Payment to be made to: https://imare.in/buy-online.aspx
(Under Category - Value added Courses) *10% discount available for IME(I) members*

**FOR MORE INFORMATION** : **@IME(I)** - **email:** training@imare.in, Ms. Anukampa
**(M)**. 9819325273, **(T)** 022 27701664 / 27711663 / 2771 1664.
**@ MASSA Maritime Academy Chennai** - **email:** mmachennai@massa.in.net
Ms. Saraswathi, **(T)** 8807025336 / 7200055336 .

*After registration and payment, please email the details of the receipt to:* ***training@imare.in***

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