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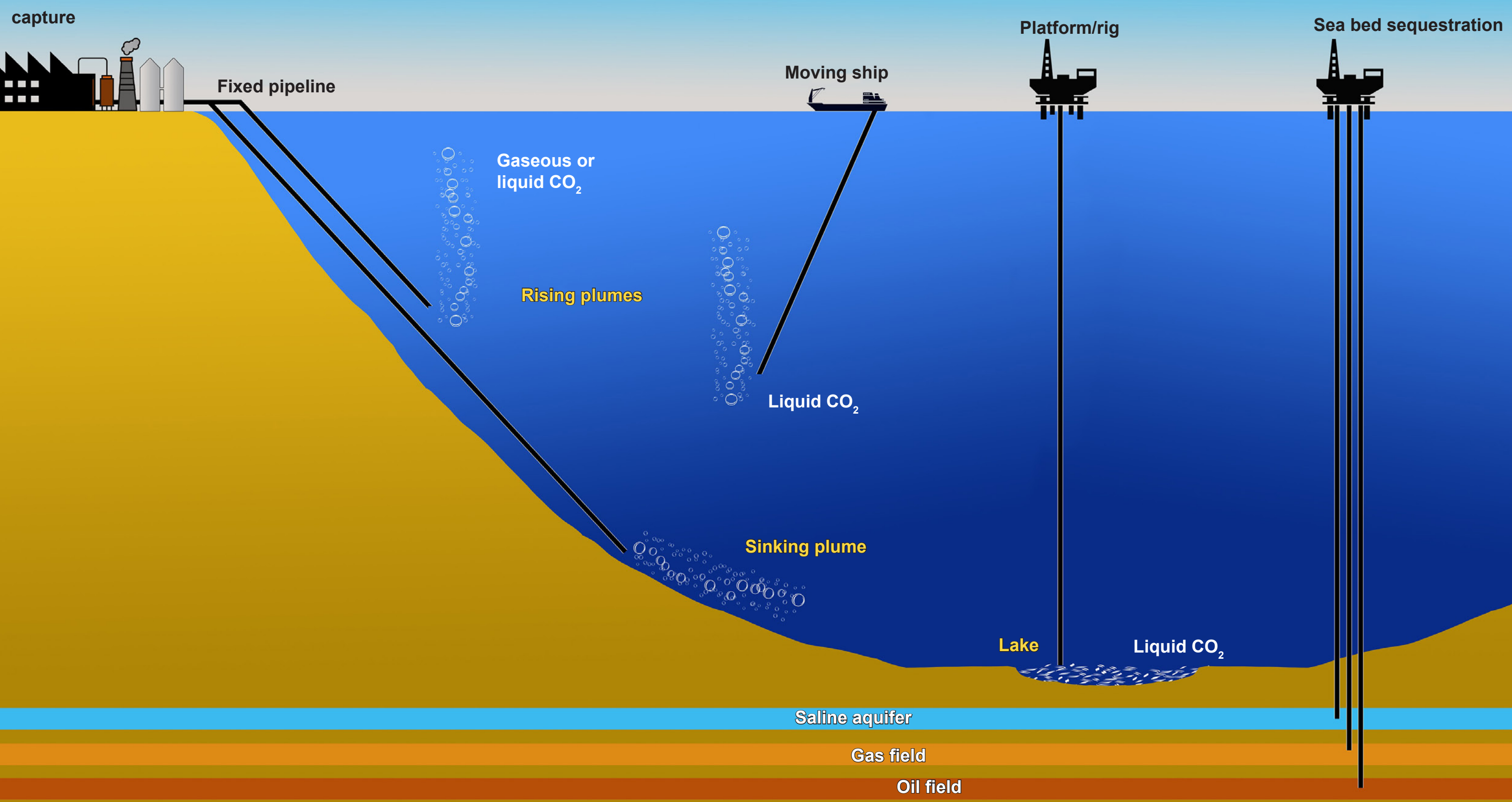

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2024

Wishing you health, happiness and prosperity in the new year.

Happy New Year

EDITORIAL

The eight laws of learning are explanation, demonstration, imitation, repetition, repetition, repetition, repetition, repetition.
- John Wooden (US Basketball Guru)

The COP28 passed by and some called it a Copy Paste sitting. Well, almost. It could have been a Conference of Parroting but for some moves. A quick look at select outcomes could explain better. The Loss and Damage Fund got operationalised garnering about US$790 million (a billion was expected; and big emitters would not loosen their purse strings). With questions on decision making and flexibility of the fund, one significant idea that was floated was that the fund must extend grants (not loans) to countries affected by disasters caused by climate change.

Another monetary vertical which fell short (in spite of US$3.5 billion +) was the Green Climate Fund. The assurance of extending funding to vulnerable areas for mitigation measures, public-private sectoral partnerships should augur well. Withstanding the keyword droppings of sustainable agriculture, renewable energy, this financing under the Global Stocktake (GST) is expected to bring benefits. The GST lacked strength in that allowing business-as-usual activities to continue.

India at COP: Did not sign the Climate-Health commitment/declaration, because Indian healthcare is at growth phase and it cannot afford to curtail the GHG emissions (which would entail reducing the gases used for cooling in the healthcare industries). India also was not part of the Global Methane Pledge/Climate and Clean Air Coalition. To be a signatory, it would involve reducing methane emissions from agricultural activities etc. India's methane comes from rice farming/cultivation and livestock and a commitment to this could affect the livelihood of small farmers. Among the firsts in the Conference, two are worth a mention: Climate & Health declaration, nature-based solutions for biodiversity conservation and climate and of course the transition from fossil fuels. And here also, India has an issue with its reliance on coal. While the climate clock ticks away, the COPs add to the repetitions of harm and mitigation. These improve our learning of course, but it might get a bit too late for the lessons to complete our understanding for necessary actions.

In this issue...

In the COP28, the GST discussions broached upon CCS (carbon Capture and Storage), the technologies requiring proof of concepts and applications. We feature a two-part series on this. There will be more to mull over in the next instance.

The Part A of the CO_2 Capture and Sequestration penning by Dr. Veda has some revelatory highlights. Making a case for this innovative measure, Dr. Veda explains methods and means. The interesting takeaways include the India Energy Security Scenario (IESS) 2047, which is an energy scenario modelling and simulation software developed by the National Institution for Transforming India (NITI), which could help the researchers. CO_2 sequestration methods and potential for capture, particularly of the oceans, are discussed with data.

Next, Karan Doshi analyses an interesting fire safety aspect on board container ships. The Author takes us through the discussion with discernible data on the classification of container ships and the fire accidents. Predictably, cargo holds and deck appear to be locales. An interesting observation is on the requirement of external help to combat the fires. The sections on reasons for fires, CO_2 systems, difficulty in locating and fighting the fires and limitations will be interesting for practicing marine engineers. This is a comprehensive container fire discussion and an easily understandable one.

We move on to another interesting read on plan approval process and related issues for new vessel builds. Narayana Prakash brings out the processes of plan approvals and the complexity of specifications in simple terms from an end user's perspective. He presents the case in a conversational tone with judgemental statements which will connect well with the Superintendents and sailing engineers. Whereas the moot point being the consideration of 3D modelling at approval stages also, the issues raised makes the article thought provoking and debatable as well.

Elstan Fernandez in the Competency Corner, continues to inject practical value for on board maintenance and competency examinations. The picks from the MER Archives (Jan 1984) include a few instrumentation problems on board which many could relate with. The Postbag also has good thought picking discussions on dry running of EGBs, thrusters and electrostatic hazards. Sanjiv shifts to lubrication of gears under Lube matters #30.

2024 comes in with the promise of exciting times and a redolence of the viral, pandemic times. Let us hope the variant vanishes. Meanwhile, here is the first issue for the year.

Dr Rajoo Balaji
Honorary Editor
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Happy New Year 2024

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Administration Office
IMEI House
Plot No. 94, Sector - 19, Nerul,
Navi Mumbai 400 706.
Tel. : +91 22 2770 16 64
Fax : +91 22 2771 16 63
E-mail : editormer@imare.in
Website : https://imare.in/

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In This Issue

ARTICLES

COLUMNS

Cover Credits (Design & Pictures): **Dr. N. Vedachalam**

SETTING SAIL INTO ACADEMIC EMINENCE!

Celebrating academic achievement!

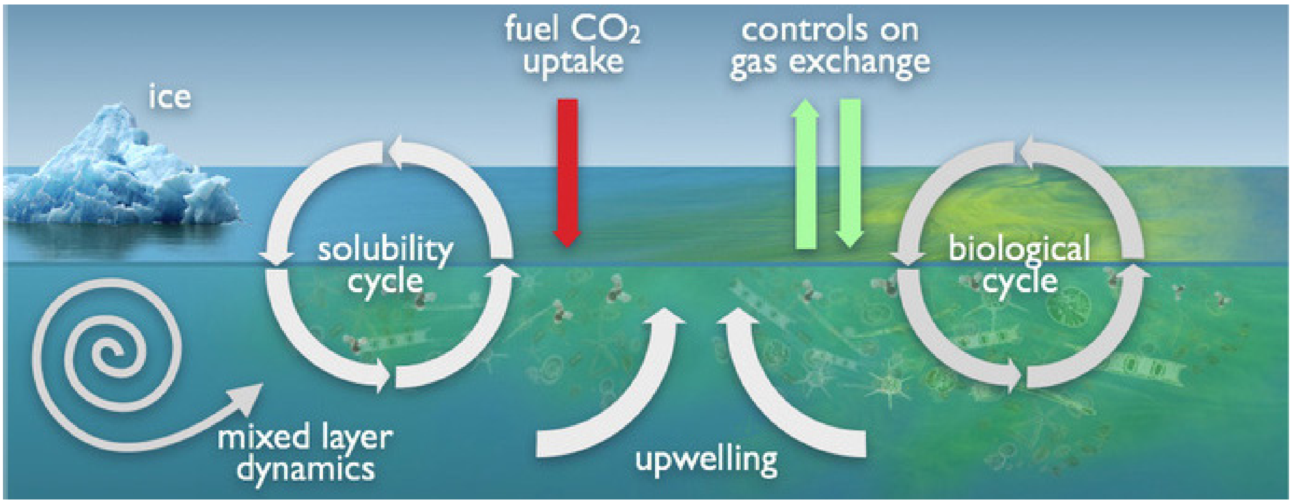
Mr. Sanjeev Vakil, CEO of the HIMT Group of Institutes, was conferred a PhD by the esteemed Indian Maritime University (IMU) on October 27, 2023. Her Excellency, the Honorable President of India, Smt. Droupadi Murmu was the Chief guest for the graduation ceremony.

The event was graced by a host of distinguished guests, including Shri Sarbananda Sonowal, Union Minister for Ports, Shipping, and Waterways, and AYUSH, Shri. R.N. Ravi, the Hon'ble Governor of Tamil Nadu, Shri. Shripad Naik, the Hon'ble Union Minister of State for Ports, Shipping and Waterways, and Tourism, and Dr. K Ponmudy, the Hon'ble Minister for Higher Education, Government of Tamil Nadu.

Dr. Malini V. Shankar, Vice Chancellor of IMU, and Dr. Rajoo Balaji, the Pro Vice Chancellor of IMU presided over the ceremony, and many eminent personalities from the maritime industry witnessed such once in lifetime graduation ceremony, where in President of India was the chief guest.

Over a six-year journey marked by unwavering commitment, Mr. Sanjeev Vakil has not only steered HIMT to new heights but has also paralleled this with a scholarly pursuit that culminated in an outstanding academic feat. His seminal research titled "Maritime Education and Training of the Past, the Present, and for the Autonomous Ships of the Future", exemplifies an exceptional fusion of visionary leadership and scholarly innovation. This pivotal achievement underscores a voyage of growth for HIMT under his guidance, setting a benchmark in both educational excellence and professional maritime leadership.

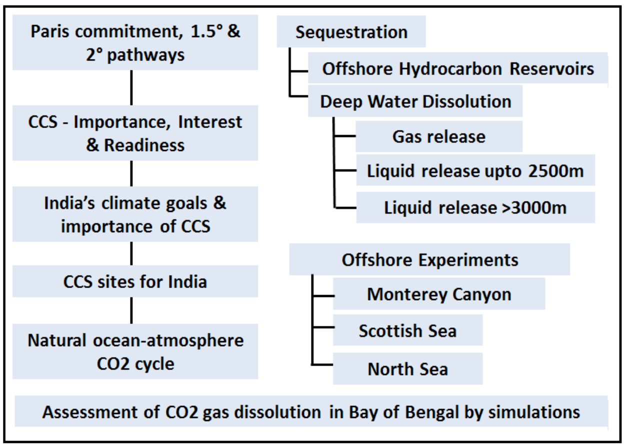
Importance of Ocean CO_2 Sequestration in India's Climate Goals and Assessment of CO_2 Gas Dissolution in the Bay of Bengal-Part A



N. Vedachalam

Abstract

Clean, sustainable, cost-effective and reliable energy supply is essential to meet the social, economic and environmental targets. Carbon Capture and Sequestration (CCS) technologies provides a near-term pathway to rapidly reduce the impacts of existing emissions-intensive infrastructure/processes, while zero-carbon alternative solutions mature. The article discusses the global developments in CCS, its importance in the Indian energy sector, emerging scientific and technological trends in ocean CO_2 sequestration and the details on the outcome of the key offshore CO_2 release experiments conducted hitherto. The gaseous CO_2 dissolution pattern when released at 1000m water depths in the Bay of Bengal is presented through numerical modelling and simulations. The details presented indicates the opportunities for CCS in India, need for carrying out ocean location- specific CO_2 release experiments and environmental impact assessment in support of national legislation and public acceptance of CCS.



Introduction

Anthropogenic climate change due to an increase in greenhouse gases (GHG) in the atmosphere is a phenomenon, capable of affecting life and planet ecology. Under the business-as-usual (BAU) pathway, the global cumulative carbon dioxide (CO_2) emissions are expected to reach an alarming ~7.6 trillion tons by the end of the century. Understanding its importance and based on the foundations of the United Nations Framework Convention for Climate Change (UNFCC) under the Kyoto protocol, the Copenhagen and the Cancun agreements, developed countries have agreed to mobilise US$100 billion annually to assist developing countries in reducing emissions and adapting to climate change. The Paris convention has set countries' minimum obligations, increased transparency and accountability that hold respective governments accountable for their commitments. The UN Climate Change Conference in Glasgow (COP26) held in 2021 has brought in new building blocks to advance implementation of the Paris Agreement through actions that can get the world on a more sustainable and low-carbon pathway by means of reducing cost of low-emission technology and promoting an economy-wide green transition.

Achieving the ambitious Paris and COP26 climate goals require unprecedented clean transition in all sectors by means of sustained innovation and investment. By determined implementation of climate pledges and policies it is possible to could cut down global GHG emissions by ~30% by 2030, while 1.5ºC and 2ºC pathways would require extremely ambitious efforts and quicker emission cuts, in addition to the determined mitigation efforts **(Figure 1)** [1]. Even though the Paris agreement has set essential targets, the ability of the UNFCC bodies, such as the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) to help participating countries achieve the National Determined Contributions (NDC) by mobilising essential climate finance is challenging, which was voiced by India during CoP26 [2]. The recent pandemic and geo-political disturbances have set in various uncertainties in sustained funding required to achieve the targeted clean transition. Amidst these challenging situations, in order to achieve the targets, large-scale negative emission technologies (NET) for removal of the GHG from the atmosphere by deliberate human efforts is essential.

> **"The International Energy Agency (IEA) energy-related Sustainable Development Goals (SDG) indicates that the mass CO2 captured globally will increase from 40 million tons per annum (MTPA) in 2022 to 5635 MPTA by 2050"**

The CCS is expected to provide a near-term pathway to rapidly reduce the impacts of existing emissions-intensive infrastructure/processes, while zero-carbon alternative solutions mature. The International Energy Agency (IEA) energy-related Sustainable Development Goals (SDG) indicates that the mass CO_2 captured globally will increase from 40 million tons per annum (MTPA) in 2022 to 5635 MPTA by 2050 [1].

The contribution of various technologies to certified emission reduction (CER) of ~ 750Gt by 2050 **(Figure 2)** indicate that CCS could contribute to 13% of the CER, out of which CCS contribution to power generation and industry shall be ~62 and 33Gt, respectively. CCS can reduce emissions across most industry sectors directly, both as a retrofit technology for existing industrial and energy facilities, as well as incorporated into new developments. Thus, CCS is considered as an essential technology for the global effort to achieve net-zero GHG emissions by 2050. The interest in the CCS and the technical readiness of major energy consuming nations is shown in **Figure 3** and the growth in the global CCS capacity is shown in **Figure 4** [3].

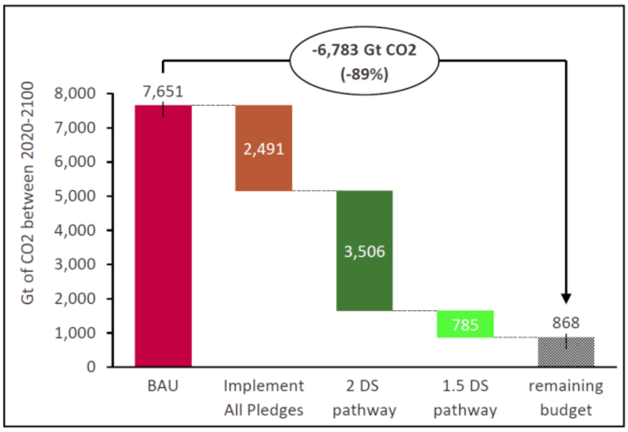


Figure 1. Global CO_2 emissions under various pathways [1]

GHG reduction targets and importance of CCS for India

Even though India's contribution to the global historical emissions is <5 %, at present India is the 3rd largest GHG emitter in the world. Currently, 62% of the installed electricity generation capacity and 70% of the energy production is contributed by the fossil fuels, in which 52% is from the coal-fired and 10% from the natural gas fired power plants. During 2021, ~1800 TWh of electricity was produced from ~226GW of fossil fuel-based plants. Considering climate change concerns, energy security, planned economic growth and the Paris commitment, India has committed to increase its cumulative installed non-fossil-fuel-based electricity generation capacity in the electricity generation portfolio (EGP) to 40% and reduce the emission intensity by 35%

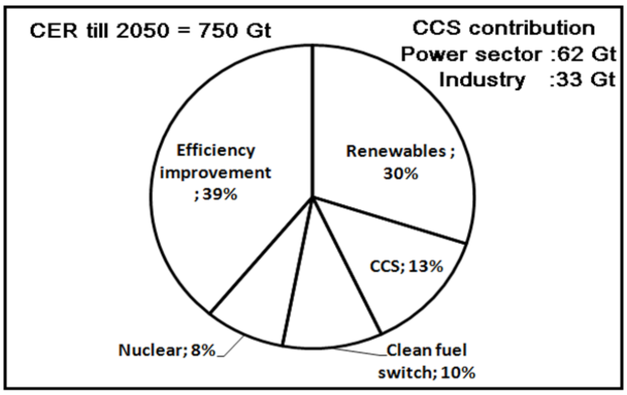


Figure 2. Global CER targets and expected contribution of CCS

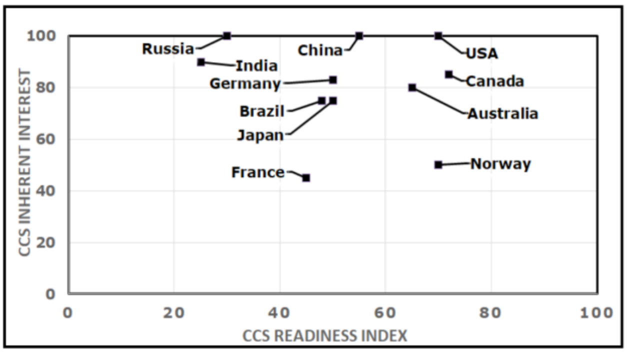


Figure 3. Interest and readiness of CCS in major countries

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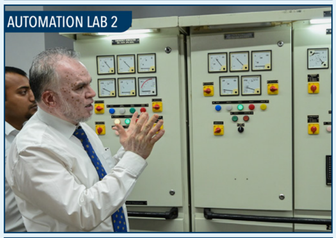
16.	Maritime Safety Management - Module 1 (Occupational & Behaviour Based Safety)	10-12	07-09, 21-23
17.	Maritime Safety Management - Module 2 (Risk Assessment)	16	26
18.	Maritime Safety Management - Module 3 (Shipboard Safety Officers)	17	27
19.	Maritime Safety Management - Module 4 (Accident Investigation)	18	28



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CERTIFIED MARITIME TRAINING PROVIDER DNV DNV-ST-0029 by 2030. The GHG reduction potential in India is evident from the number of projects (~30% of that in Asia) registered under the UNFCC Clean Development Mechanism (CDM). The commitments made by India during CoP26 summit is depicted in **Figure 5** [2].

India Energy Security Scenario (IESS) 2047 is energy scenario modelling and simulation software developed by the Government of India (GoI) - National Institution for Transforming India (NITI). The software has provisions to model various economic growth scenarios and simulate a range of potential future energy scenarios for India, for diverse energy demand and supply sectors, leading up to 2047 [4]. The software based on bottom-top approach is based on inputs from relevant government departments. The IESS determined effort scenario (DES) is considered for the simulations. The DES considers a GDP growth rate of 8.7%/year, an increase in manufacturing's share of GDP at 1.13% per year, and an urbanisation rate of 0.7%/year. **The considered DES leads to a GDP of US$17 trillion, 34% share of manufacturing in GDP, population of 1.7 billion, and 51% urbanisation by 2047.** The results of the simulation for DES till 2047 are shown in **Table 1**.

Even under determined efforts, coal shall contribute to 45% and 31% of India's primary energy needs by 2030 and 2047, respectively

Table 1. Electricity generation installed capacity till 2047 [4]

Source	2020	2030	2047
Coal	52%	45%	31%
Natural gas	10%	6%	6%
Renewable	16%	33%	50%
Hydro	19%	12%	10%
Nuclear	3%	3%	3%

Reconciling the climate goals with India's energy security and economic growth requires significant transformation in the energy sector. Various efforts are undertaken by the GoI in reducing the emissions of the fossil fuel-based energy sector. The cumulative GHG emissions through 2047 with the implementation of clean-fossil and renewable energy during normal and DES computed using IESS is shown in **Figure 6.** Under DES, it is possible to obtain a cumulative emission reduction of 24 $GtCO_2$ during the period 2022-47. In **Figure 6,** red indicates cumulative emission under BAU scenario, green indicates emission under DES and blue indicates the difference, i.e. cumulative emission reduction.

Considering the health impacts due to road transport emissions and to reduce oil import dependence, policies are initiated to increase the usage of electric vehicles (EV). From the IESS 2047 simulations it is identified that by determined implementation of the EV policies, the electric grid-supported charging infrastructure shall support ~10% of the on-road vehicles with ~140 TWh of energy in 2030 and >33% in 2047 with ~280 TWh of energy.

The transformation helps to achieve cumulative crude oil import savings of ~US$ 150 and 0.53 trillion by 2030 and 2047, respectively, as well as reduce CO_2 emissions from the road transportation sector cumulatively by ~1 and ~5.5Gt, in 2030 and 2047, respectively (Figure 7).

Even under determined efforts, coal shall contribute to 45% and 31% of India's primary energy needs by 2030 and 2047, respectively. The importance of coal in the energy sector can be seen from their increasing imports **(Figure 8).** The estimated growth in the CCS-based power generation capacity and the achievable GHG reduction is depicted in **Figure 9.**

Natural CO_2 cycle

There are two main mechanisms that transfer CO_2 from the atmosphere to the ocean **(Figure 10).** The first main mechanism is the physical solubility pump, by means of which ~90% of atmospheric CO_2 is transferred to the

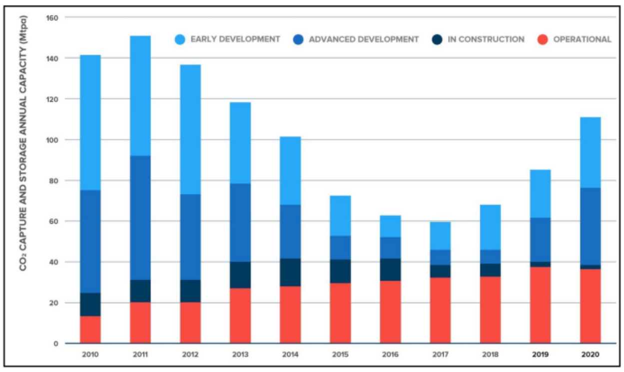

Figure 4. Global growth in CCS facilities

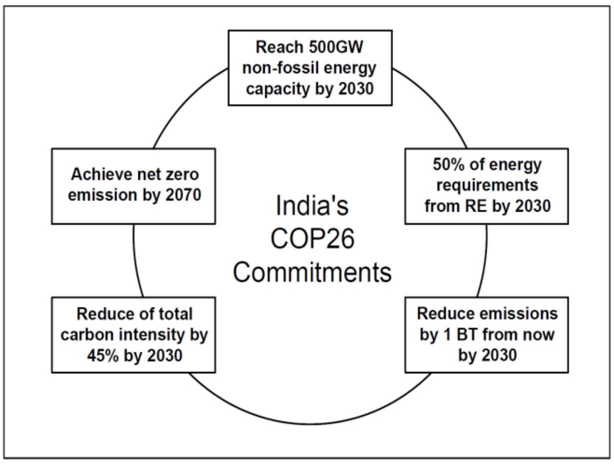

Figure 5. India's CoP26 commitments [2]

ocean by simple dissolution of the gas into surface seawater mainly in the mixed thermocline region (within which fairly rapid thermodynamic equilibrium occurs), and successive down-welling of the surface water and upwelling of the deeper waters through global thermohaline circulation system. Deep-ocean waters, with temperatures down to 2°C and pressures >100 bar are highly under-saturated, and its excess solubility enables ocean to provide a sink for increased atmospheric CO_2 over a centennial time scale [7].

The other mechanism is by means of biological pump that is based on the biological mechanisms that exports the Particulate Organic Carbon (POC) from the ocean surface waters down to the deep-ocean. The ocean is the home to plankton (that is microscopic organisms) that flow with the ocean currents. It represents >95% of the marine biomass that includes an extraordinary diversity comprising of viruses, bacteria, microalgae, reproductive cells, fish larvae, micro-crustaceans, etc. A part of the plankton, phytoplankton, also called microalgae, behaves just like plants. Through photosynthesis, it absorbs CO_2 and produces >50% of the O_2 we breathe. The starting point for the biological pump is the process of photosynthesis, through which the production of organic carbon takes place in well-lit (euphotic) shallow ocean waters. This process of generating organic carbon through photosynthesis is called primary production and is the base of the marine food web. The biomass of phytoplankton is successively consumed by small, then larger marine animals, which release organic carbon as faecal pellets. The falling particulate matter and decay products, both organic and inorganic, are collectively known as "marine snow." Through this process an estimated 0.2 Gt-C/year is deposited onto the ocean floor.

Carbon capture technologies include pre-combustion capture, post-combustion capture and oxy-fuel combustion systems

Carbon Capture and Sequestration (CCS)

CCS is a technology that can reduce the amount of CO_2 released into the atmosphere from power plants and other industries that use fossil fuel. **CCS involves three main stages, including, collecting or capturing the CO_2, transportation of collected CO_2 to suitable storage sites and pumping it deep underground into the rock or ocean to be securely and permanently stored away from the atmosphere over long periods (Figure 11)** [8].

Carbon capture technologies include pre-combustion capture, post-combustion capture and oxy-fuel combustion systems. The pre-combustion system involves converting solid, liquid or gaseous fuel into a mixture of hydrogen and CO_2 using gasification process.

In the post-combustion capture, the CO_2 is captured from the exhaust of combustion by absorbing it in a suitable solvent and the absorbed CO_2 is liberated from the solvent, compressed for transportation and storage.

Other methods for separating CO_2 include high-pressure membrane filtration, adsorption/desorption processes and cryogenic separation. In the oxy-fuel combustion process, the oxygen required is separated from air before combustion and the fuel is combusted in oxygen diluted with recycled flue-gas instead of air. At present, the capturing stage accounts for 80% of the full CCS chain costs.

A global patent review on the nascent carbon capture process technologies reveals that 37.5%, 35.5%, and 27% are based on solvent, sorbent and membrane-based technologies. The increasing number of patents shows the awareness on the potential relationships between the climate change and CO_2 release, the emphasis on reducing energy penalty, cost, health and environmental issues [9].

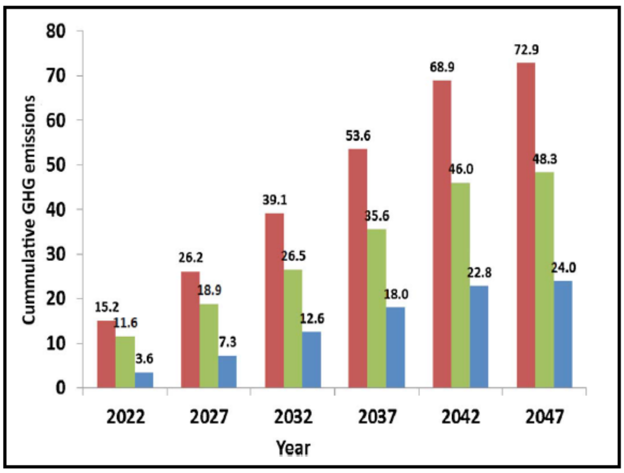

Figure 6. GHG emission during normal & determined scenarios [5]

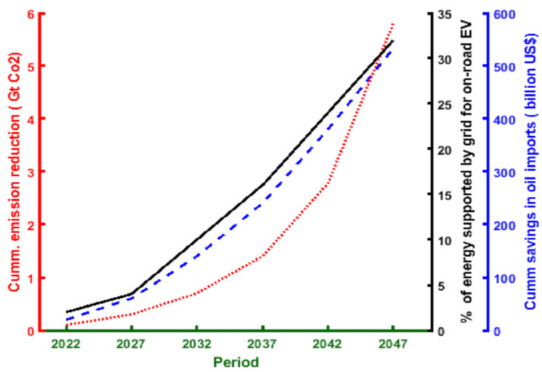

Figure 7. GHG emission reduction by EV implementation [6]

The technologies for removing CO_2 from large point sources that satisfy safety, efficiency and economy are maturing. The global CCS institute has identified 75 large scale projects, with 24 in US, 21 in EU, 11 in China and 19 in other countries. The US, with an installed coal-based electricity generation capacity of ~300GW, has research and demonstration CCS in a few north American host sites and 8 large scale carbon capture technology demonstration projects with a cumulative annual capture capacity of ~25 million tons of CO_2. The first industrial-scale CO_2 capture plant at Huaneng power plant in China has demonstrated that this technology is a good option for the capture of CO_2 produced by commercial coal-fired power plants and it is understood that electricity purchase price increased by ~30%, which indicates that technology still needs to be matured before commercial implementation [10].

High-level estimates of India's storage resources include more than 1000 $MtCO_2$ in oil fields, 345 $MtCO_2$ in coal formations and crude estimates exceeding 63,000 $MtCO_2$ in saline aquifers

After the CO_2 has been captured, it must be dehydrated and compressed before it can be transported to a safe storage location. **The dehydration process is necessary because, if left untreated, the comingled water and CO_2 will damage mild steel over time by forming corrosive hydrides and acids.** Anti-corrosion steel could be used but would be considerably more expensive given the large scales of transportation needed in Gt-level CCS capacity. In the treatment process, CO_2 is transported (via small anti-corrosion steel pipes) to purification and dehydration tanks, where it is purified to levels > 99% CO_2. There are several technologies to dry CO_2, however, tri-ethylene glycol (TEG) is efficient, as well is available widely for use in the natural gas industry. The treated, gaseous CO_2 is then liquefied using compressors and chillers. The liquefaction process is necessary because gaseous CO_2 would necessitate larger pipelines and additional compression throughout the network. Finally, after traversing the pipeline, the CO_2 will be stored. In addition to storage, there are also methods for carbon utilisation, which aim to extract value from captured CO_2 by using it in other products.

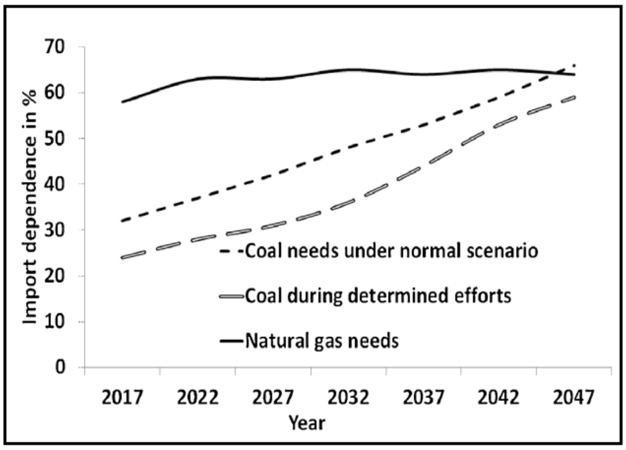

Figure 8. Import dependence of fossil fuels till 2047

Refrigeration stations and/or additional pumps and compressors shall be needed throughout the length of the pipeline to ensure temperature, pressure, and flow specifications are maintained **(Figure 12).** Just-in-case compressors and pumps may also be required at injection sites to ensure the pressure is higher than the backpressure of the storage cavern, especially as time progresses and the sites' pressure builds.

CO_2 sequestration in geologic formations

Geological storage is currently the best large-scale, verifiable, and permanent CO_2 storage method, and all CCS scenarios examined are based on this type of sequestration. Geologic storage includes natural saline reservoirs, depleted oil/gas fields, or other stable formations with high capacities. The global storage

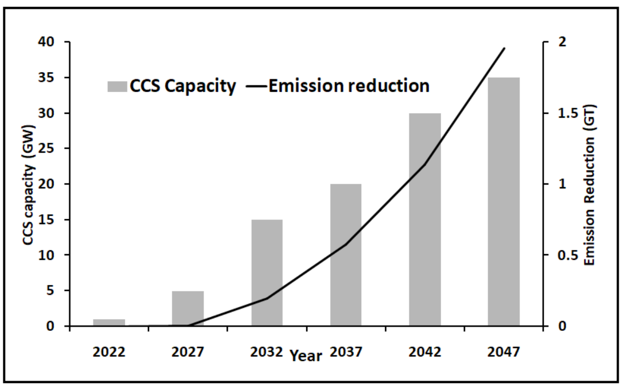

Figure 9. Growth in CCS based power plants & emission reduction

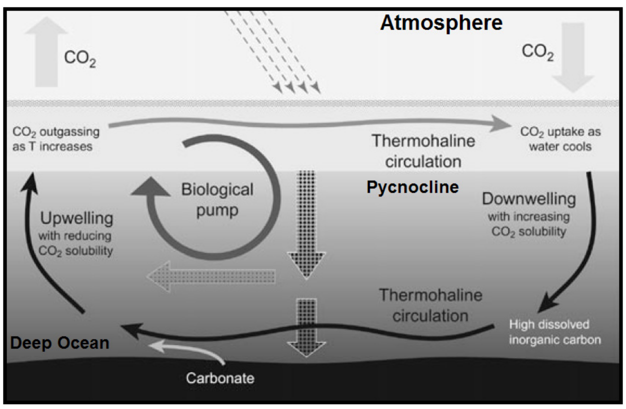

Figure 10. CO_2 flux exchange between atmosphere and oceans

capacity estimated for CO_2 sequestration is summarised in **Table 2.**

Table 2. Geological storage capacities identified till date [3]

Reservoir type	Storage capacity in Gt-Co_2	
	Lower estimate	Upper estimate
Oil and gas fields	675	900
Un-minable coal seams	15	200
Deep saline formations	1000	10000

The geological storage potential of the Indian Subcontinent has only been characterised at the regional level. Much of the required data for characterisation exists due to India's long history of oil and gas operations in both onshore and offshore basins. High-level estimates of India's storage resources include more than 1000 $MtCO_2$ in oil fields, 345 $MtCO_2$ in coal formations and crude estimates exceeding 63,000 $MtCO_2$ in saline aquifers. India's most suitable storage basins are situated along the west coast (onshore Cambay, offshore Mumbai Saurashtra Basins) and east coast (Krishna-Godavari, Cauvery, Bengal Basins). Additional storage potential is ranked possible in several other Indian basins, including Kutch and Mahanadi; however, these basins require basic storage suitability analysis to define their storage resources. The Assam Basin in India's far northeast is suitable, but emissions sources are sparse in this region.

The identified potential CO_2 storage locations in India (both onshore and offshore) are shown in **Figure 13** [12]. There are 105 Gt of CO_2 storage capacities in deep saline aquifers, 360 Gt in deep waters and 200 Gt in basalt formations. In India, the most crucial aspect for CCS implementation is a reliable storage capacity assessment based on site-specific geological data.

CO_2 Sequestration in offshore hydrocarbon reservoirs

Long-term sequestration of anthropogenic CO_2 in deep ocean sediments takes advantage of the current offshore infrastructure. Another reason to utilise offshore CCS is that much of the technology needed to implement offshore schemes is already well understood and developed, as it utilises methods and technologies that have been developed by the offshore hydrocarbon industry. Both ashore and offshore CO_2 injection into geological oil and gas bearing structures has been extensively used to Enhance Oil Recovery (EOR) [13].

The first use of injected CO_2 in an EOR scheme was in 1972. Hence, there is over 50 years of experience of transporting CO_2 and injecting it into geological features in the hydrocarbon industries. These industries also have extensive experience of transporting gasses along seabed pressurised pipelines and of building and installing the infrastructure needed to drill into geology deep below the seabed. However, the multi-physics process of injection and post injection fate of CO_2 and the feasibility of sub seabed disposal of CO_2 under different geological and operational conditions have not been well studied for all potential storage locations.

The injected CO_2 is stored in geological structures consisting of permeable rock (such as sandstone) lying below an upper impermeable layer (such as mudstone or caprock). Such geological structures often have already captured rising hydrocarbons (i.e., depleted oil and gas fields), or saline water (i.e., saline aquifers) and hence have demonstrated that they lie below an impermeable layer. The Intergovernmental Panel on Climate Change (IPCC) in their special report on CCS noted that "observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1000 years." [14]. **Hence geological storage of CO_2 aims to retain the gas for 100 to 1000 years at least.**

Monitoring programmes for the assurance of offshore geological storage by understanding the variability and heterogeneity of marine carbonate chemistry are underway. The North Sea that presently hosts three commercial CCS projects including Sleipner and Snohvit is identified as a strategic CCS development hub. The Utsira formation is a 200-250m thick massive sandstone

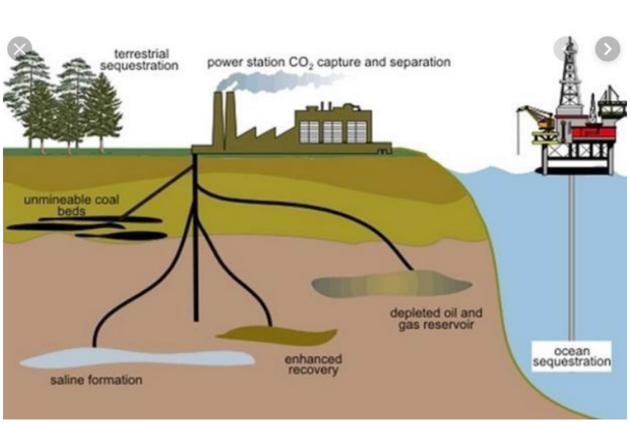

Figure 11. Concept of underground & Ocean CO_2 sequestration

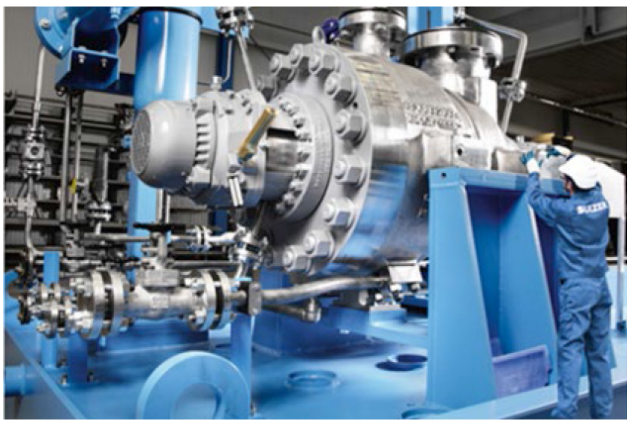

Figure 12. CO_2 liquefaction systems [11]

and is identified to store 600 billion tons of CO_2 and ~15.5 million tons of CO_2 have been injected over the since the project started to 2015 [15].

For understanding the technical challenges in the offshore CO_2 sequestration process, **Figure 14** summarises the different physical phases of CO_2 when subjected to different temperatures and pressures. Also shown are the typical temperatures and pressures that CO_2 is transported at in offshore pipelines, and on vessels, as well as typical ambient conditions in the North Sea [11].

At ambient (atmospheric) temperatures and pressures, pure CO_2 is a colourless, odourless, inert and non-combustible gas which can dissolve into water. When transported to an offshore CCS storage site, it is most common for CO_2 to be pumped into a pipeline at the shoreward end as a supercritical fluid (pressure 200 bar, temperature 45ºC), but as temperatures decrease along the pipeline due to heat loss, it changes into a liquid **(Figure 14).** The transport of CO_2 in tanks on board ships is most commonly as a liquid. However, at the temperatures and pressures found within a geological store, CO_2 can exist in five phases (dissolved in water, solid, liquid, gas, supercritical fluid), all existing in different parts of the geological structure at the same or different times depending on a range of factors within the rock.

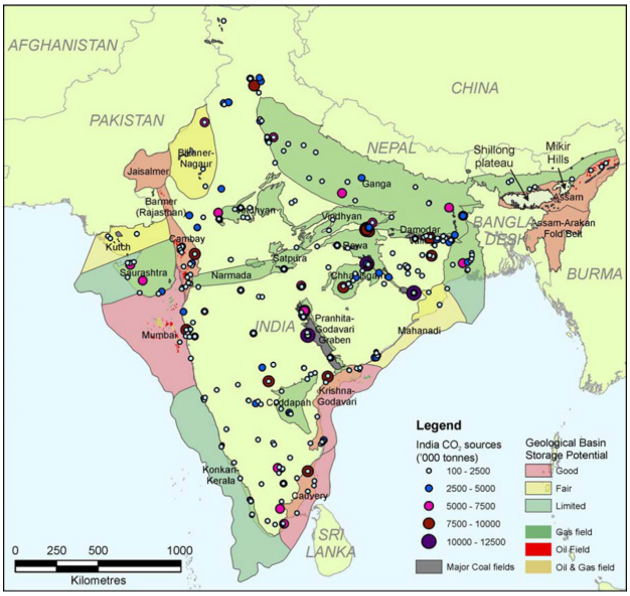

Figure 13. Identified CCS storage locations in India [12]

CO_2 Sequestration in deep waters

Deep-ocean waters provide a CO_2 solubility sink that is coupled to the atmosphere through the physical solubility and biological pumps. In this process, the world's oceans contain an estimated 39000 Gt-C (143,000Gt-CO_2), ~50 times more than the atmospheric inventory, estimated to have taken up almost 38% (500Gt-CO_2) of the 1300Gt of anthropogenic CO_2 emissions over the past two centuries. Thus the highly unsaturated and its excess solubility and stability (due to the formation of the hydrates) enables oceans to provide a sink for CO_2 over centennial time scales. Long-term storage of CO_2 in the ocean relies on its retention in deep waters that have a ventilation time of several centuries, as well as the natural tendency of CO_2 to partition into seawater versus the atmosphere. Options that have been investigated to store carbon by increasing the oceanic inventory include biological (fertilisation), chemical (reduction of ocean acidity, accelerated limestone weathering) and physical methods (CO_2 dissolution, supercritical CO_2 pools in the deep ocean). The physical methods that are proposed for CO_2 sequestration in the ocean are summarised in **Table 3** and represented in **Figure 15** [7].

Table 3. Various techniques for ocean CO_2 sequestration

Physical concept	Technical scheme
Direct CO_2 dissolution	Rising plume
	Neutral buoyancy (isopycnal) spreading
	Sinking plume
Liquid CO_2 isolation	Pipe feed to seafloor lake
	Sinking cooled liquid & CO_2 slurry

The next issue....

Presents the details of ocean CO_2 release experiments conducted in the Monterey Canyon, Scottish Sea and North Sea, and physiochemical processes when the CO_2

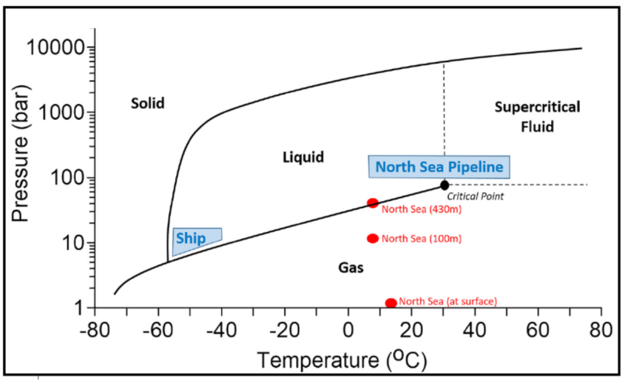

Figure 14. Parameters related to CO_2 sequestration in North Sea [11]

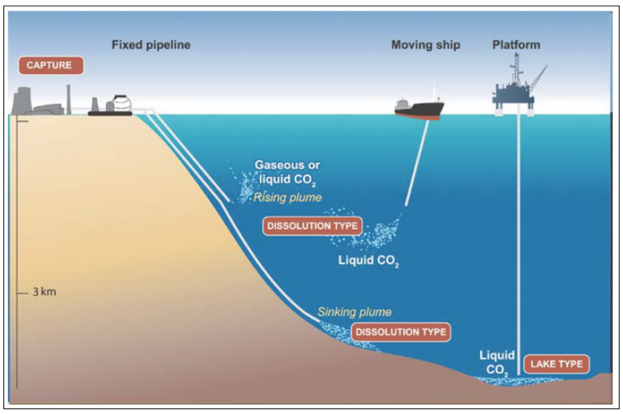

Figure 15. Physical techniques for ocean CO_2 sequestration [7].

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(gas and liquid) is released directly into the ocean water in various depths < 500m, 500-2500m and >2500m. A numerical model is also developed in MATLAB software and simulations are carried out to understand the gaseous CO_2 dissolution when released at 1000m water depths in the Bay of Bengal.

ABBREVIATIONS

BAU	business-as-usual
CCS	Carbon Capture and Sequestration
CER	certified emission reduction
CDM	Clean Development Mechanism
CO2	carbon dioxide
CoP	UN Climate Change Conference in Glasgow
DES	Determined effort scenario
EGP	electricity generation portfolio
EOR	Enhanced Oil Recovery
EV	Electric Vehicles
GDP	Gross Domestic Product
GHG	greenhouse gases
GoI	Government of India
GW	Giga watt
IEA	International Energy Agency
IESS	India Energy Security Scenario
IPCC	Intergovernmental Panel on Climate Change
MATLAB	Matrix Laboratory
$MTCO_2$	Million Tons of Carbon dioxide
MTPA	million tons per annum
NDC	National Determined Contributions
NET	negative emission technologies
NITI	National Institution for Transforming India
PoC	Particulate Organic Carbon
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technological Advice
SDG	Sustainable Development Goals
TEG	tri-ethylene glycol
TWh	Terawatt hours
UN	United Nations
UNFCC	United Nations Framework Convention for Climate Change

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About the author

Dr. N. Vedachalam is is currently Scientist G in Deep Sea Technologies division of National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. He is the Project Director for India's first indigenously-developed deep-water manned scientific submarine Matsya6000. He holds a Bachelor's degree in Electrical and Electronics engineering from Coimbatore Institute of Technology (1995), Master of Business Administration and PhD in Techno-economics of marine gas hydrates from College of Engineering - Anna University, India. His 27 years of experience include industrial power, process, offshore and subsea domains at Aditya Birla group, General Electric & Alstom Power Conversion in France. Technical exposure includes development of multi-megawatt subsea power and control systems for Ormen Lange subsea compression pilot; Ocean Thermal Energy Conversion and wave energy systems; subsea renewable power grids; unmanned and manned underwater vehicles; ocean observation technologies and industrial systems. His research interests include energy, subsea robotics and reliability. He has more than 100 publications in indexed journals, holds an international and two national patents in subsea robotics and subsea processing. He is a recipient of the national meritorious invention award in 2019 for the development and usage of underwater robotic vehicles. He is a member of Indian Naval Research Board, member of Bureau of Indian Standards and was the Secretary of IEEE OES - India Chapter. He is a regular contributor to MER.

Email: veda1973@gmail.com

Fires in Cargo Areas Onboard Containerships – An Analysis of Accidents

Karan Doshi

Abstract

Fires on containerships in the cargo areas have been prevalent over the past several years and have been growing in number. The present paper aims to analyse the causes of such fires. The paper presents statistics of cargo fire incidents on containerships from 2010 – 2020. The paper also identifies contributing factors for the cargo fires from a study of accident investigation reports.

KEY WORDS

Containerships, Cargo fires, Dangerous Goods, Fire Safety

INTRODUCTION

Fires on Containerships within the Cargo area may have severe and devastating consequences when considering loss of life, damage to cargo as well as damage to the ship. Further, with the growth of container ship sizes over the previous decade, fires occurring within the cargo area are a major concern. It has been remarked that a major fire may occur once in every 60 days on a containership (TT Club, 2019). This concern has also been recognized by the International Maritime Organization who agreed to constitution of a new output to improve the fire safety of containerships (IMO, 2021).

In the present paper, the factors behind the occurrence of such accidents are studied with a view to identifying potential directions for further work so as to improve the fire safety of Container Ships.

STUDY OF CONTAINER SHIP FLEET

A study of the container ship fleet would be useful to identify if particular categories or sizes have been vulnerable to such fires. It is common practice to categorize container ships in terms of their TEU capacity. Hence the following nomenclature will be used within the paper as shown in **Table 1.**

Table 1. Categorisation of Container Ships by TEU Capacity

Type	TEU Capacity
Small Feeder	0-1000
Feeder	1001-2800
Sub-Panamax/ Panamax	2801-5100
Post-Panamax	5101-10000
Sub-Neo/Neo-Panamax	10001-14500
ULCS	>14500

It is acknowledged that the present method of categorization of Containerships is one of the many ways and not the only way. (e.g. There are some feeder container ships in service whose capacity exceeds 2801 TEU. Likewise there are also some Post Panamax Ships with TEU capacity less than 5100). It is a reasonable step to presume that such categorization will not lead to loss of generality in the study. The Neo-Panamax and ULCS ships are predominantly the two-island configuration container ships, i.e. the E/R and the Wheelhouse are separated, with the wheelhouse located towards the fore.

With the above categorization, the ship fleet in service as on 1 January 2021 was extracted from the IHS Maritime Database (IHS Maritime, 2021). The following are the salient findings:

- 5300 Container Ships in service were identified. This also includes 11 Ro-Ro Containerships (carrying both commercial vehicles and container cargo) and 107 open hatch containerships

- The composition of the active ship fleet is shown in **Figure 1.** It can be observed that Feeder Container ships (Small Feeder, Feeder) constitute more than 50% of the Fleet. The larger ship sizes (Panamax – ULCS) also constitute 45% of the fleet. In terms of the capacity of containers carried by the ships, it can be seen that the Post Panamax and higher sizes together account for more than 66% of the total TEU capacity carried across the Containership segment.

The containership fleet has registered a steady growth over the past decade. This can be observed by **Figure 2 and Figure 3** which display the TEU Capacity range for each container ship size and the Fleet Size increase over the past decade. The growth in TEU capacity from the feeder to the ULCS is significant with each ULCS equivalent to nearly 20 feeder ships.

It can be observed that the total TEU capacity of the ships increased nearly 1.7 times as compared from 2010 to 2020. Likewise, average TEU capacity per ship has increased from 2913 TEUs to 4388 TEUs.

Another notable factor is the average age of the container ship fleet. The Neo-Panamax and the ULCS sizes are the youngest with average age less than 10 years. This can be observed from **Figure 4** where the ages of the ships within the various size categories are plotted.

It can be observed that since 2014, there have been at least two fires per year on Post Panamax Container ships

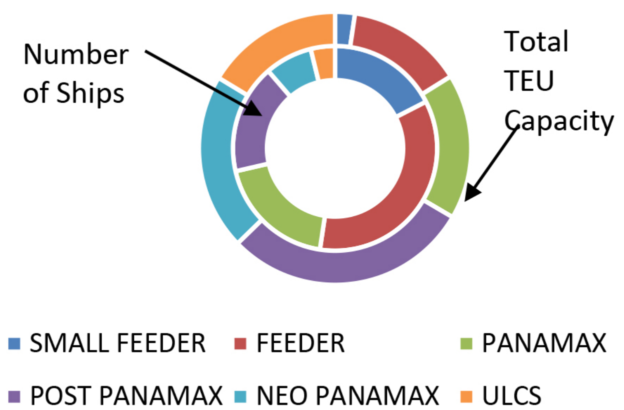

Figure 1. Composition of the active containership fleet

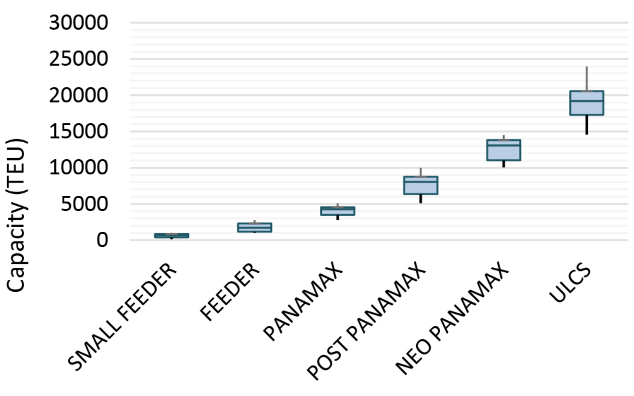

Figure 2. TEU Capacity ranges (Box Plot) for different container ship sizes

FIRE ACCIDENTS ON CARGO AREAS ON CONTAINERSHIPS

Total of 72 accidents were identified between 2010 - 2020 from the various sources of data as listed below

1. IHS Maritime Casualty database (IHS Maritime, 2021)
2. IMO GISIS MCI module
3. EMSA EMCIP platform
4. Various Investigation reports

A study of the accidents was performed. The number of accidents distributed between the various ship sizes is shown in **Figure 5.** It can be observed that since 2014, there have been at least two fires per year on Post Panamax Container ships. Since 2015, there has been at least one fire on a Neo-Panamax or ULCS. Since 2015, there have been 7 accidents on container ships on an average per year, with most of these accidents occurring on Panamax or higher size ships (accounting for 80% of the TEU capacity).

The accident frequencies for various ship sizes are shown in **Figure 6.** It can be observed that the ULCS size category has the highest frequency, this frequency is several times the accident frequency for the relatively smaller sizes, i.e. the post Panamax and the Neo-Panamax.

A total of 5 losses of container ships were recorded in the period of study. These were one small feeder ship, three feeder ships and one ULCS. Two of these losses were on ships with age greater than 20 years. Two of the ships had ages exceeding 10 years. The ULCS was less than one year of age at the time of accident.

A total of 9 fatalities (including missing persons) were recorded on container ships from 2010-2020. 8 of these occurred on one ULCS and one Post Panamax ship. 7 injuries to crew were also recorded in the above period. The average annual fatality rate for ULCS is estimated at $5x10^{-3}$/ship year and for Post – Panamax is estimated at

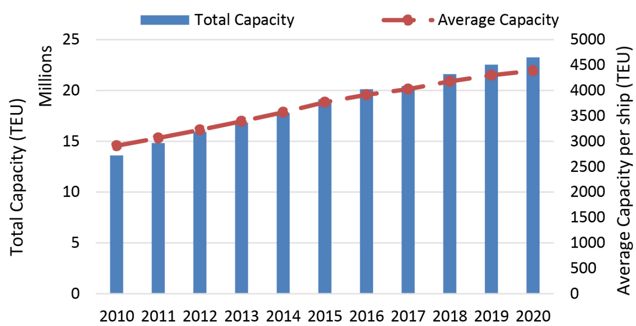

Figure 3. Growth of Containership fleet over the previous decade

1.92×10^{-4}/ship year. The fatality rate is very high for ULCS, which is attributed to the single fire accident on a ULCS ship leading to four fatalities.

It was noted that firefighting assistance was almost inevitable in order to suppress and control fires on ships with Post Panamax and above sizes

It was observed that more than 50% of the fires initiated within the cargo hold and 36% on the deck. The location for 10% of the fires was not reported **(see Figure 7).** The location of the fire with respect to the containership size is shown in **Figure 8.** It can be observed that for Neo-Panamax and ULCS sizes, more fires were observed to have initiated from the deck. Whereas for Panamax and Post Panamax ships, more fires were initiated within the cargo hold as compared to the deck.

Assistance was required by the ships for firefighting or to be towed to a site where firefighting could be performed (to take the ship away from a traffic separation scheme). **Figure 9** shows the proportion of cases where firefighting was necessary using external assistance. It can be seen that for nearly 60% cases, firefighting assistance was necessary. It was noted that firefighting assistance was almost inevitable in order to suppress and control fires on ships with Post Panamax and above sizes.

The statistics of country of origin of the voyage are depicted in **Figure 10.** (Note that this however may not be the country of origin of the cargo contained within the container). It may be noted here that the container could have arrived from other areas for transhipment to a regular container shipping route. It is hence more suitable to observe this trend in terms of the region where the voyage originated rather than at the Port or Country Level. It can be observed from **Figure 10** that 74% of the voyages originated within Asia. Out of this, 78% of the voyages originated within East Asia region. Voyages originating from Malaysia and China account for more than 50% of the voyages from East Asia. For all the 5 ULCS on which accidents occurred, the departure port was in Malaysia. 4 out of the 7 accidents on Neo-Panamax ships and 7 out of 23 accidents took place where departure port was in Malaysia or Singapore.

The statistics of location of the occurrence of accident are plotted in **Figure 11.** It can be observed that nearly 36% of the accidents occurred in the South East Asia region. 24% of the accidents occurred within the Asian Gulf and the Red Sea region. **These zones would be characterised by relatively high external air temperatures and humidity especially for the former.** The Gulf region including the Arabian sea, Red Sea and Suez have been witness to accidents for 2 ULCS (out of 5), 6 Neo-Panamaxes (out of 7) and 4 Post Panamax (out of 23) ships. Post Panamax ship accidents have been more prevalent in the waters around South East Asia and the Orient.

With reference to the cargo onboard which was envisaged to be responsible/hypothesised to be responsible for the fire, data pertaining to cargo carried within the container (where fire initiated/hypothesised to be initiated) was only available for 32 out of 72 accidents. 10 out of 32 accidents were related to Charcoal or similar type cargo. 7 out of 32 accidents were attributed to carriage of cargo containing chlorine content (e.g. calcium hypochlorite, Sodium dicholoroisocyanurate dehydrate etc.). 2 out 32 accidents were attributed to

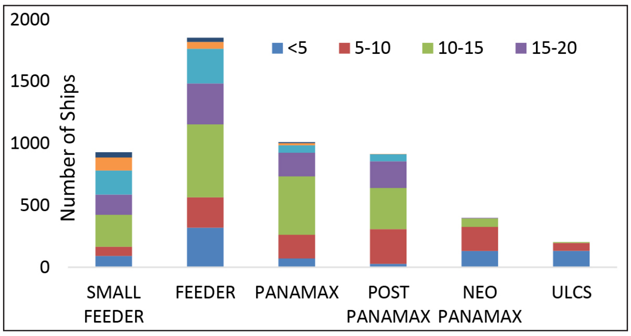

Figure 4. Age of the ships within the various sizes

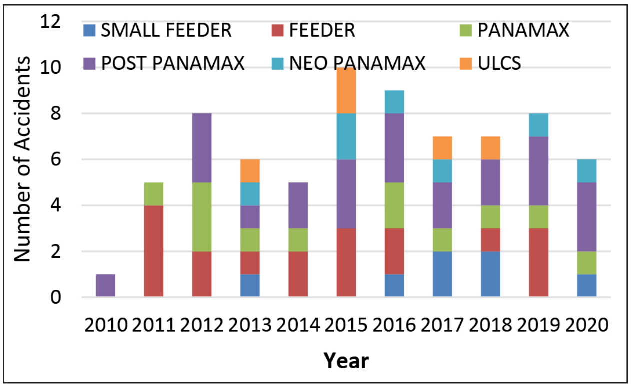

Figure 5. Accidents pertaining to Fire within Cargo Areas on Container Ships

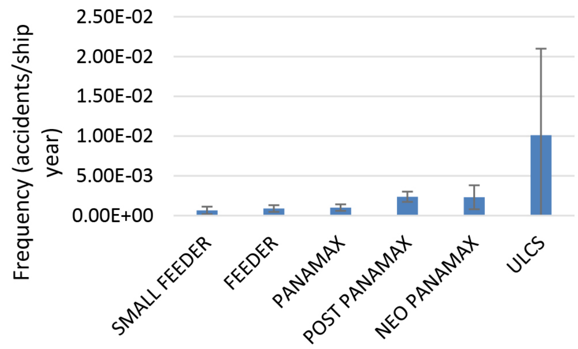

Figure 6. Accident Frequency for the various containership sizes

carriage of lithium batteries. It could not be confirmed from the accident reports whether such cargoes were appropriately declared, rather the impression appeared to be on the contrary (i.e. misdeclaration or improper declaration)

STUDY OF INVESTIGATION REPORTS

Accident investigation reports of containership fires pertaining to fires within cargo areas were obtained from IMO GISIS, EMCIP and National transportation accident investigating bodies websites. A total of 20 accident investigation reports were downloaded for containership accidents between 2010-2020. The particulars of these reports are shown in **Table 1.**

Sr.no	Name of Ship (At time of accident)	Date of Initial Event	Size
1	Amsterdam Bridge	09-09-2012	Panamax
2	APL Austria	12-02-2017	Post Panamax
3	MSC Flaminia	14-07-2012	Post Panamax
4	Hanjin Green Earth	01-05-2015	Neo Panamax
5	Caroline Maersk	26-08-2015	Post Panamax
6	Charlotte Maersk	07-07-2010	Post Panamax
7	Hansa Brandenburg	15-07-2013	Feeder
8	Eugen Maersk	18-07-2013	ULCS
9	Maersk Honam	06-03-2018	ULCS
10	Yantian Express	03-01-2019	Post Panamax
11	MSC Katrina	20-11-2015	Neo Panamax
12	Ludwigshafen Express	21-02-2016	Neo Panamax
13	MSC Daniela	04-04-2017	Neo Panamax
14	Zim Rio Grande	20-07-2012	Panamax
15	Barzan	07-09-2015	ULCS
16	Filia	11-11-2019	Feeder
17	Northern Guard	06-07-2014	Panamax
18	CMA CGM Rossini	15-06-2016	Post Panamax
19	Croatia	23-02-2020	Post Panamax
20	CCNI Arauco	01-09-2016	Post Panamax

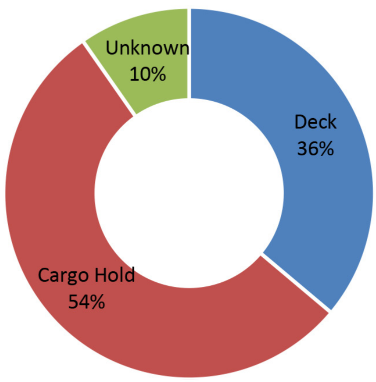

Figure 7. Location of Fire

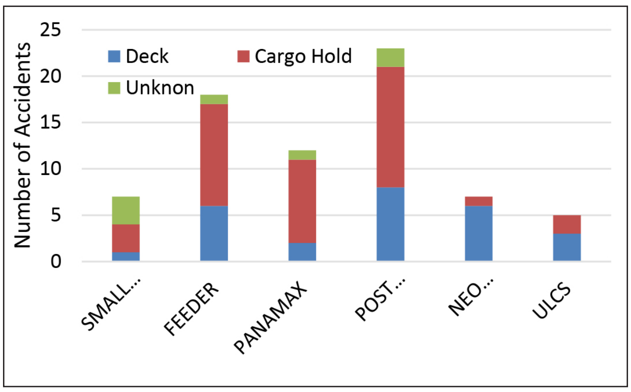

Figure 8. Location of the Fire versus the Containership size

The container ship cargo fires stages are demarcated as below for a systematic understanding of the hazards applicable

- Fire initiation
- Fire detection
- Fire Control and Suppression
- Evacuation and Abandon Ship

FIRE INITIATION

Containers shipped globally may have the following deficiencies which could contribute to initiation of fire onboard ship:

- Inadequate labelling, marking, placarding
- Inadequate stowage of goods within the container
- Mis-declared contents or no declaration (of dangerous goods)
- Inadequate packaging of goods within the container

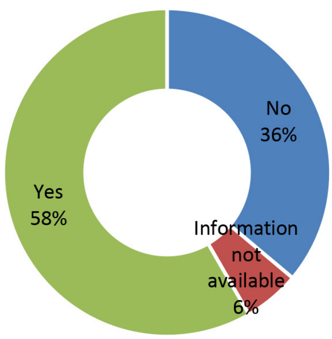

Figure 9. Use of External assistance for firefighting

- Inadequate structural condition leading to damage of container and exposing contents to external climate (which could lead to reactivity of contents)

Cargo Misdeclaration/Non-Declared dangerous goods cargo or improperly packed cargo was observed to be a possible contributing factor in the 12 out of the 20 accident investigation reports. This is an issue which has also been identified by several studies (NCB, 2019a,b; IMO, 2019; IMO, 2020)

At present, there is no SOLAS requirement for fire & smoke detectors to be installed on deck to indicate any fires within the containers stowed on hatch covers

Another aspect which may lead to initiation of the fire is the exposure of containers to high temperatures. This could be via the following modes:

- Containers placed in cargo holds above or adjacent to the heated fuel tanks are susceptible to temperature increase. The cargo in the container may hence catch fire especially if there are undeclared or **mis-declared flammable dangerous goods** contained within.
- **High temperatures and humidity** in the cargo hold (due to insufficient ventilation, ambient weather conditions etc.)
- **Closure of passive ventilation flaps** for the cargo holds during the voyage coupled with tropical environment may also lead inadequate ventilation and thus high temperatures within the cargo hold
- **Failure of the mechanical ventilation system** for the cargo hold may also be a possible contributing factor
- Containers stowed on deck are exposed to **high ambient temperatures & solar radiation** when travelling through the tropical regions. The containers in the top tier and the container ship sides on the deck may thus be exposed to continuous high temperature and solar radiation especially during the mid-day which has the potential to de-stabilise the contents of the container.
- **Clogging of Container ventilation openings** could also be a possible contributing factor
- Damage to containers during rough weather may lead to collapse of the container stack as a whole and **expose cargo to oxygen** (which may trigger a reaction depending upon the cargo)
- **Lights kept switched on** within the cargo hold may also be a potential source of heat to support initiation and subsequent growth of fire

DETECTION OF FIRE

Fire and Smoke detection systems are only installed within the cargo holds of container ships. At present, there is no SOLAS requirement for fire & smoke detectors to be installed on deck to indicate any fires within the containers stowed on hatch covers. Therefore, it is possible that a fire on deck could be detected very late. Detection of fires on deck is only from visual means when there is an explosion or smoke is seen rising from containers on deck. This was indeed the case within 6 of the 20 accidents studied.

Within the cargo holds, the detection system is a smoke-based extraction system; the piping of which is common to the installed CO_2 firefighting system. The sampling locations are installed towards the top of the cargo hold. Hence there could be a lapse in time between the actual onset of the fire and the sampling of the smoke/fumes by the detectors. The large vertical extent of the cargo holds also contributes to increase in time for the vapours to rise. Fumes/smoke heavier than air will not be possible to be detected until it is too late. Late detection of fire within the cargo hold was noted for 5 out of 20 accidents studied.

SUPPRESSION OF FIRE

Fire within the cargo hold is controlled and typically extinguished by releasing CO_2. For this purpose, the natural and forced ventilation flaps of the cargo hold should be closed as the first step. It is common that this is not possible many times during actual practice due to the following reasons:

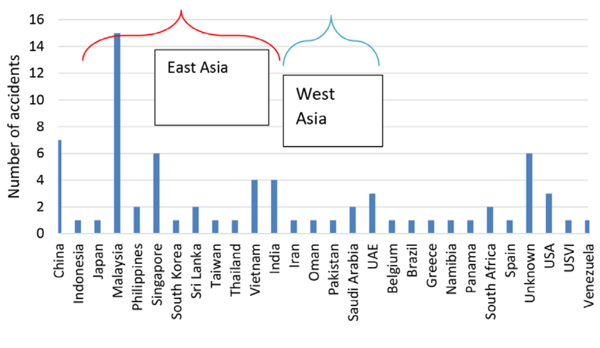

Figure 10. Country of Port of origin of voyage

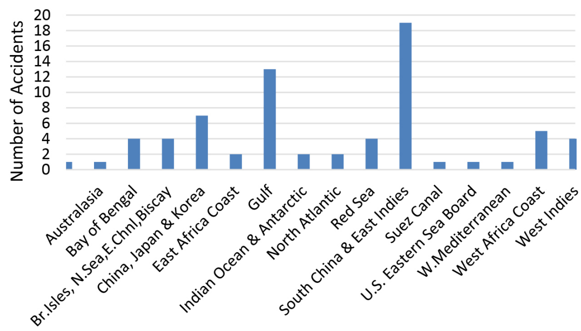

Figure 11. Zone of occurrence of accident

- Ventilation Flaps (located on the cargo hold hatch coaming boundary) have to be closed manually. Due to excess heat and smoke (including toxic fumes) emanating from the cargo hold, this becomes difficult or even impossible. This was observed within 3 of the accidents.

For example, calcium hypochlorite based cargoes decompose releasing oxygen which renders the purpose of release of CO_2 ineffective

- The presence of smoke would reduce visibility in the vicinity of the cargo hold making it difficult to firstly locate the flaps. This was observed in the case of one accident.
- The fumes from the cargo hold could be toxic in nature again hampering the crew from getting near the flaps and closing the same. This was observed in the case of one accident.
- There is always risk of possible explosion suddenly which could deter the crew in their efforts (as in most cases, the contents of the container under fire are not known, or indeed the location of the fire within the cargo hold is not known).
- The mechanism to close the flaps may not be functional or difficult to operate especially considering the challenging conditions – smoke, heat, low visibility and the crew adorned with fire-fighters suits and equipment. This was observed in the case of one accident.

Hence there may be a delay in making the cargo hold ready for release of CO_2 and consequently release of CO_2 is delayed.

Another major issue observed in the study was the malfunction of the CO_2 firefighting system, via the following modes:

- **No release or deficient release of CO_2** upon activation (this may be attributed to inadequate design/installation of the system (observed within 2 accidents) or lack of training or familiarisation (e.g. open or close positions of valves) (as observed in the case of 1 accident and also the fact that periodic drills would not involve actually releasing CO_2 to verify functionality)
- **Inadequate release of CO_2** – Quantity of CO_2 released is not enough as some cylinders may not discharge properly. This was observed in the case of 3 accidents.
- **Wastage of CO_2** – The hatch covers on the cargo hold are not weathertight (i.e. there are gaps between the hatch covers which implies that some quantity of the released CO_2 may escape through these gaps. This is however considered during the design of the system.
- **Quantity of CO_2 onboard inadequate** – This was observed in the case of 1 accident which had fire in shipment of Lithium Batteries. The quantity of CO_2 required for such cargoes needs to be reviewed.
- **Release of CO_2 in spaces other than cargo holds** – This occurred in the 1 accident where CO_2 was accidentally released in spaces accessible normally to persons

CO_2 based fixed fire-fighting system may also not be always appropriate to fight the fire. For example, calcium hypochlorite based cargoes decompose releasing oxygen which renders the purpose of release of CO_2 ineffective.

Manual firefighting within the cargo hold is difficult and may also be dangerous due to the following reasons:

- **Low visibility** within the cargo hold due to smoke and possible high temperatures due to switching off the ventilation. Illumination also being switched off also leads to this issue (as observed in the case of one accident)
- **Difficulty in accessing the seat of fire**
- **Toxic & Corrosive fumes, heat** and the possibility of explosion at any time
- Crew would have to wear the fire-fighters suits and descend within the cargo hold location of fire. This is made difficult firstly from the weight of the suits, limited quantity of oxygen (last typically 30 minutes), physical effort to climb down and climb up again (before the oxygen is exhausted). Sometimes, this may not be easy due to the **size of the access doors or the manholes & ladders** to descend down into various regions of the cargo hold. This was observed in the case of one accident. It was also remarked that the size of the access openings may not be sufficient to let firefighters through donned with their outfits, BA sets and/or fire hoses (as observed in the case of one accident)
- **Difficult to access the seat of fire** within the burning container from the cross-deck structures – Containers are located at some distance away from the cross deck. When fighting fire in a container within a higher tier container, it may not be safe or possible to attempt to gain a closer access to the container.
- It may be necessary to extinguish the fire by accessing it within the container. For this, the container has to be penetrated with a lance and then water mist is injected by inserting a hose. It may happen that the crew is unable to perform this based upon the following factors:

- o Container fully filled with cargo (and seat of fire is towards the rear of the container), thereby preventing the water mist from having any impact. (observed in the case of two accidents though the fire was on the deck)
- o Location from where the container must be penetrated is not clearly marked, hence arbitrary positions may be selected. If structural stiffening is located in the way of the selected position, then it may be difficult to drill a hole to permit the hose to pass through (as observed in the case of one accident**)**
- o Difficulty in managing the drilling of hole through as the container is some distance away from the cross deck structure, at higher tier of stowage, this may present a risk (as observed in the case of one accident).
- o Inexperience - Crew not trained or may not have performed such drilling operation previously or regularly (observed in the case of one accident**)**.
- o Drilling Equipment not able to penetrate the container wall (as observed in the case of one accident)
- o Company procedures & training not able to account for deviations which may be faced in the process (observed in the case of one accident)
- o Lances not available onboard (observed in the case of one accident)

- Access to a particular tier or the cargo hold in general may have been blocked due to explosion and debris.

Firefighting on deck is accomplished using hoses rigged to deck hydrants. Water is discharged from the hoses to fight the fire and also to keep the other containers cool (boundary cooling). External Assistance (firefighting tugs) is also commonly sought in fighting deck container fires. Firefighting on deck presents challenges to the crew as elaborated below:

- Containers in the aft most stack on deck on fire – It is difficult to access and extinguish the fire in such locations. This was observed in the case of one accident.
- Low spacing between the container stacks along the transverse direction of the ship – For an inboard stack on fire, the space available to the crew to effectively gain access to the container stack on fire is dangerous low. This was observed in the case of two accidents. Further, the smoke, toxic fumes and heat are a further hampering factor. Possibility of explosion is also a threat to the safety of the firefighters
- Containers in higher tiers - It may not be possible to direct the water jet from the hose effectively on containers in the higher tiers. It would not be possible to penetrate the container and extinguish the fire (observed in the case of one accident).
- Blocked accessways - Access may be blocked due to explosion and fallen debris (as observed in the case of one accident). Accessways may also be blocked due to smoke and have reduced visibility. This was observed in the case of one accident**.**
- Insufficient rigging – The length of the fire hoses may not be sufficient so as for the firefighters to take them to the site of the fire (as observed in the case of one accident). Compatibility of the coupling flanges (e.g. different coupling diameters) between the hose and the hydrant may not be appropriate (as observed in the case of one accident). There may not be enough hoses on the ship (as observed in the case of one accident)
- Boundary Cooling of adjacent containers started very late as observed in the case of one accident.

The following factors may also influence the fire suppression efforts:

- External weather conditions can influence the firefighting. For example, cold weather and rough sea conditions can influence or be detrimental to the firefighting efforts (observed in the case of two accidents).
- Strong winds can affect the reach of the water jet from the fire hoses making it unable to reach the fire as observed in the case of one accident.
- Failure of the compressor or no onboard available to replenish the breathing apparatus sets (observed in the case of two accidents).
- Blackout caused due to the smoke from the fire entering the engine room air intakes and thereby stopping the engines, generators and the fire pumps. This would also hamper the firefighting efforts. The smoke may also enter the bridge and the accommodation via the respective air intakes. This would be detrimental to the firefighting and co-ordination efforts on the ship. This was observed for four accidents.
- Firefighting tugs direct enormous quantities of water during their operation on the containership's deck. Due to gaps between the hatch covers, this water enters the cargo hold. It is also noted that there were cases where the bilge pump or the bilge pump actuators failed leading to a sizeable quantity of water accumulating in the cargo hold. This is a potential hazard to the stability as well as the structural integrity of the ship (as observed for two accidents). (Fire in the cargo hold can also damage the controls with which the valves can be operated remotely)
- Firefighting in the night with reduced visibility may be comparatively difficult as compared to that during the day (as observed in the case of two accidents). Further, cold weather or winter conditions also may not be favourable to manually fight the fire, especially in the night.

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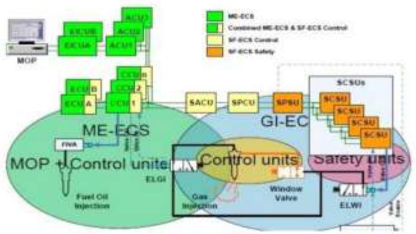

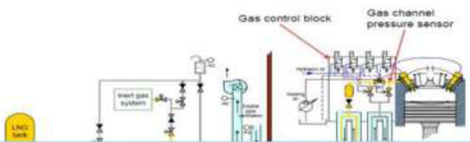

ABOUT THE TRAINER

Mr Raghu Ivaturi is a senior Marine Engineer with more than 30 Years of experience in senior ranks in Marine industry.
He has been training seafarers of leading international shipping companies for the last 25 years in various parts of the world.
He has wide experience in Operating Dual Fuel Engines

- Exhaustion of the crew in continually fighting the fire (observed in the case of one accident). This may also be attributed to the heavy firefighter's suits.
- Damage to some electronic equipment on the bridge due to the firefighting water which penetrated within in the process (observed for one accident)
- Some Breathing apparatus sets may be stowed in the fore of the ship. However these are padlocked and cannot be accessed readily during emergency (as observed in the case of one accident)

EVACUATION AND ABANDONMENT

Hazards faced during evacuation and abandonment are described as below:

- Decision to abandon ship taken too late (observed in the case of one accident)
- Abandon ship decision not communicated clearly to all crew (observed in the case of one accident, where it was not the Master who made this announcement)
- Public Address system malfunctions (as observed in one accident) and hence the abandon ship message is not received by all crew (observed in another accident)
- Lifeboats may not be in a state of readiness (observed in the one accident)
- Muster Station may be engulfed by smoke (observed in one accident)
- Lifesaving appliances could be damaged by fire/ explosion if in proximity to the site of fire especially if the fire is within the containers stowed on the hatch covers. (This was observed in one accident)
- No evacuation/escape route available to access the lifesaving appliances (observed in two accidents)
- First-aid kit not available or accessible to treat the injured (due to blockage of passageways or no first aid kit available in the fore part of the ship as observed in one accident)
- Lifeboat difficult or not possible to manoeuvre due to fallen containers within the sea (observed in one accident).
- All crew may not have participated in the lifeboat drills. This may lead to lack of familiarisation (as observed in one accident)
- Substantial crew change before the voyage, new crew may thus not be fully familiarised (in one accident, 25% of the crew were new and joined the ship before the voyage)

CONCLUSIONS

A comprehensive study of the fires on container ships in the cargo area has been performed. Data was considered from previous incidents in the past decade. Accident investigation reports were also studied. Common contributing factors have been identified.

Using the results from the present study, it is endeavoured to develop a detailed risk model so as to identify key risk contributors (in accordance with the IMO FSA Guidelines). This is envisaged to further contribute to ultimate goal of improving the fire safety of containerships. The outcome of this study will be further utilised in developing risk models. This will constitute step 2 of the FSA study.

ACKNOWLEDGEMENTS

The author sincerely thanks the Indian Register of Shipping for their support. It should be noted that the views presented in this paper are those of the author and may not necessarily reflect those of the Indian Register of Shipping.

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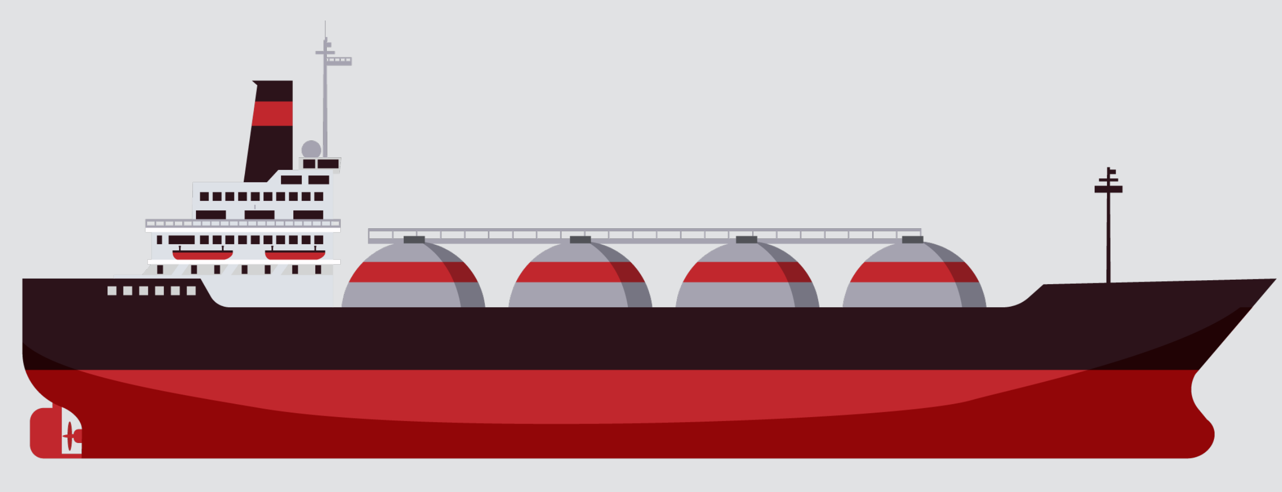
About the author

Karan Doshi is a Senior Surveyor working within the Rule Development, Associated Research and External Affairs Division (RDAREA) of the Indian Register of Shipping (IRS). He is a Civil and Structural Engineer by background having joined IRS in 2009. He has worked on structural strength analysis of containerships, liquefied gas carriers and FPSOs. He also takes interests in monitoring regulatory developments. He has also contributed to development of IRS Rules and Regulations, IRS guidelines on various topics. He has represented IACS at the International Maritime Organization at the III and the PPR sub-committees.

Email: karan.doshi@irclass.org

NEW SHIP BUILDS – THE ISSUES PLAGUING PLAN APPROVALS



Narayana Prakash

Abstract

The transition towards digitalisation is moving fast in the shipbuilding industry. The whole industry seeks to capitalise on technological transformation to improve design, fabrication, and operational processes as well as improve the health, safety, and quality processes in shipyards. Maritime organisations face the daunting question of how to simultaneously meet growing demand and regulatory changes. While emissions regulations will continue to evolve, at the new building stage, appropriate approvals need to be taken at the incipient stage.

Plan approval is the integral system of the shipyard construction process, and includes a thorough evaluation of all main drawings, scantlings, systems, and installations to ensure that the design meets the operational requirements and complies with International, Flag State, and Classification Regulations and Specifications and can be overwhelming to maritime professionals.

The process of new shipbuilding typically starts with standard procedures for ship plan approval, construction survey, and issuance of a construction certificate.

The need for this article came when we realised that several Plan Approval experts post comments as a wish list/ as per their whims and fancies and not as per agreed Specifications. The oversight matters to be, approved, rejected, or modified. The outline specifications are the first basic step towards the formation and all possible comments must be brought under one umbrella. It's the outline specs that form a part of the pricing of the vessel to a larger extent before the proceedings of detailed specifications and further proceeding to form full-fledged Shipbuilding Specifications. On the contrary, the Shipyard Design house investigates Production difficulties and disagrees with certain norms and procedures.

The Basis of the Design is to maximise the maritime contribution in the Merchant Navy fleet and investigate the size of the product and its activities. It's the experience gained through ship operation that a good designer learns and implements the improved design which can be utilised in all future approvals.

Key words: Plan approval; shipbuilding; shipyard; Design

Details of plan Approval

Plan Approval Process:

'Ship Plans Approval' refers to the 'Concept' to 'Delivery' and beyond, a process of reviewing and evaluating the plans based on the applicable rules and regulations by the Administration, Flag State, and Owners that are always passing through the Improvement phase when failure is observed during the operation of the vessel.

The approval of the project management plan is confirmation that the project information and management strategy have been developed to a level of detail sufficient to proceed to the design phase for the development of a design solution in compliance with the project objectives and requirements. It is accompanied by detailed specifications of the hull and machinery. This general arrangement plan and the specifications form the basis of the contract between the shipowner and shipbuilder.

The detailed Plan approval examination ensures: -

- Design complies with contract specifications, shipyard standards, and statutory requirements
- The design is fit for purpose, including operation and maintenance
- Quality of the design meets the Owner's expectations
- Over complexity is removed from the design during design development
- Early identification of potential build problems that arise
- Identification of areas that will require additional supervision focus
- All correspondence and drawings are monitored, managed, and controlled throughout the process

> **This general arrangement plan and the specifications form the basis of the contract between the shipowner and shipbuilder**

This process is achieved by an independent audit involving the design review, equipment and material supply, construction and through-life maintenance of the vessel. The Flowchart of Plan approvals is shown in **Figure 1.**

The concept of agreeing to disagree continues and this article on Plan Approvals regarding Ship Building has been prepared with the intention to remove the misconcepts related to Classification Society Rules, Flag State rules and Ships operational level.

The distributed Plan approval Architecture

1. Operationally necessary- to respond effectively to improving maritime operations
2. Technically feasible as a result of advances in technologies for networking
3. Affordability-no more expensive, and possibly less expensive
4. Scope for Continuous improvement

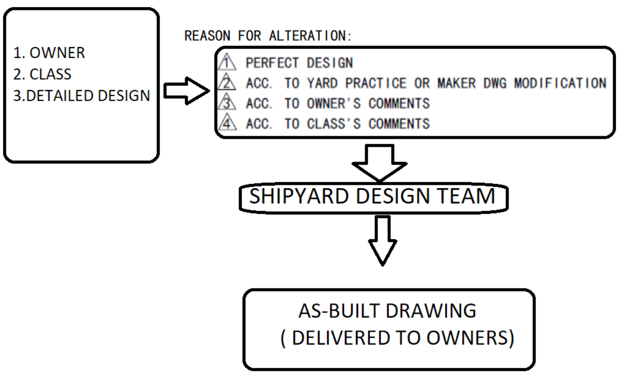


Figure 1. Plan approval flow process

On the other hand, the research must continue to build on ongoing analysis, experimentation, testing, prototyping, and the analytic results from force structure assessments, future fleet architectures, and intelligence updates to refine required capabilities and characterise the technical and operational risk of an objective operation of the ships.

'**Ship Plans and Specifications'** refer to plans showing the detailed drawings of each specific plan of the ship.

Outline specifications.

A skeleton specifications in a bound copy of about 40-50 pages with all the deliverable and prices will be included in the outlines. If the equipment capacity or any specifics of the machinery has to be included, the price will be quoted separately.

Original Specifications for approval

The specification normally has been divided into the following parts:

1. Part 1 General: This is applied to all parts of the specifications. Whereas sections from Sr. 2 to 4 are applied to other parts, if not stated otherwise.
2. Part 2 Hull
3. Part 3 Machinery

The machinery section must be perused to read the owner's requirements and trading pattern. The equipment selection is purely based on the capacity selected basically for the intended purpose. The generators' capacity and Load balance must be calculated to ensure sufficient power requirements are dealt with. Similarly, it is extended for Boilers and purifiers.

4. Part 4 Electric and automation

The above 4 parts are shipyard design standards and are issued to owners in the same original form. In today's shipbuilding, orders are never vetted by a responsible person in the design house and are never altered in any form whenever any topic of interest is obsolete or outdated. Needless to say, it is the owner's new building team that goes through the specifications and corrects – removes/ deletes or makes modifications. The time has now come for the shipyards' design teams who initially originated the specification to have a closer look to identify and make it more meaningful for the final built-up of the product.

The specifications and plans are also intended to explain each other, and anything shown on the plans and not stipulated in the Specifications or stipulated in the specifications and not shown in the plans, shall be deemed, and considered as if embodied in both. In the event of a conflict between the Specification and plans, the **Specifications** shall govern and prevail.

However, with regards to such inconsistency between the Contract and Specifications as may occur later by any change or changes in the Specifications agreed upon by and among the Parties after execution of the Contract, then such change or changes shall govern.

> *"In today's shipbuilding, orders are never vetted by a responsible person in the design house and are never altered in any form whenever any topic of interest is obsolete or outdated"*

The time has come now for the need to review the specifications and drawings and all deviations to be upgraded and improvised with a Revision. Each Shipyard must now develop standard Bulk Carrier/Tanker /LPG/ Container vessel-specific Specifications, being reviewed at the micro level, and if any owner extra requirements shall be included and presented with extra cost.

AGREE TO DISAGREE DURING PLAN APPROVALS

There are certain comments made in shipyards all over the world and few comments from owners are replied to in their standard formats as shipyards would not like to budge from their position or standalone point of view. An illustration follows.

The Motor Overloads are subjected to be tested by lowering the set point that is designed for. Standard replies from the Shipyard Design team are:

a) Reducing the setting on the starter makes it very hard to obtain the temperature and test the motor overload. The running time may be in hours.

b) The starter temperature also depends on the weather of winter or summer. The motor overload testing by a short circuit is the maker's standard function requirement.

c) The performance chart of the thermal relay of the hatch starter is to be reviewed. If the electric current is not bigger enough, the reaction time is very long,

d) *Finally, the Shipyard agrees to add this method to the procedure after deliberations by Owners Plan approval experts.*

The overload test intends to see that the contactor releases when the amperage exceeds the set value. This cannot be the case by pressing the button because that is mechanically releasing the contact – NOT ELECTRICALLY!

All involved personnel must understand that Class Rules cannot define every situation and cannot be prescriptive in every situation. However, one must understand the intent of a test and use one's technical judgment on how the intent should be met.

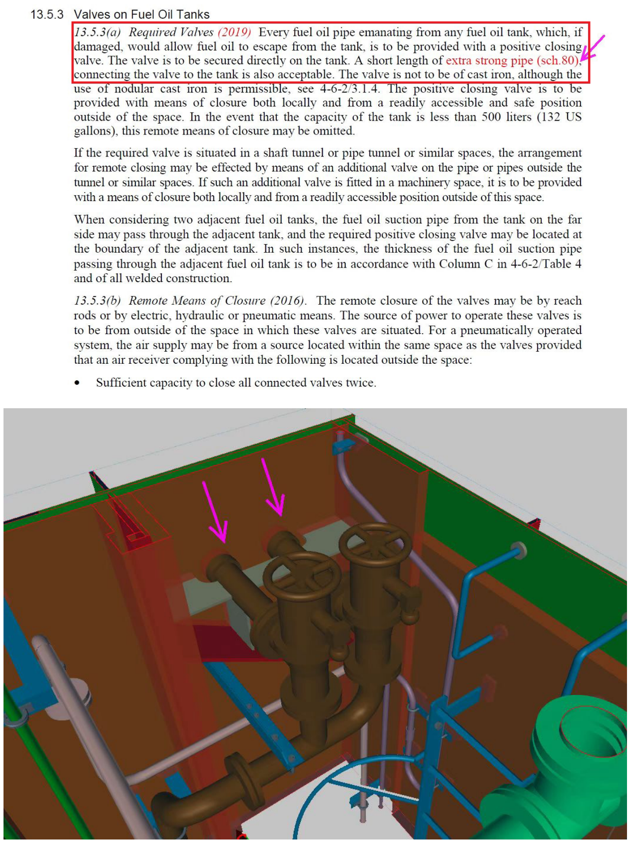
In this case, the overload relay is supposed to open the motor contact when the amperage exceeds the set value. And that is what is supposed to be demonstrated during the test. Last of all, do not use trip buttons to do a test in this manner which serves no purpose.

The Class rules do not define the procedure for testing and shipyard takes this to their advantage level. The time has come to question the Class and include the procedures that are to be verified during the construction process. What we can infer is that the shipyard disagrees in the first stage and when the owners plan approval experts push enough with logical stand then the shipyard agrees at a later stage.

There are several cases that the author experienced and is beyond the scope of the article.

OMITTED DURING THE PLAN APPROVAL STAGE-FOUND DURING THE PRODUCTION STAGE

For a plan approval expert handling different Projects, and dealing with the shipyard which has already built a series of 30-40 ships, there can still be missed-out information.



13.5.3 Valves on Fuel Oil Tanks

13.5.3(a) Required Valves (2019) Every fuel oil pipe emanating from any fuel oil tank, which, if damaged, would allow fuel oil to escape from the tank, is to be provided with a positive closing valve. The valve is to be secured directly on the tank. A short length of extra strong pipe (sch.80), connecting the valve to the tank is also acceptable. The valve is not to be of cast iron, although the use of nodular cast iron is permissible, see 4-6-2/3.1.4. The positive closing valve is to be provided with means of closure both locally and from a readily accessible and safe position outside of the space. In the event that the capacity of the tank is less than 500 liters (132 US gallons), this remote means of closure may be omitted.

If the required valve is situated in a shaft tunnel or pipe tunnel or similar spaces, the arrangement for remote closing may be effected by means of an additional valve on the pipe or pipes outside the tunnel or similar spaces. If such an additional valve is fitted in a machinery space, it is to be provided with a means of closure both locally and from a readily accessible position outside of this space.

When considering two adjacent fuel oil tanks, the fuel oil suction pipe from the tank on the far side may pass through the adjacent tank, and the required positive closing valve may be located at the boundary of the adjacent tank. In such instances, the thickness of the fuel oil suction pipe passing through the adjacent fuel oil tank is to be in accordance with Column C in 4-6-2/Table 4 and of all welded construction.

13.5.3(b) Remote Means of Closure (2016). The remote closure of the valves may be by reach rods or by electric, hydraulic or pneumatic means. The source of power to operate these valves is to be from outside of the space in which these valves are situated. For a pneumatically operated system, the air supply may be from a source located within the same space as the valves provided that an air receiver complying with the following is located outside the space:

- Sufficient capacity to close all connected valves twice.

Figure 2. Discrepancies observed.

One such case under the purview of the Plan approval experts are the P&I drawings which they approve them after due reviews. Then there are the detailed design drawings which must be collected by the ship owner site team and checked carefully with the Class rules. For example, the penetration of a pipe through the bulkhead and the end-to-end stage of pipelines are to be reviewed with the type of pipes about the schedule of piping.

> *The Class rules do not define the procedure for testing and shipyard takes this to their advantage level*

Valves on Fuel Tanks

As per ABS class requirements 13.5.3 (a) required valves (2019) every fuel oil pipe emanating from any FO Tank, which, if damaged, would allow FO to escape from the tank, is to be provided with a positive closing valve. The valve is to be secured directly on the tank. a short length of extra strong pipe (sch.80), connecting the valve to the tank is also acceptable. But, observed penetration pipes size is φ89*4 during the inspection and to change to Sch.80 pipes (pipe thickness 7.5mm).

Figure 2 shows the Discrepancies observed.

In short, there is inconsistency in piping dimensions noticed for piping drawings, which needs to be closely reviewed and monitored.

INTER-RELATIONS BETWEEN HULL OUTFITTING, MACHINERY AND ELECTRICAL EQUIPMENT

Very Few plan approval experts check all drawings for interdependency and interrelations concerning layout and fouling. Since plan approval experts are designated for General and Hull and painting, Hull and outfitting, Machinery, and outfitting, and Electrical and outfitting, very few experts look in totality.

A case has been observed with the Australian ladder of the Bulk Carrier where in the heavy ballast Cargo Hold there is no sufficient gap between the Landing platform for painting **(See Figures 3 and 4)**.

PLAN APPROVAL CONCERNING THE OPERATION OF SHIPS

In most cases, the Plan approval experts do not keep up with the latest regulations of various terminals and ports. The titbits of information received when one vessel is detained in a port or when a vessel is given a remark due to non-compliance of the existing regulations serve as inputs for experience.

As a standard practice, the Experts must be in close liaison with Managers /Owners and get the port info to be incorporated in the approvals.

One example is the Australian port and terminal regulations which vary from port to port. Whether the vessel complies with all these is a matter to review.

1. Port Hedland Mooring Management Standard
2. Hay point mooring management standards
3. The requirement at Dampier and Port Walcott of minimum SWL of tug bollard is 65T.
4. Requirements of secondary support for gangways.
5. Recommendations for helicopter hatch access requirements for Dampier/Port Walcott **(See Figure 5).**

The second case observed was that a void space was found to have a lot of bunker piping and valve handlings. A manhole of 800 X 600mm was provided as a means of access. There were no ventilation and lighting arrangements inside the void space. Later after many

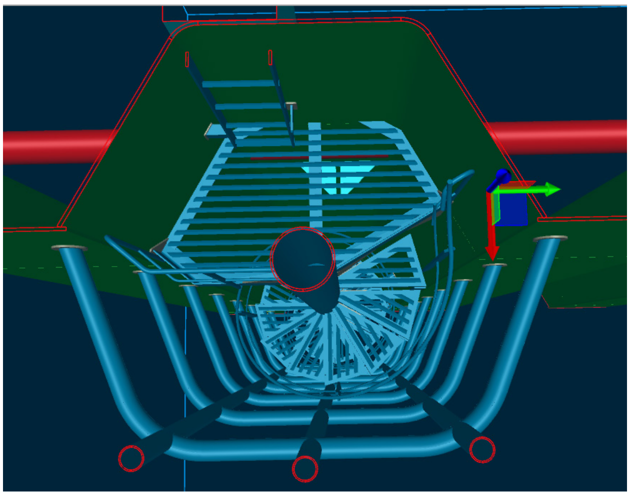


Figure 3. Landing platform in Cargo Hold

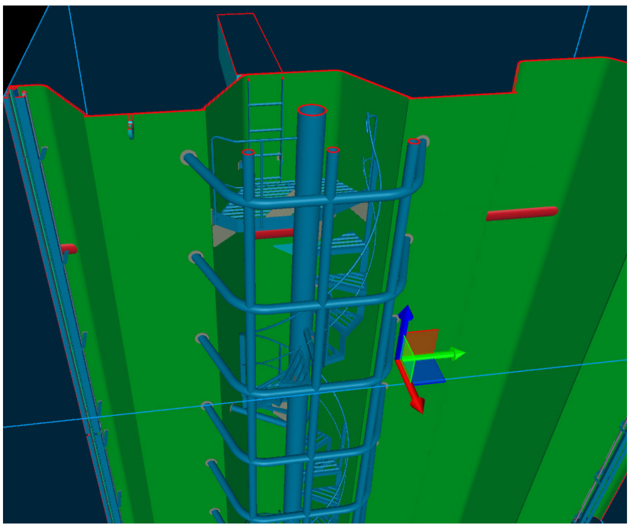


Figure 4. Arrangement of ladders

Figure 5. Helicopter hatch access requirements

deliberations, it was decided to have a watertight door along with lighting and ventilation arrangements.

During the plan approval stage, this important information was unknown, and it was only known by the supervision team who had experience on board ships in the operations of ships where the modifications were affected. The above is not a Class issue but an owner's point of consideration.

Another case is the fuel changeover procedure but during the plan approval stage, no experts discuss the calculations for the time of changeover of the Fuel. This requires certain volumetric inputs of the fluid inside the pipeline. The Chief Engineer of the vessel can easily calculate the time of changeover if the volumetric input is known. See **Table 1**.

OWNERS VS CLASS APPROVALS

While the Class follows its regulations to accomplish the approvals, owners investigate Class regulations plus the operations point of view. In several piping systems, we note that the Class approves the drawings without many comments if they are not operationally considered. **For a Piping drawing, found that the main engine had no isolating valve for a particular unit to drain out water during the decarbonisation of a particular unit. It was found only after 15 years of operation and a valve was installed in Dry Dock.**

During a recent plan approval it was found that the need for an isolating valve was missing to isolate the AE from the LT expansion tank in case one AE needs to be isolated from the other two running generators. Such plan approvals happen only when the person has experience working on ships. Then the vessel delivered shall be operated seamlessly and maintained by the ship's crew without any bottlenecks.

PLAN APPROVAL FOR TRADING PATTERNS

Since a vessel is used for trading all over the world, it is the responsibility of the Plan approval experts to keep updating all regulations that are at least the vessel intending to trade.

The Old Panama Canal arrangement can be used only in Old Panama Canal transit. The New Panama Canal regulations can be used for both canals. Owners must keep in mind to design as per the latest new Panama Canal requirements.

PLAN APPROVAL FOR OWNERS' SPECIFIC REQUIREMENTS/GREEN SHIPPING

Major Extras Over Standard Specifications (Figure 6)

1. Class Notations: ABS +A1, E, Bulk Carrier, CSR, AB-CM, BC-A (Cargo holds 2 & 4 may be empty), Grab[20], +AMS, +ACCU, BWT, BWE, CPS, TCM, UWILD, ESP, ENVIRO, RRDA, GP, SMART INF.
2. EEDI Ph 3
3. Main engine is made in Korea by Hyundai Heavy Industries, Ulsan.
4. Mass flow meters specified for accurate measurement of fuel oil consumption.
5. Main seawater motors and ER ventilation fan motors fitted with Variable Frequency Drive
6. High-efficiency propeller, rudder bulb, and half stator duct applied as fuel-saving devices.
7. All normal lighting changed to LED lighting.
8. Fitted with Ballast Water Treatment System, IMO & USCG approved. Capacity 2 x 1000 m3/h.
9. LSA increased to 30 persons from 25 persons.

Table 1. Volumetric Inputs

No		PIPE SIZE	Total L (mm)	Vol m3
1	F.O SUPPLY UNIT → M/E INLET	DN50	17963	0.15
2	M/E OUTLET → F.O.SUPPLY UNIT	DN40	31087	0.16
3	→ G/E INLET	DN32	45408	0.17
4	→ G/E OUTLET	DN32	42249	0.16
5	CHANGEOVER VALVE → F.O SUPPLY PUMP FOR BOILER →BOILER INLET	DN40	44807	0.23

10. Ballast gauging system digital type and interfaced with ship's loading computer.
11. Painting: Upgraded specifications. Low friction paint was applied on the hull to improve fuel savings.
12. Brake drums of mooring winches of stainless-steel material.
13. All mooring ropes upgraded to HMPE type.
14. Deck cargo crane slewing bearing upgraded to heavy-duty double roller type.
15. Vessel's inner bottom is additionally strengthened for 2 tier x 25T steel coils.
16. Arrangements provided for deck cargoes.
17. Tug push area local strength 64T.
18. Industrial type washing machines.
19. Cleanliness factor for heat exchangers increased to 85% from the originally specified 90% for plate coolers.
20. ECDIS
21. SSD Radars
22. V-Sat communication system with Iridium Certus backup system will be provided by Owner.
23. CO2 Flooding System – Fixed Fire Fighting on board.
24. Performance Monitoring

APPROVED DURING PLAN APPROVALS BUT DOES NOT SERVE PURPOSE IN REALITY

A case of Bunker FO davit provided but cannot satisfy the requirement of LO bunkers which are close by position. **(Figure 7)**

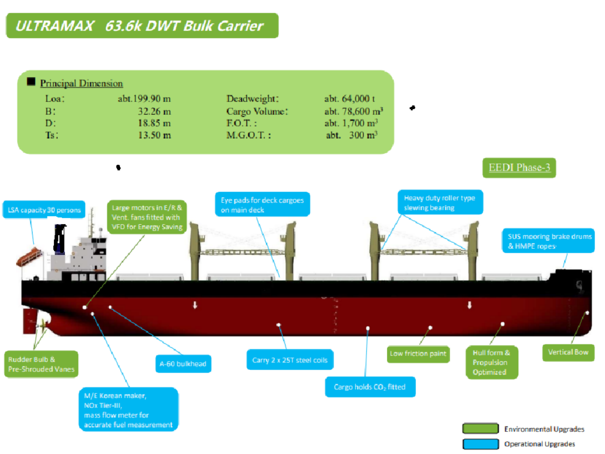


Figure 6. Extra Features
Courtesy: COSCO Shipping Ltd.

In several piping systems, we note that the Class approves the drawings without many comments if they are not operationally considered

PREFERRED ROUTING OF VARIOUS PIPES

It was observed during the 3D Modelling that the steam pipelines were very closely installed near the ladder /normal passage. **(Figure 8)**

ERECTION JOINTS AND MACHINERY INSTALLATIONS-OVERLOOKED GAPS

During Plan approvals normally, plan approval experts never think of the Block division and where machinery is being installed. There has been a case where the foundation of the Auxiliary generator was installed in two portions. Later the welding was carried out at the Pre-erection stage. This is not an acceptable shipbuilding practice and at the design stage, this must be considered. **(See Figure 9)**

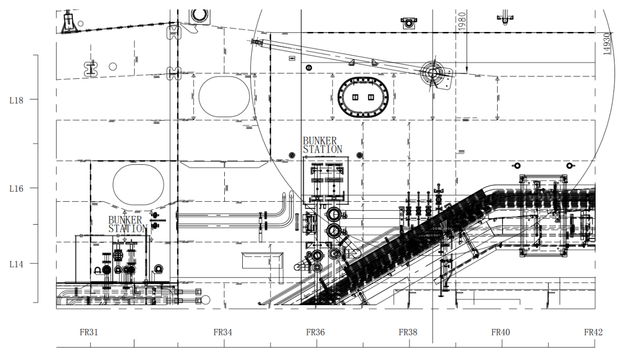


Figure 7. Bunker Davit arrangements

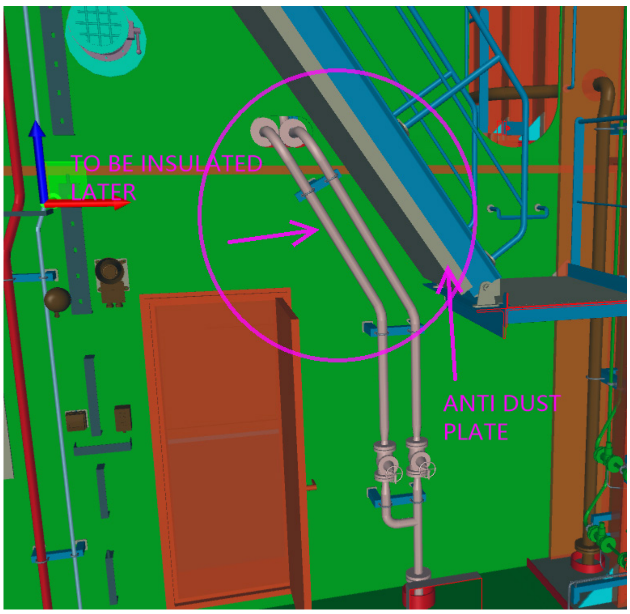


Figure 8. Safety ignored in the passageway

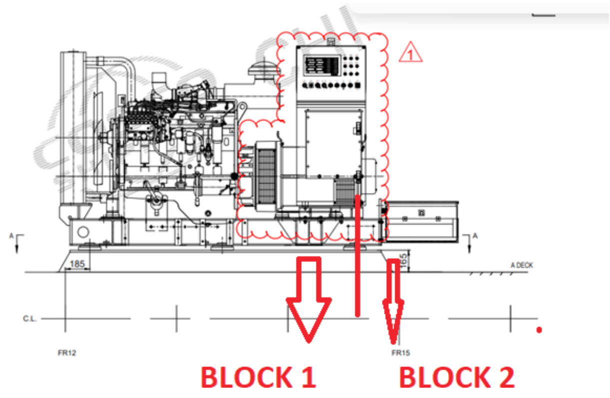


Figure 9. Generator Foundation split into two Blocks

PLANNED AT PLAN APPROVAL STAGE BUT TEETHING PROBLEMS AT PRODUCTION STAGE

Nowadays all Shipyards are in a hurry to complete production as soon as possible. In the melee, the sequence is disrupted when one Equipment or some piping preferred routing is modified due to system characteristics. Then one piping system can be bifurcated into 2/3 systems to complete installations, and flushing can be done as an integrated system later.

The Main Engine is not installed, and delays are expected. Hence, the process will be to complete the piping installation inspections by bifurcations and later, after the ME installation completes, the flushing actions are planned. **(See Figure 10)**

The state of hurriedness and to avoid the slipping of key milestones, shipyards tend to bypass certain standard operating procedures (e.g., without the Block Erection being completed or welding complete, the piping installation, and the tightness tests are commenced). The repercussions could result in disasters. In such cases, a 'STOP WORK' notice must be issued.

3D MODEL PLAN REVIEWS

Once the Plan approval is complete, the shipyard invites the owner team for a 3D Model review. Here all the operational issues are resolved to consider the maintenance and operational **(See Figure 11).**

UNCLEAR ISSUES

There have been instances where the site supervision team comes to know certain requirements of the Ship staff who operate the vessel, only at a later point of time.

Another issue to illustrate is that there is no requirement by any Class to have a manual operating whistle on the wheelhouse. But there is a provision for a 24-volt DC supply voltage from the battery and 220v voltage supply from the normal power supply.

The time has come to review the Class rules and incorporate, manual operation in case of power failure for operating solenoid valves.

During Plan approvals, a few issues arose when the designers installed the battery room Door opening Right-Handed instead of Left handed, which was fouling with the Natural vent of the room **(See Figure 12).**

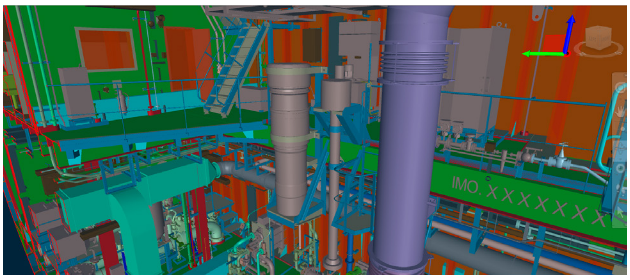


Figure 10. Sequence of construction and shipbuilding practice

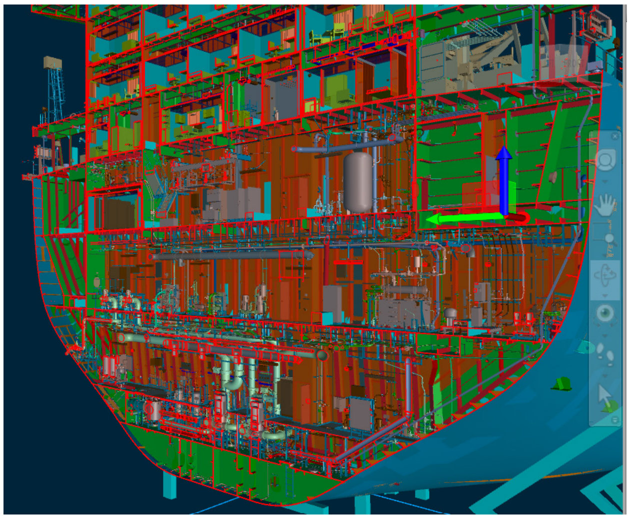


Figure 11. Cut section from Aft

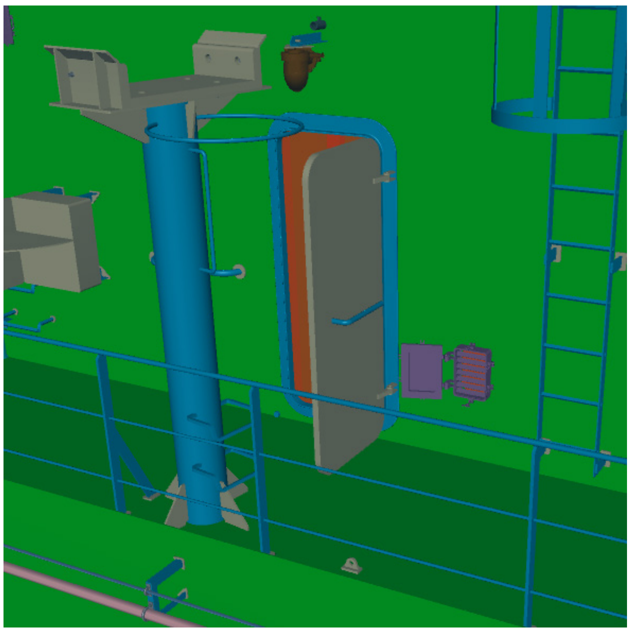


Figure 12. Natural vent fouling with the door

Implementing 3D models throughout the design and approval processes of new ships is the way of the future, unlocking a new level of collaboration and information-sharing in the ship design process

CONCLUSION

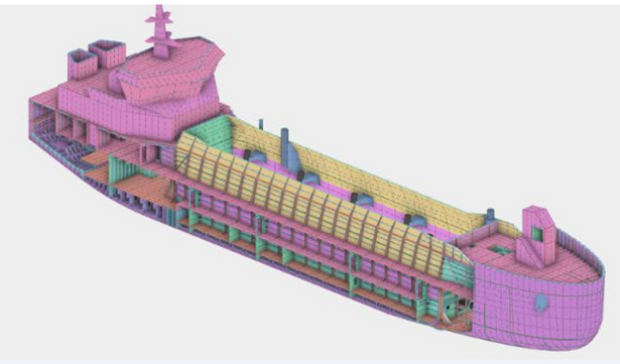
THE WAY OF THE FUTURE

Future IMO and ILO Legislation may address all discussed issues. Owners must rethink for the future and must align themselves to follow Regulations that have emerged.

Implementing 3D models throughout the design and approval processes of new ships is the way of the future, unlocking a new level of collaboration and information-sharing in the ship design process. This creates a win-win situation that helps teams innovate together, enabling them to make the most of time and resources to deliver the best possible designs. This will save a significant percentage of design time when we integrate this way of working as a standard. This is particularly important at a time when the decarbonisation transition is increasing the pressure on designers and shipyards to create a new generation of greener and more efficient vessels and incorporate new fuels and technologies on board.

Vessel steel hull Design evaluation based on 3D models in parallel to its classification review process and has become possible, thanks to the new data exchange format - OCX.

The OCX is an open standard that facilitates data exchange of 3D ship models for class approval. This Open Class 3D Exchange standard has been developed by a consortium of software companies including NAPA and Aveva, together with classification societies including DNV, Bureau Veritas, and Lloyds Register. In close collaboration with Finnish software developer NAPA and Bureau Veritas, Damen has presented the three-dimensional design of their TSHD 2500 (Trailing Suction Hopper Dredger with 2500 m^3 hopper capacity). All the mission equipment as specified for a client had been integrated into this design. Bureau Veritas assessed the steel hull structure to be strong enough and safe to SOLAS standards, with all the heavy equipment operators.



Damen Takes Lead in 3D Model Based Class Approval

Figure 13. 3D model Courtesy: Damen Shipyard

3D model-based class approval is the future of the Design process **(See Figure 13)**. We expect to be able to save significant percent of design time when we integrate this way of working as a standard.' This is a good point to design in 3D. Also, using Space Mouse (3Dmouse) in 3D will help more to save design time and navigate the 3D model intuitively. We also hope that other CAD software such as Solid Works, Fusion, and NX will start implementing this standard. The big benefit is the enhanced project team collaboration within the same, fully digital, transparent daily work context, applicable for designers and approval engineer at the same time.

A Milestone But Not Unexpected

Shipyards are integrating smart technologies to advance automation, and data-driven intelligence and improve operations and work processes. We expect to be able to save significant percent of design time when we integrate this way of working as a standard.' This is a good point to design in 3D. Also, using Space Mouse (3D mouse) in 3D will help more to save design time and navigate the 3D model intuitively. We also hope that other CAD software such as Solid Works, Fusion, and NX will start implementing this standard. Plan approval experts must detect, identify, and track to realise the optimum design for the seamless operation of the vessels.

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About the author

Narayana Prakash is a Senior Chief engineer, who worked for 15 years at sea, 15 years in the construction of ships (site supervision), and about 7 years in the design of ships and plan approvals. Presently working as Senior Site Project manager for KC Maritime Ltd Hong Kong.

Email: getnp65@outlook.com

Troubleshooting of Alternators Part 1B

Elstan A. Fernandez

1.6 Precautionary Measures to be Taken After Repairs

After maintenance and repairs, no-load running checks should precede synchronising and loading.

1. Run in the engine (prime mover) without any load, otherwise known as 'idling'.
2. Stop the engine after about 30 minutes, let it cool down and check the bottom-end bolts, bearings and other systems / auxiliaries.
3. Restart the engine and load it partially – about 50% of the generator's full load for about 1 hour; continue to check all parameters and log (record) them adequately. Whilst the machine is on load, particularly check for excessive temperature rise and stability.
4. Then slowly increase the load to about 80% of the generator's load; if this is satisfactory, a full-load trial may be carried out.
5. During the period that the engine is running, check all trips and cut-outs; temperature and pressure simulators may be used to simulate abnormal conditions as the generator / engine may not reach these limits if all is well with the systems. If the machine runs 'hot' then almost certainly internal condensation on its insulation would result when the machine cools down. As with all electrical equipment, dirt, overheating and dampness are detrimental!
6. Synchronising trials may be carried out after it is ascertained that all parameters are stable and have been recorded.

1.6.1 Checking the Main Stator Winding

a) The voltages between phases, and each phase to neutral, should be balanced, to within 1% of the nominal voltage.

b) On a single-phase machine the voltage between L1-L4, and L2-L4 or U-N and W-N, must be balanced.

c) If the voltage is 10% or more below the nominal voltage, but is balanced within 1% phase to phase, proceed to 1.7.1.

a) If the voltage is unbalanced by more than 1%, this indicates that a fault exists with the main stator windings.

b) This test should be repeated with all external connections removed from the Generator terminals, to eliminate the possibility of external shorts in the output cables, or the circuit breaker.

c) Further tests may be made on the resistance values of the main stator windings with a Kelvin Bridge resistance test meter. (Refer to the Operation and Maintenance manual for main stator winding resistance values).

1.7 Symptoms of a Main Stator Fault

A fault in the main stator windings will produce short circuit currents between the coil turns in the windings.

When separately exciting with a battery, the current will also create heat in the damaged winding, which can also be heard as a slight loading of the engine.

The three fault symptoms:

1) Unbalanced Voltages.

2) Heat and / or a burning smell from the windings.

3) Engine sounds loaded, are all indications of a faulty main stator winding.

A faulty winding must be repaired or replaced.

1.7.1 The Voltage is Balanced but the Reading is Low

If the output voltage is more than 10% below the nominal voltage, but is balanced within 1% Phase to Phase, (or Phase to Neutral), the main stator is OK, but there is a fault elsewhere. This indicates that a fault exists in either the main rotating rectifier assembly, (diodes and Varistor), or one of the excitation windings, (the main rotor, or exciter stator, or exciter rotor).

First check that the D.C. battery supply is not lower than the allowable value, and that the engine speed is correct. This could give misleading results if incorrect.

1.8 Testing the Rotating Rectifier Assembly

The diodes on the main rectifier assembly can be checked with a multimeter. The flexible leads connected to each diode should be disconnected at the terminal end, and the forward and reverse resistance checked. (Refer to article 1.4).

Whilst it is acceptable to use a multi-meter in the resistance measuring mode - as the first part of the process to identify if a diode is serviceable, the only certainty is that this test will identify a diode that is either short circuit or open circuit. A multi-meter – diode test or resistance mode - will not deliver a voltage high enough to determine if the diode's P-N junction is able to block current flow in the reverse polarity direction, when that diode is subjected to the voltage levels associated with operating working conditions.

The rectifier assembly is split into two plates, positive and negative, and the main rotor is connected across these plates.

Each plate carries 3 diodes, the negative plate carries the negative based diodes, and the positive plate carries the positive based diodes. Care must be taken to ensure that three identical polarity diodes are fitted to each plate. When fitting the diodes to the plates they must be tight enough to ensure a good mechanical and electrical contact, but should not be over tightened. The recommended torque tightening is 4.06 to 4.74 Nm, (14 to 17 kg/cm).

The practical method of testing a diode's reverse voltage blocking capability involves subjecting the suspect diode to a bench test. Using a safe 240 V 50 Hz mains supply, the diode is connected in series with a 240 V (nominally) 40 W filament light bulb.

The diode is serviceable if the bulb illuminates at half brilliance with a flickering effect, which indicates the bulb is obviously only being supplied with power for every half cycle that is aligned with the diodes forward conducting direction.

The diode is unserviceable if the bulb illuminates at full brilliance showing no signs of 'flickering'.

1.9 Testing the Surge Suppressor (Varistor)

The Surge Suppressor (Varistor) is a protection device, which prevents high voltage transients from damaging the main rectifier diodes.

High Voltage transients are created by fault conditions in the distribution system. The Voltage transient returns back to the Generator output terminals, enters the main stator windings, and by mutual inductance, is transferred to the main rotor windings, and the main rectifier assembly.

The Surge Suppressor can be tested with a Multimeter on M Ω range. A good Surge Suppressor should have a very high resistance, (more than 100 M Ω in either direction).

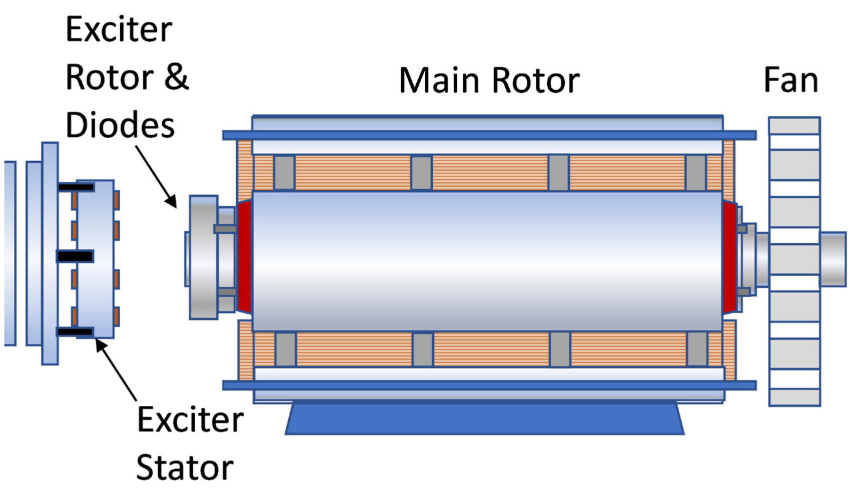


Figure 8. Main Parts of the Alternator

If the output voltage is more than 10% below the nominal voltage, but is balanced within 1% Phase to Phase, (or Phase to Neutral), the main stator is OK, but there is a fault elsewhere

A faulty Surge Suppressor will be either open circuit (usually showing signs of burning) or short circuit in both directions. The Main Rectifier will work normally with this device removed.

However, it should be replaced as soon as possible, to avoid diode failure in the event of further transient fault conditions. Occasionally, a very high transient may totally destroy the Surge Suppressor. This would result from extreme fault conditions, such as lightening, (electric storms), close to overhead distribution lines, or out of phase synchronisation of the Generator, when paralleled to multiple Generator systems, (or the Mains, Utility, supply).

In the event of a Surge Suppressor failure, all rectifier diodes should be replaced, including any which appear to test okay.

A multi-meter – diode test or resistance mode - will not deliver a voltage high enough to determine if the diode's P-N junction is able to block current flow in the reverse polarity direction, when that diode is subjected to the voltage levels associated with operating working conditions

1.10 Testing the Main Excitation Windings

After establishing and correcting any fault on the rectifier assembly, the battery test should be repeated, and the output voltage checked. If the output voltage is still more than 10% below the nominal voltage when separately excited, this indicates that the fault must be in one of the excitation windings. To test the main rotor, exciter stator and exciter rotor winding, the resistance values must be checked against correct values, which are given in the Operation and Maintenance handbook, supplied with the generator.

Note: *The charts require identification of the frame size, number of rotor poles, followed by the main stator and rotor core length (A, B, C – G, H, J, etc). The Main Stator core length and winding number are shown on the Generator nameplate.*

If in doubt, refer to the manufacturer, with the generator's serial number or machine I.D number, for identification.

1.10.1 Exciter Stator

The exciter stator resistance is measured across leads X+ and XX- (F1 and F2 or J and K), which should be disconnected from the Automatic Voltage Regulator (AVR), terminals. A standard multimeter, set on the lowest resistance range, will be suitable for this test. The exciter Stator winding Insulation to earth should also be tested with a 'Megger'. As a low insulation can affect the AVR performance. Minimum value 1 Megohm. (See article 1.2 for details).

1.10.2 Exciter Rotor

The exciter rotor is connected to the 6 X AC connection studs on the Main Rectifier assembly. Disconnect the 6 leads from the AC connection studs, and check the resistance value across three of the leads, which are connected to the same polarity diodes, (bolted to the same rectifier plate). The resistance value is very low, and requires a Kelvin Bridge test meter for accurate results. A visual inspection will usually identify any burnt or damaged windings

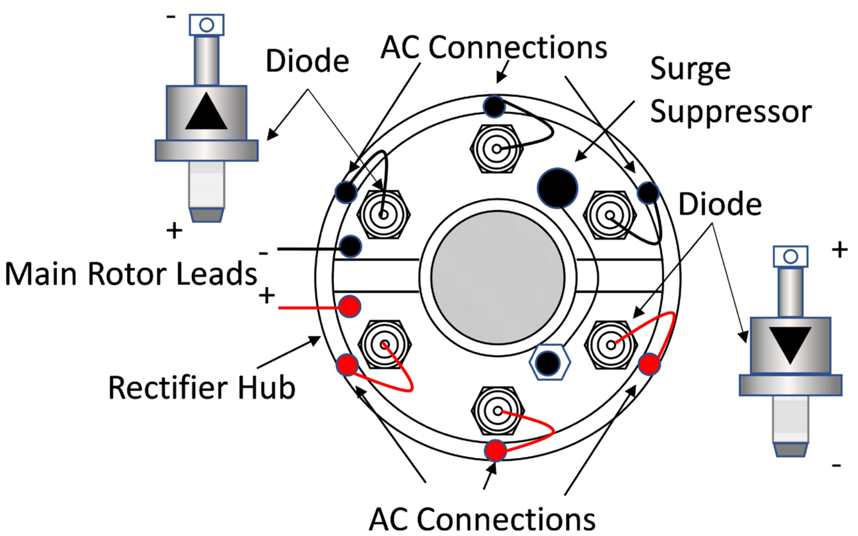


Figure 9. The Three-phase Rectifier (Rotating Diodes)

1.10.3 Testing the Main Rotor

The main Rotor leads are connected to the main rectifier plates. Disconnect one of the leads to check the resistance value. A good quality Multimeter will measure resistances of 0.5 to 2 ohms with reasonable accuracy, however if the resistance is found to be lower than the quoted figure, it should be verified with a more accurate measurement.

1.11 Testing the AVR Sensing Supply (Feedback)

Checking the sensing supply from the main stator is the final test, which can be carried out while separately exciting the Generator with a battery supply. Make sure the output voltage is approximately correct, i.e. within 10% of the nominal voltage). The previous tests should have cleared any fault in the windings or rectifier assembly and the correct output obtained from the main stator with the battery. With the Generator running at nominal voltage, the sensing supply should be between 190 and 240 V. If the supply is incorrect, or unbalanced, the fault should be traced back via the wiring circuit to the main stator connections

1.11.1 Two-phase Sensed AVRs

The sensing supply is across AVR terminals

Note. *For generators supplied before 1989, the parallel droop CT, and close regulation CT, (when fitted), is generally connected into the sensing supply via a burden resistor, fitted in the terminal box.* Refer to the Operation and Maintenance manual supplied with the Generator for details

1.11.2 Three-phase Sensed AVRs

The sensing supply is connected to the AVR terminals marked 6, 7, and 8.

Note 1: *The sensing supply is connected via an isolation transformer, or an isolation module, (PCB), fitted in the generator's terminal box. Check primary and secondary of transformer, or input and output of PCB.*

Note 2: *For generators supplied before 1989, the parallel droop CT, and close regulation CT, (when fitted), is generally connected into the sensing supply via a burden resistor, fitted in the terminal box.*

The sensing supply is connected via a separate 3-phase sensing unit, the sensing supply leads are connected to the 3-phase sensing unit, which has a DC output to the AVR. Refer to the Operation and Maintenance Manual supplied with the generator for details.

Acknowledgements and References

Thanks to my dear classmates Lakshman Singh Yadav and Harbhajan Singh for co-authoring a very popular series with me, titled 'Marine Electrical Maintenance and Troubleshooting', comprising of four books.

About the author

Elstan A Fernandez: 44 years in the Maritime and Energy Industries; Author / Co-author of 80 Books

Chartered Engr, FIE, MIET (UK), MLE[SM] Harvard Square (USA); Joint Inventor with a Patent for Supervised BNWAS; Promising Indian of the Year in 2017.

Email: elstan.a.fernandez@gmail.com

LUBE MATTERS # 30

TRIBOLOGY OF GEARS

Sanjiv Wazir

Introduction

The earliest known usage of gears dates to 350 BC. Gears are machine components with teeth. They operate in pairs. Each shaft possesses appropriately shaped teeth (gear), equally spaced around its circumference, so that, as it rotates, the successive tooth goes into the space between the teeth (gear) of the other shaft. Thus, it is a machine component in which rotary power is transmitted by the toothed surface on the output shaft of a prime mover to the toothed surface of the driven shaft. Gears are amongst the most widely used machine components. They are usually fitted in a gear box and used to:

- increase torque from the prime mover (e.g., engine/ motor) to the driven equipment.
- reduce the speed generated by the prime mover.
- change the direction of motion.

Torque and speed are inversely proportionately related when power is held constant. Therefore, as torque decreases, speed increases at the same ratio.

Gear terminology

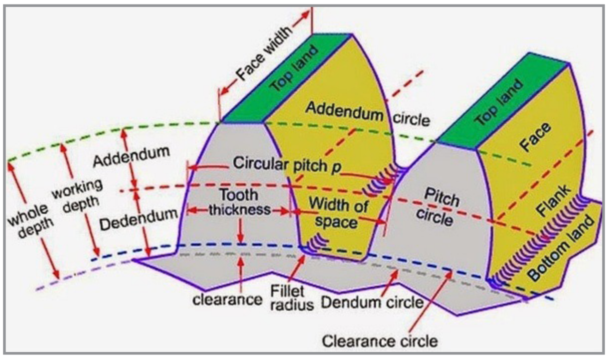


Figure 1. Nomenclature of spur gear teeth (1)

Types of gears

1A. Parallel Axes (rotary): When the two shafts of the gears are parallel. E.g., Spur gear, **Figure 1,** internal gear, and helical gear, etc. Such gears have high efficiency.

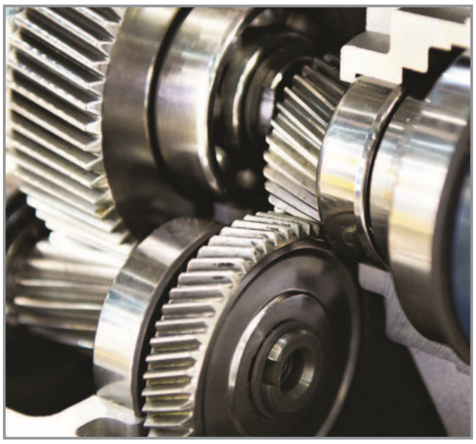


Figure 2. Helical gear train (2)

Figure 3. Herringbone gear (2)

A helical gear, **Figure 2,** is a development from the simpler spur gear. Unlike on a spur gear, in a helical gear the teeth are not parallel to the shaft. This causes multiple teeth to engage enabling higher load capacity, smoother power transmission, and less noise vis a vis spur gear. Because the gear teeth are at an angle to the gear shaft, an axial thrust is generated putting added stress on gear shaft bearings. In heavily loaded helical gears thrust bearings may be needed in the gearbox to counter the axial load.

A further development from helical gears are the double helical gears, (aka Herringbone gears), **Figure 3.** Here thrust loading on the shaft is avoided and thrust bearings are not required. They are typically used in large, heavily loaded, parallel axes gearboxes.

1B. Parallel Axes (linear): This is another form of spur gear, but with a round pinion gear engaging on a straight rack, **Figure 4.** It is used to convert rotary motion to linear motion.

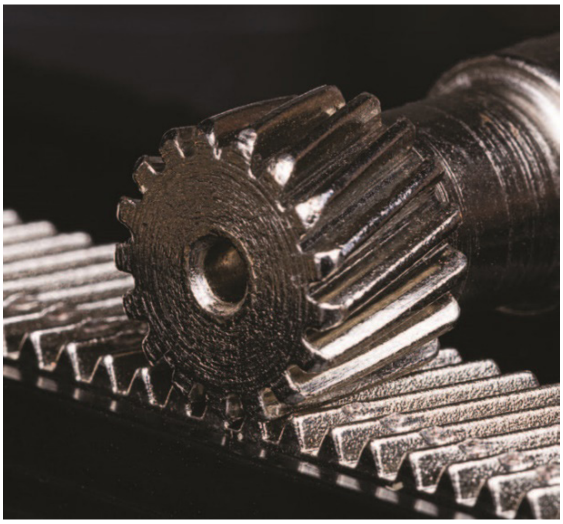


Figure 4. Rack and pinion (2)

2. Intersecting Axes: In these, the two shafts of the gears intersect each other. E.g., Straight Bevel Gear **Figure 5,** Spiral Bevel Gear, **Figure 6.** Such gears have high efficiency.

Figure 5. Bevel Gear set (2)

Figure 6. Spiral Bevel set (2)

Bevel gears are used to change the direction of motion. These pairs are mounted on shafts that typically intersect at 90 degrees to each other. Depending on which gear in **Figure 5** is the driving gear, the output speed is either increased or decreased, and the torque decreased or increased, respectively. Spiral bevel gears, **Figure 6,** take the concept of helical gear to bevel gears. They carry heavier loads and run quieter than the straight bevel gears. Here the teeth need to be curved to enable engage with the opposing gear.

3. Non-parallel, Non-intersecting Axes: When the two shafts of the gears are neither parallel nor intersecting. E.g., Worm gear and screw gear belong in this group.

> *“In a spur gear set, only one tooth per gear is fully engaged, which makes them noisier than other gear designs”*

Figure 7. Worm gear (3)

Worm gears, **Figure 7,** are different from other types of gears in that a spirally grooved screw moves against a toothed wheel. They can achieve large reductions in speed in a compact space and transmit high loads at high-speed ratios of up to 60:1.

Gear teeth engagement

Spur gears are the most widely used gears. They are simple and cheap to manufacture. In a spur gear set, only one tooth per gear is fully engaged, which makes them noisier than other gear designs.

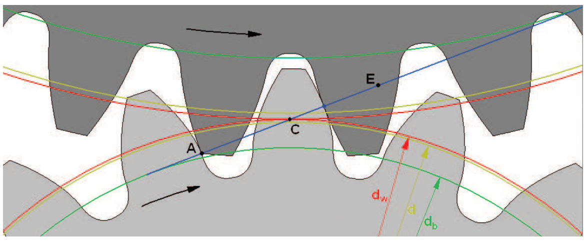


Figure 8. Spur gear engagement (4)

If, in **Figure 8,** the lower gear is assumed to be the driving gear, and the rotation is clockwise, then the upper (driven gear) is rotated counter clockwise. The first contact (A) is between a point near the root of the driving tooth (its dedendum zone) and a point at the top of the driven tooth (its addendum zone). As the gears rotate, the contact point moves from point A to E.

On the driving gear tooth, the contact point slides up its dedendum flank, on the driven gear it slides down its addendum flank, until it reaches the point C, where the pitch circles of the two meshing gears converge. After the pitch circle the contact point on the driving gear slides up its addendum flank, and on the driven gear it slides down the dedendum flank, until there is no longer any contact at point E. The line A to E is known as the line of action.

Gear tooth flanks do not conform to each other. Their involute contact is non-conformal, and contact area at any time is small. Relative motion is not only sliding. The involute curved profile of each tooth face enables some rolling.

In the gear types 1A, 1B, and 2, as the gear teeth mesh, the teeth roll and slide on each other. Rolling is continuous throughout meshing, from root to tip on the driving tooth and from tip to root on the driven tooth. Sliding varies from a maximum velocity in one direction at the start of meshing, zero velocity at the pitch line, to a maximum velocity in the other direction at the end of meshing.

At point C, where the pitch circles converge, the contact is purely rolling, increasing efficiency by eliminating sliding friction in the zone where load transfer is highest.

In metal gears, the influence of pressure (maximum Hertzian pressure can reach 10000 -40000 Bars) on the lubricant viscosity (Pressure-Viscosity Coefficient "α"), **Figure 9,** along with the elastic deformation of the bodies, plays a key role in oil film formation.

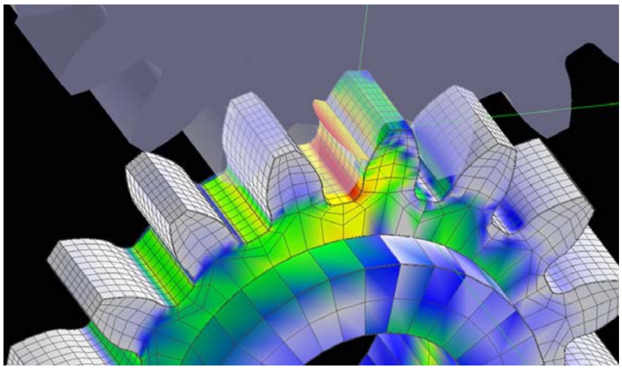


Figure 9. Spur gear – Contact pressure Distribution (5)

A lubricant subjected to 10000 bar pressure can undergo a 22000-fold increase in viscosity compared to its viscosity at atmospheric pressure. The lubricant behaves more like a solid than a liquid. This is known as hard EHL, where there is no asperity contact under full-film EHL (refer to LM 23-Lubrication Regimes Part II for more details of EHL).

Surface roughness of the interacting surfaces has a strong impact on the tribological behaviour. Depending on operating conditions, asperities of two mating gear flanks may at times be subjected to direct metal to metal contact too. In the boundary and mixed lubrication regimes, when the average lubricant film is close to or less than the composite surface roughness, the load is wholly or partially supported by the contacting surface asperities. Collisions here may cause local high pressures and temperatures, plastic deformation, and sometimes crack growth in the bulk material.

Tooth dimensions

Root clearance: The gear teeth tips do not reach the root of the opposing gear to prevent gears pushing each other away. This gap is called the "tip/root clearance," **Figure 10.**

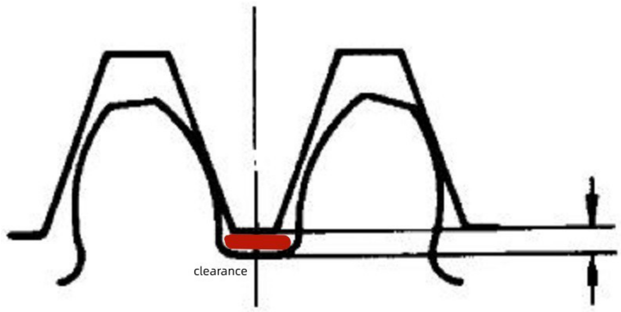


Figure 10. Tip/Root Clearance (5)

Adequate root clearance is necessary to compensate for manufacturing tolerances, thermal expansion and prevent interference between the gear teeth. Root clearance also allows for the proper lubrication of the gear teeth, which is essential for reducing wear and extending the life of the gears.

Backlash: The gap between the back side of the driving gear tooth and the next driven gear tooth is called "backlash," **Figure 11.**

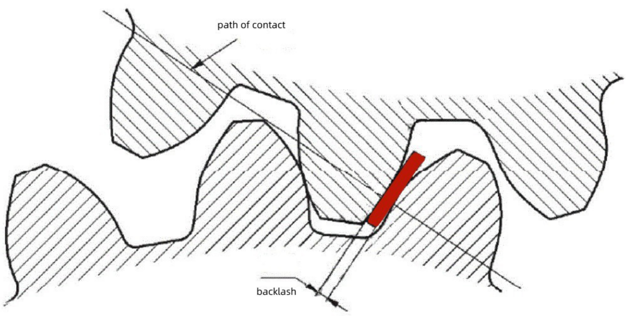


Figure 11. Backlash (5)

Backlash becomes critical when gearsets operate in forward and reverse directions. Excessive backlash will cause hard impact between the gears when changing direction. Backlash is necessary for gear mating because it allows for the smooth operation of gears. Without the appropriate amount of backlash, the gears may seize, causing wear and damage to the teeth. Excessive backlash, on the other hand, can cause the gears to rattle, leading to noise and vibration. Backlash also compensates for changes in operating conditions such as thermal expansion, bearing deflection, and lubrication.

Backlash also compensates for changes in operating conditions such as thermal expansion, bearing deflection, and lubrication

Lubrication

In a gearbox, lubrication is usually applied by so-called splash lubrication; the gears dip into a reservoir of oil in the bottom of the gearbox and splash the oil around. The gear pairs in a gearbox rotate even if they are not transmitting any load. These load-independent losses are an important source of the total transmission losses and are sometimes minimised by lowering the oil viscosity.

Industrial gear oils are classified according to the ISO viscosity grades (VG) system. The typical industrial gear oil viscosities range from ISO VG 68 to ISO VG 680.

Automotive gear oils are classified according to the SAE J306 standard and rage from SAE 65 to SAE 250 (refer to LM 9 – Viscosity for more details on viscosity). In engine applications a high bulk viscosity is not ideal since it increases hydrodynamic friction losses. Instead, a high-pressure viscosity coefficient is desirable.

Low speed, high load, sliding and rolling contact that prevails in gear teeth engagement, is likely to result in boundary and mixed lubrication regimes, where temperatures rise in the contact zone due to frictional heat. Anti-wear (AW), Friction modifiers, and EP additives are useful in these lubrication regimes, **Figure 12.** The friction modifier additives reduce the friction by physical adsorption of polar materials on metal surfaces. These additives are more easily sheared than AW additives, which form a protective layer by physisorption or through mild chemical reaction with the metal surface.

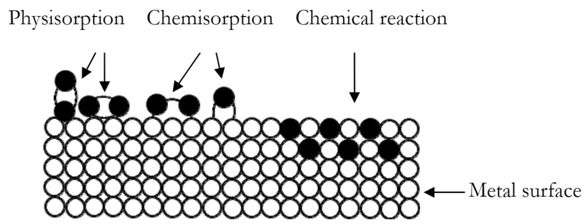


Figure 12. Additive interaction with metal surface (5)

AW and EP additives mainly chemisorb to the surface, but if high loads and high shear occur, the hydrocarbon chains of the surface-activated additives get removed, which allows a reaction to occur between the polar ion (e.g. sulphur or chlorine) and the metal, forming for example iron sulphide, which is much softer, and much lower shear strength than steel. This compound fills the surface valleys, presenting a larger load carrying area, and facilitates effective film formation, and thus reduces friction and prevents local welding and wear.

In worm gears, both sliding and rolling occurs as the teeth pass through the mesh. Due to the low rotational speed of the worm wheel, this sliding and rolling velocities are slow, hence the velocity tending to carry the lubricant into the contact area is low. The rotation of the screw (worm) introduces a high rate of sliding. The combination of the two sliding actions produces a slide that in some areas is directly along the line of contact. This high rate of side-sliding in worm gears results in significant frictional heating. The sliding action tends to wipe the lubricant along the convergent zone and this, combined with the low rolling velocity, makes it necessary to use high viscosity lubricants, typically ISO 460 or 680 viscosity grades.

Compounded gear oils have been used extensively in worm gears with immense success in a wide variety of applications. These are mineral oil-based with rust and oxidation inhibitors and acid-less tallow or synthetic fatty acid (the compounding agent), giving excellent lubricity to minimise sliding wear. Gear oils that contain active EP additives are not normally recommended for worm gears, due to the constant wiping action of the high rate of sliding.

Polyalphaolefin (PAO) or polyalkylene glycol (PAG) synthetic oils have become lubricants of choice for many worm gear applications due to their friction-reducing and extended life characteristics.

Wear and Failure modes affecting gears

Gears usually experience a slow continuous wear process, but gear life can be suddenly terminated due to bending fatigue, since a tooth breakage will immediately stop the gear function. Some important wear and failure modes affecting gears are:

Bending fatigue, Figure 13, occurs over time in response to repetitive loading. This loading can lead to

- microscopic cracks in the gear, in areas of stress concentration or discontinuities, such as fillets, notches or inclusions,
- followed by crack propagation perpendicular to the maximum tensile stress.
- and finally, a fracture when the crack grows large enough, causing sudden fracture.

Figure 13. Bending fatigue crack at root fillet (7)

Usually, the origin of the failure is at the surface of the root radius of the loaded side of the tooth and is at the midpoint between the ends of the tooth. If there is a misalignment in the system, fatigue initiating will be in areas where stresses are exceeding design limits.

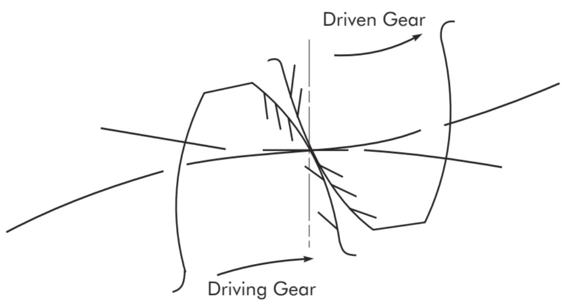
Polyalphaolefin (PAO) or polyalkylene glycol (PAG) synthetic oils have become lubricants of choice for many worm gear applications due to their friction-reducing and extended life characteristics

Surface/sub-surface fatigue is the failure of a material because of repeated surface or sub-surface stresses beyond the fatigue limit of the material. This can result in micro pitting, (< 1 mm in diameter), or macro pitting, (> 1 mm in diameter).

Surface fatigue, **Figure 14** may cause initial or corrective pitting (akin to running in-wear) in local areas of high stress due to uneven surfaces on the gear tooth. This can develop within a brief time, reach a maximum and with continued service, polish to a lesser severity. It usually occurs in a narrow band around the pitch circle.

Figure 14. Pitting due to surface fatigue (5)

Destructive pitting, **Figure 16,** is surface damage from cyclic contact stress transmitted through a lubrication film that is in or near the elastohydrodynamic regime on surfaces undergo rolling/sliding contact under heavy load.



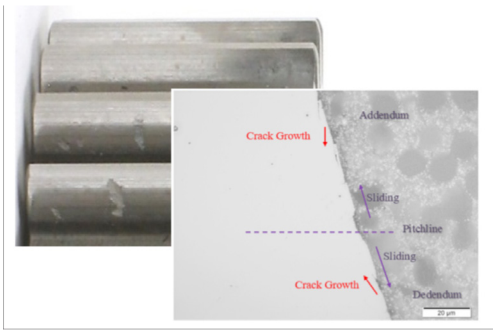
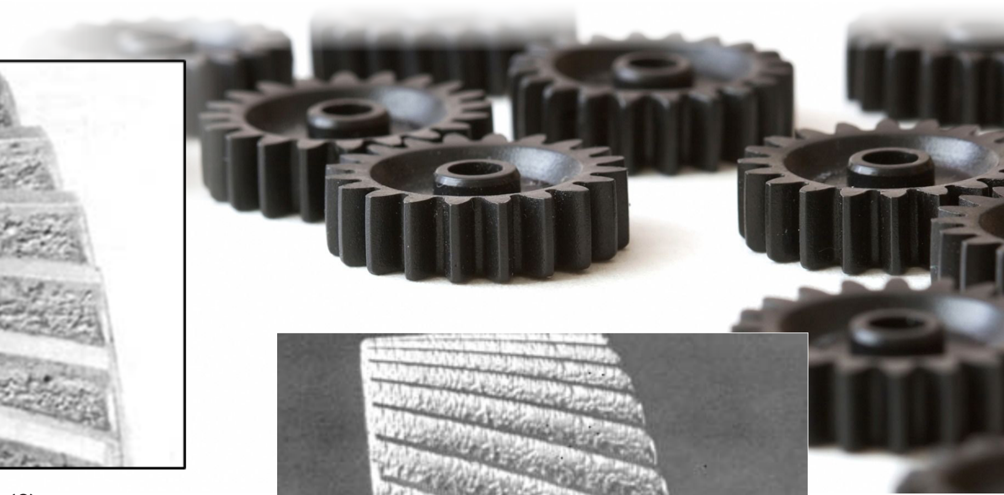


Figure 15. Diagonal microscopic cracks, with directions as shown, are often observed on surfaces of gear teeth (5,7)



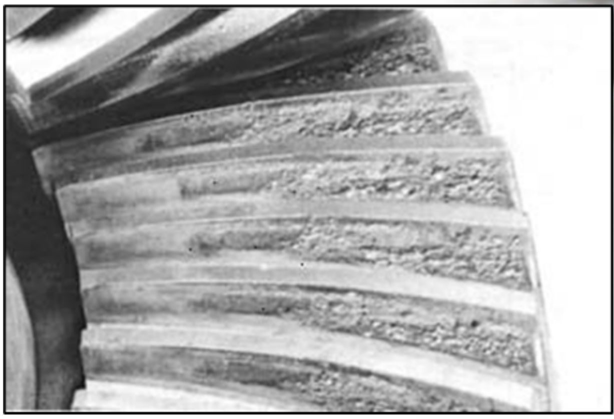


Figure 16. Destructive Pitting (6)

The combined effect of the rolling and sliding stress can result in near-surface fatigue cracking at the point of maximum shear stress below the contact surface. Cracks will propagate toward the pitch line and away from the sliding direction, **Figure 15.** Damage is often local to the region of negative sliding in the dedendum between the tooth root and pitch line.

Wear can occur at varying rates ranging from light to moderate to severe.

Light or polishing wear is the normal slow running-in loss of metal at a rate that will not affect satisfactory performance of the gears during the design life of the gears. Adhesive or abrasive wear mechanism that can occur under boundary lubrication condition gradually wear out the asperities of the contacting surfaces leaving fine, smooth surfaces (6)

Moderate wear refers to wear that is visible but will have negligible impact on the gear performance or life. Tooth flank will indicate material has been removed from the entire contact area, but more from the dedendum area. Moderate or normal wear depends on the lubrication regime, the nature of the load, the surface hardness and roughness, and on the contaminants present in the lubricating oil which might promote abrasive or corrosive wear. Careful maintenance of the lube system, correct viscosity, filtering, or more frequent lube changes should be considered (6).

Destructive wear, **Figure 17,** is surface destruction by abrasion or adhesion, which has changed the tooth shape to such an extent that smoothness of meshing action is impaired, and gear life is appreciably shortened.

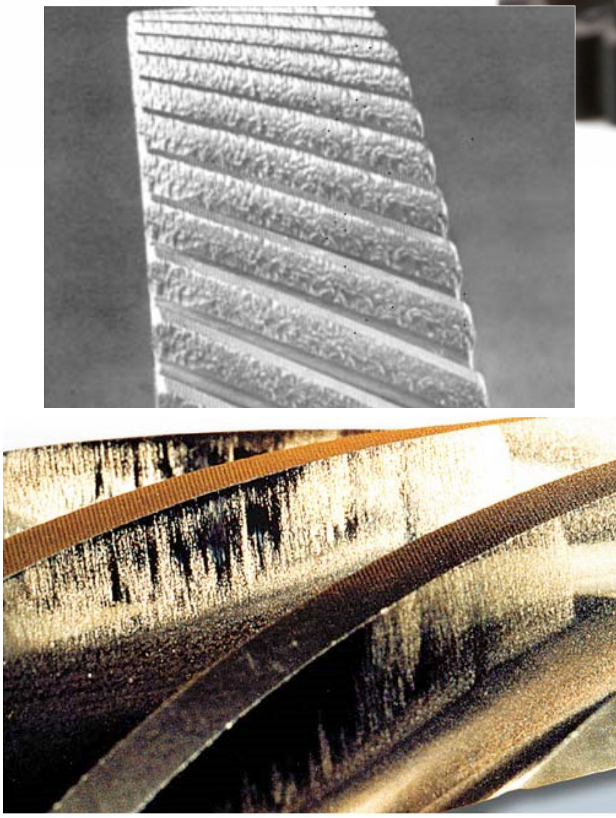


Figure 17. Destructive wear by (L) Abrasion (6), (R) Adhesive wear (scuffing) (5)

Continued operation results in further greater wear and may eventually lead to tooth breakage.

Conclusion

Gears are one of the important means for transmitting torque and changing direction of motion in many applications ranging wrist watches to ships propulsion. Without an efficiently functioning and long-lasting gear set, the prime mover may be rendered powerless. The design and optimal performance of the gear box is dependent on understanding the friction and wear characteristics of the system and application of correct lubrication.

About the author

Sanjiv Wazir is a mechanical engineer from IIT-Bombay. He is a marine engineer and a consultant on marine lubrication. Sanjiv is a Certified Lubrication Specialist (CLS) from the Society of Tribologists & Lubrication Engineers (STLE), USA; a fellow of the Institute of Marine Engineers (India); and a member of the Tribology Society of India. He often lectures on tribology and lubrication. For MER, he has written a series of articles on tribology & lubrication issues under 'Lube Matters' column.

Email: sanjiv.wazir@gmail.com

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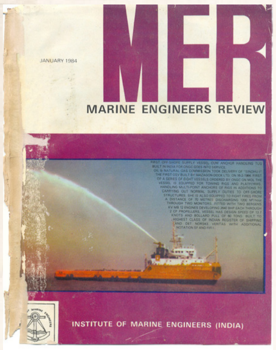
Going Astern into MER Archives



The issue's first article is on safe and economical Navigation. The write-up introduces navigation instruments of the times. An interesting observation is on the lesser availability of the number of satellites for few systems on board. The objective is to get the precise position of the vessels which will help in charting the routes and thereby optimise costs. The discussion on microcomputer based autopilot, the mentions of Loran-C, Decca Navigator, ARPA tec., are bound to bring back memories for many senior marine engineers.

The next one discusses shipboard computers and integrated machinery monitoring. While describing the additional features, it is mentioned that colour graphics can be shown on separate screen depicting the state of valves and pumps, fuels/lubes/water flow and trend analyses.

The point of time of the digital dawn 40 years back sure sounds exciting.

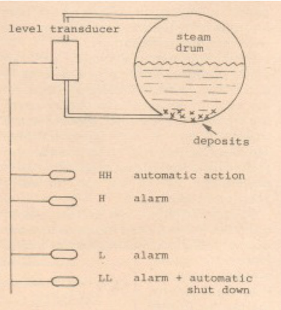


Fig 1: Boiler water level control which could give false sense of security.

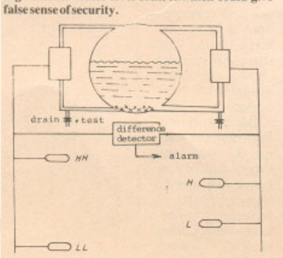


Fig 2: Pipes of different diameter would prevent symmetrical blocking.

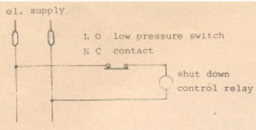


Fig 3: Pressure switch with normally-closed contacts.

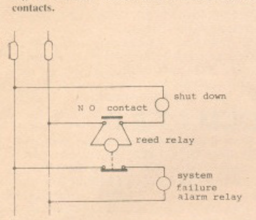
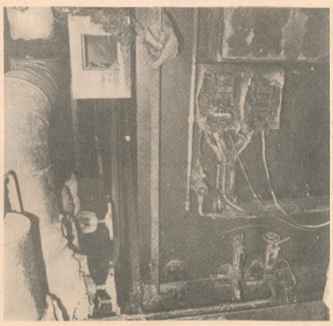


Fig 4: Circuit providing fault alarm without actuating the shut-down relay.

Fig 5: The consequences of disarming a fire-detection system—a severe fire. The cause was believed to be an oil-fired heater causing cracking of the heated oil.



The next one on Instrumentation-related machinery failures has many examples which can be related to by many engineers.

Few samples:

- Pressure gauge with a permanent error
- Boiler drum bottom deposits and location of the instrument draw-off
- Over-ride of real alarm (boiler low water)
- Switching off fire alarm audible function
- Disconnection of smoke detector (presumed malfunction)

The article rightly emphasizes on the robustness of alarm and protection system, especially of boilers.

The next one is a serious analysis on ship financing. There are good references to the Dutch, German, Japanese and Korean practices. A very good takeaway is the mention on Japanese shipping companies surviving due to the cross-shareholding between banks (which had lent monies to them). The model worked so because, the cross-shareholding ensured long term cargoes which helped in cash flow situation of the companies.

The article under 'Ship Design' describes a LASH (Lighter Aboard Ship) arrangement on a Soviet nuclear icebreaking vessel. There could be a revisit to such designs as the shipping routes get busy in the poles.

The next one is on an operational issue of low grade fuels. This would have been the experience of all marine engineers of those decades who dealt with problems of high viscosity oils. However, the article has a reassuring tone that visbreaking oils can be digested by medium and slow speed engines with suitable counter measures (of course).

The Postbag has some mouth-watering discussions. The question of dry running an EGB, the carbon and hydrogen fires. Carbon catching fire at 765 deg. C (about 407 deg. C) cuts ice as also the question of historical evidence for iron burning in the presence of steam (generating Hydrogen and sustaining the fire) satisfying the equation (see the letter and also Marine Steam Boiler by Milton & Leach).

Others worth a read are on the replacement-repair of carbon seals with polypropylene and on a central hydraulic power system. The elaborate discussions on thrusters and electrostatic hazards are worth a good, intense thought.

It is hoped that such discussions are brought in to the MER forum. The relevant extracts may be quickly referred to and some letters may be forwarded to initiate discussions.

POSTBAG

Dry running

Sir,
According to this item on p20 in the June issue 'The gas temperature, particularly on a medium-speed engine, is above the ignition temperature of carbon and therefore a fire can occur quite spontaneously'. Could the author specify what the ignition temperature of carbon is?

Also, 'many manufacturers now recommend that circulating pumps are kept running for at least 48 h after the engine is secured'. Could you specify the engine makers and the engine types on which such practices are used?

Further to your explanation of hydrogen fire, would you agree that at a temperature in excess of 705°C, which can be reached in case of a local soot fire, the iron of the tube would ignite and burn in the presence of steam and also produce hydrogen, which then burns explosively on coming into contact with air, as per the following exothermic reactions?

$$2Fe + 4H_2O — Fe_3O_4 + 4H_2$$

$$4H_2 + 2O_2 — 4H_2O$$

Or the situation in a WHR unit could be limited to the steam being dissociated into oxygen and hydrogen, with the hydrogen catching fire.

S Das Sarma

Singapore

Sir,
In reply to Mr Das Sarma, carbon ignition can occur at 765°F, which is below the exhaust temperature of some medium-speed diesels. When the exhaust gas boiler is run dry the temperature of the boiler tubes quickly attain that of the exhaust gas and any carbon on them is raised close to this temperature. Diesel combustion creates an oxygen-rich exhaust and even isolated incidences of engine sparking have been known to give ignition.

It is not normal for an engine manufacturer to specify operating procedures for the exhaust gas boiler. This would normally be the responsibility of the boiler manufacturer. To my knowledge, the following exhaust gas boiler manufacturers specify continuous running of the circulating pumps for an extended period after the engine has been secured: Deka-McKillup; Green Economizers; Osaka Boiler; Aalborg; and Mitsubishi.

I agree that the iron in a carbon steel boiler tube could ignite, giving the reaction which Mr Das Sarma outlines. But, to date, I have been unable to find sufficient historic evidence to conclude that this reaction does, in fact, take place.

John McKillup

Deka-McKillup,
Ohio, USA

A guide to the selection and application of gland packing

This article appeared in the November issue. Unfortunately, in the first paragraph under the sub-heading 'General guidance' the word 'not' had inadvertently crept into the sentence. Hazardous vapours or gases do, in fact, require inert gas flushing through a lantern ring.

Cost cutting seals

Sir,
I would like to offer a simple and very effective solution to the problems experienced with mechanical seal failure on seawater centrifugal pumps.

On a ship operating in shallow water the seal's carbon faces were rendered useless in a very short time. Sand tore the faces, causing leaks, and seaweed blocked the strainers which caused the pumps to run dry, overheat, and break the seal.

A solution was to replace the carbon with a duplicate machined from polypropylene bar. These plastic replacements were very successful. The softer material was able to absorb the sand into its structure without causing damage and pumps could be run dry with no harmful effects.

With carbon seals costing about £150-200 and a polypropylene seal priced at about £5, the savings in time and money are obvious.

Another suggestion to save costs is to make personnel more aware of the enormous costs of spare gear. Many ships have a mountain of used but still servicable compressor valve plates and springs. When a complete new valve can cost over £100, the mountain can be transformed into spares, ready for further use.

Perhaps it would be a good idea to put a price tag on all spares to encourage a thriftier approach by ships' staff.

A C Mather

Middlesex

Central hydraulic power

Sir,
The use of a centralised hydraulic power system on board ship is a good thing, but several comments on the article by Mr R A Burnison (Sept 83 MER) are called for.

Even after careful and early consideration of a central plant, problems still arise. The proper operation of sophisticated hydraulic consumers needs a great deal of coordination by the yard, or the hydraulic power supplier.

Indeed, no one in his right mind should consider connecting hydraulic steering gear to the central power plant because the power required needs to be delicately matched and because the classification societies would only approve, if at all, with the utmost reluctance.

The reason for this is that every manufacturer of specialised marine hydraulic systems is reluctant to disclose hard-obtained experience to anyone.

The piping necessary to connect the central power plant to the different consumers might prove very bulky and difficult to install in an accessible way. For a 90 m dredge, about 3000 m of piping was necessary to connect 36 consumers. Such a system, containing some 6000 litres of fluid, can be difficult to keep oil-tight. In fact, due to several incidents, none of them very important, the fluid losses were considerable.

Such an installation becomes difficult to drain, nor is deaeration easy. Keeping every pipe connection easily accessible is also a problem.

It is not yet proven that an hydraulic power plant is cheaper, more efficient and easier to maintain than an electric or steam system.

Remote and/or automatic control of hydraulic machinery can itself be fully hydraulic. This is, however, rather cumbersome and it seems current practice, at least on the Continent, to control hydraulic power by electric signals. While this increases the length of necessary wiring, it proves most economical in the case of dredgers and other specialised vessels.

G Delhasse

NV Mercantile-Beliard
Belgium

Thrusters

Sir,
With reference to the letter from Mr P Jacobs (Schottel America) (Postbag June 1983): we agree with him about the relationship between thrust, velocity and area. However, there are two significant points to be made.

Into the well-known physical laws regarding thrust one should first insert actually measured physical constants. If we use Mr Jacobs' equation and insert 4·9 kgf/hp and the jet velocity he has used of 18–21 m/s (using 18 to be on the low side) we find that, for a 1000 hp unit we would have a thrust of 4900 kgf and an area of 0·109 m^2.

Using results from the real world, it is interesting to note that, substituting the actual area and velocity into the equation, a 1000 hp unit has a thrust of 8848 kgf, ie: not 4·9 but 8·85 kgf/hp.

The matter has been over simplified because, when a ship is underway, there are more complex relationships relating

We reserve the right to edit and shorten readers' letters

—Editor

POSTBAG

to thrust than the simple equation used, which is for a jet of liquid emitted into a gas medium according to Bernoulli's theorem.

We actually have a submerged jet of water in water, quite different from that of a water jet in air. The water issuing from the jet nozzle is affected by the surrounding water and is decelerated; the entrained water around it is accelerated. This makes it easier to manoeuvre around docks and riverbanks because of the natural braking effect of the water in-situ. The basic reaction force is created at the instant the water leaves the hull.

We carefully match the hydraulic characteristics of the impeller to the valve, piping, inlet and nozzle to maximise energy transfer. Thus, we obtain an efficiency at the impeller of 82 to 88%, not 70%.

There is no simple generalised curve from which anyone can calculate thrust underway; each vessel will have its own peculiar characteristic. Those that we have published are plotted from data taken by our customers.

Secondly, steering underway is quite a different thing from thrust. If we had 100% of the thrust at 15 knots that we had at 0 knots, the steering effect on the ship would still be quite different because the stability of the ship's hull and rudder increase as the square of its forward speed. Pressure differences on the hull and on the rudder tend to make the ship act like an aerofoil going through a fluid and increase exponentially, while the thruster effect stays constant or, most likely, diminishes.

The only way to overcome this is 'augmented steering', that is, the thruster is coupled to the steering mechanism so that they work together, enabling the ship to steer in a tighter circle. This is still true at fairly high speeds.

C M Aker
Omnithruster Inc

Electrostatic hazards

Sir,
The points Dr Rees (Postbag Oct 83) and Mr Victory (Postbag Dec 83) make were considered in Transactions*. However, we accept that the article in MER could not, because of its abbreviated form, say all that we said in our paper and that MER readers might misunderstand certain statements.

In the paper we made a number of references to ISGOTT (International Safety Guide for Oil Tankers and Terminals and Mr Victory has taken exception to some of its contents. The Guide was drafted by a committee of experts from all parts of both industries involved and it reflects their consensus view of desirable precautions that, if properly and conscientiously carried out, will minimise the hazard.

*Trans IMarE (TM) Vol 95, 1983, Paper 44

We made it clear in the paper that some companies may wish to take a more conservative approach to the subject and they have the opportunity of doing so by demanding more stringent operational precautions than those contained in ISGOTT. While some may argue ISGOTT is not perfect, it is considered by the industry to be an acceptable basis for ship operations. It is also endorsed by IMO.

Complete safety (if that is possible) of in-tank operations can only be guaranteed by proper maintenance and operation of the plant. Education and training is therefore of the utmost importance, both in the drafting of regulations and in the training of personnel.

On ships which do not require IGS, it is to be preferred to wash tanks only in the 'too-lean' condition. Additionally, all possible precautions should be taken to limit the generation of electrostatic charge by using portable tank cleaning machines and by limiting their number and water throughput. This 'two-platform' approach, by removing two sides of the combustion triangle, fuel and ignition source, is a policy that offers the greatest practical and accepted safety margin.

We have several comments relating to W D Rees' letter.

With regard to grp pipes, we agree that the 'worst case' situation is where a grp pipe is used to transfer a low-conductivity petroleum product. A detailed analysis showed that, to keep the maximum potential developed on the pipeline during cargo-handling operations below 100 V, and thus comply with BSI recommendations, the resistance per unit length of pipe should not exceed 1·5 M Ω/m. This is consistent with BP's conclusion to the effect that the maximum resistance between the ends of a grp pipe should not exceed 10^8 Ω since they have made the sound, but less conservative, assumption that a pipeline potential in excess 1000 V is needed to generate hazardous discharges.

We do not agree, however, with Dr Rees' statement that to produce a homogenously conductive pipe by adding carbon black to the grp requires a carbon black concentration greater than 30%. We have found that adequate conductivity can be achieved by adding less than 1% by weight of a certain type of carbon black to the resin. This does not affect the physical properties of the pipes so produced. Also, the pipes can be regarded as being homogenously conductive because the carbon black forms a multitude of filaments that are less than 0·2 mm apart and which extend in all directions.

On crude-oil carriers, a significantly higher pipe resistance can be safely tolerated than on products carriers since a potential will only develop on the pipeline during tank washing and inerting operations (crude-oil has a relatively high conductivity and does not acquire a charge during pumping). Both laboratory and shipboard trials have demonstrated that, when a grp pipe is immersed in crude-oil or seawater, its resistance quickly falls to a safe level. This process is not reversed when the pipe dries out; thorough cleaning with a solvent is required to restore the pipe's resistance to its original high value. Thus, we concluded that ordinary, non-conductive grp pipes can be safely used on crude-oil carriers.

Dr Rees correctly points out that the electrostatic charge associated with inert-gas does not present a hazard providing the IG plant is properly operated and air is prevented from entering the cargo tanks. We recognise that our research findings relating to space potential decay times are not now relevant to crude-oil tanker operations since that, to obviate the hazard presented by pyrophoric iron sulphides, air should not be allowed to enter tanks containing a flammable atmosphere. It has to be pointed out, however, that we embarked on our inert gas studies well in advance of this recommendation being made.

Where there is no hazard from pyrophoric iron sulphide, such as on products carriers, there may be circumstances in the event of a breakdown of the inert-gas plant where an emergency exists and cargo or ballast discharge must be continued and air be allowed to enter previously inerted tanks. Our research shows that this is safe, providing the precautions listed in our paper are taken.

The location of the 10 kV space potential required to produce hazardous sparks from water slugs during tank washing operations depends on the point of origin of the water slug: thus, for a slug falling from a cleaning machine and generating a spark to an earthed structure in the bottom of the tank, the 10 kV criterion relates to the potential in the vicinity of the cleaning machine; for a slug falling from the top of the tank and discharging to an earthed protrusion, such as a ladder, the 10 kV criterion relates to the potential in the vicinity of the protrusion.

The question of what is an appropriate criterion of electrostatic discharge incendivity is raised by Dr Rees. We quite agree that the charge transferred by a brush discharge is a more appropriate measure of its incendivity than the potential of the surface from which it occurs. However, surface potential is a useful criterion for hazard assessment where discharges cannot be measured or where the degree of charging is not sufficient, at the time of measurement, to produce hazardous discharges.

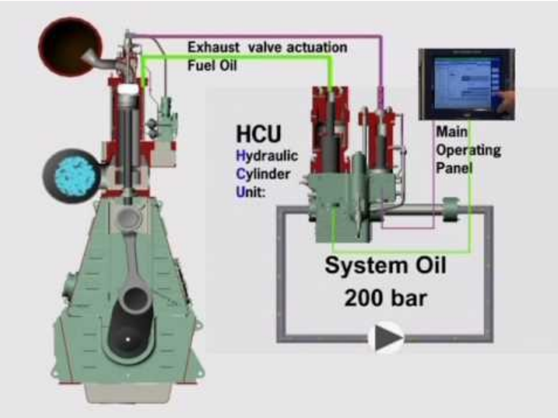
J S Mills and R C Oldham
Shell Thornton Research Centre

We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

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 : **29th – 31st Jan 2024/ 27th – 29th Feb 2024/ 26th – 28th Mar 2024/ 23rd – 25th Apr 2024/ 28th – 30th May 2024/ 25th – 27th June 2024/ 29th – 31st July 2024/ 27th – 29th Aug 2024/ 24th – 26th Sep 2024/ 28th – 30th Oct 2024/ 26th – 28th Nov 2024/ 17th – 19th Dec 2024**
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
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Ms. Saraswathi, **(T)** 8807025336 / 7200055336 .

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