FACTORS CONTRIBUTING TO FIRES IN SHIP ENGINE ROOMS

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Abstract

Engine room fires are a major cause of crew fatalities, one of the main contributors to ship casualties and result in the very costly accidents. The ship's engine room is an area where large quantities of flammable materials and potential ignition sources are constantly present within a confined space. The most common fire scenario is fuel leakage onto a hot surface, and the human factor is the root cause of most accidents on board.

The research focuses on a holistic approach to fire safety, taking into account both human and technical factors. To introduce the problem, factors determining the risk of engine room fires were identified empirically and theoretically. Firstly, potential sources of engine room fires were identified with the use of thermography. A passive experiment of a fuel spill fire was also conducted. Visualization of fire development was presented using Pyrosim and Smoke View software.

To emphasize the importance of the human factor in fire safety, results of ergonomic studies (including mental and physical workloads) were presented. In summary, correlations between human behaviour and technical factors were identified.

Keywords: fire safety, human factor, engine room, vessel

Introduction

Ship fire safety is a complex, interdisciplinary issue. It requires a comprehensive understanding of ship design and maintenance, alongside considerations of ergonomic, psychological, managerial, and legal factors. Therefore, only a holistic approach that integrates both technical and behavioural analysis can produce reliable and comprehensive research. Maintaining the efficiency of machinery, equipment and installations, along with the availability of protection measures such as fire detection and suppression systems, is equally important as the crew

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skills, experience, and well-being. Moreover, in marine transport, the variability of hydrometeorological conditions, often unpredictable and severe, can significantly affect crew working conditions and, consequently, the overall level of safety.

Although technological advancements enable the use of increasingly efficient and safer machines and devices, as well as fire detection and fire extinguishing systems, reducing human error still remains a real challenge. The solution may lie in implementing safety culture principles. This could be the fundamental value, when fully understood, accepted, and implemented by all involved, including crews, passengers, administration, and others (Krystosik-Gromadzińska, 2020; Veiga, 2021).

Ship fire safety is regulated by international organizations like the International Maritime Organization (IMO), the European Maritime Safety Agency (EMSA), classification societies, as well as shipowners, state administrations, accident investigation commissions, insurance companies and academics.

The engine room is a high fire risk area given its equipment, including machinery, devices, and installations (Pfaf, 2022) whose operation is associated with fire hazards caused by, among other things, fuel leaks. A quantitative analysis of fire risk resulting from such a scenario was conducted by Liu et al. (Liu et al., 2024). The authors conducted research on a scale model, which was verified by experimental data.

Large-scale experimental studies on the engine room platform were conducted by Wu et al. (2024) and their aim was to determine the average temperature in the engine room under various mechanical ventilation conditions.

The specificity of fires in power plants caused by leaking fuel were studied experimentally (Sarıalioğlu et al., 2020). As a result of the research, a segmented theoretical model was developed to predict the radiative heat flux resulting from a leakage fire in a ship's engine room.

A numerical study of the fire in the engine room with cylindrical obstacles was carried out by Zhang et al. (2023). During the study, the flame height, fire temperature, and fire spread speed were analysed.

A probabilistic assessment of a fire risk on a passenger ship was conducted by Kostas, Spyrou and Koromila (2020). The assessment comprised the probability of ignition, the reliability of installed suppression systems and a loss prediction (in number of fatalities) in a variety of space arrangements with different interior design materials.

Sarıalioğlu et al. (2020) analysed actual fire and explosion incidents using a hybrid method combining the Human Factors Analysis and Classification System and

Fuzzy Fault Tree Analysis. Their research has shown that the incidents tend to be more frequent on ships older than 20 years and often follow a similar scenario pattern: fuel contact with a hot surface caused by inadequate insulation. Eliopoulou and other authors (Eliopoulou, Papanikolaou, 2007; Eliopoulou, Papanikolaou, Volgarellis, 2016) have also conducted analyses of causes and consequences of accidents and fires on ships.

Fire prevention is a crucial aspect of engine room safety. Det Norske Veritas (Det Norske Veritas, 2015a, 2015b, 2016a, 2016b and Gard (2012) dedicate publications to engine room fire prevention, highlighting common causes, locations, and crew recommendations. DNV's extensive reports identify hot surfaces as most frequent sources of fires (DNV, 2016a, 2016b).

A significant challenge for engine room safety is the arrangement of risk objects in the power plant. Efforts should be made to have those objects moved and ensure their protection, through such measures as insulation or elimination of leaks. Notably, fuel leaks and unshielded hot spots, account for approximately two-thirds of engine room fires, as analysed by BSM (2023).

To mitigate these risks, it is crucial to select appropriate solutions for insulation of hot surfaces and lying pipelines without excessive use of bent flexible connections.

Additionally, when designing an engine room, it is essential to provide crew members with access to high-risk areas for inspections, surveys and repairs. This also comprises ensuring adequate lighting at these access points to enhance safety.

In firefighting at sea, a realistic virtual ship fire scenario is crucial to increase the effectiveness of simulation training. While virtual reality training is still not commonly used in the maritime industry, a scenario for a ship engine room fire in this environment was proposed by Liu et al. (2023). Similar scenarios, considering the spread of smoke, carbon dioxide and water mist, were presented by Tao et al. (2024).

A concept has also been developed to enable the use of models generated in the SMARTfire in advanced crew training in a virtual reality (VR) environment. CFD/VR integration allows producing an interactive dynamical VR simulator realistic fire training environment (Vizentin et al., 2024). Modelling results using Pyrosime and SmokeView are presented in this paper as well.

During a fire and subsequent evacuation on board a ship, the speed and appropriateness of decision-making is of paramount importance. The availability of rooms is an important variable here. Using a digital twin, a tool was proposed that provides the crew with key information in real time (Shofly et al., 2024).

Fire safety is also a crucial concern with respect to non-conventional fuels and electric vehicles, whose transport presents a new challenge in shipbuilding.

Current problems related to engine room fire safety are described by Pomonis, Jeong and Kuo, who analysed the ammonia fire hazard as compared to conventional fuel types in the event of an engine room (Pomonis et al., 2022).

The engine room operating conditions change with the use of fuels such as liquefied natural gas (LNG). When compressed natural gas (CNG) is accidentally released in the engine room of a ship, a fire may break out. Numerical studies of such scenarios were conducted by Zhang et al. (2024) and led to the demonstration of a relationship between the gas leak rate and fire development. A separate category of hazards in the power plant are explosions in the crankcase (Wiaterek, Chybowski, 2022).

The problem of fires in electric vehicles transported on cargo decks of ro-ro ships was the subject of research conducted by Węglarz, Złoczowska and Krasuski (2024). In this publication, the considerations were limited to conventional hydrocarbon fuel engine room.

1. Methodology

A holistic analysis has been proposed that examines technical and human factors and their correlations. Both the literature survey and the experimental work and modelling were envisaged to outline the complexity of fire safety in a merchant vessel.

Selected statistical data was analysed, with particular emphasis on fires in power plants of ships powered by conventional fuel. The data describing the distribution of different types of accidents, as well as the causes of fires in the engine room, were examined.

The study was conducted at a power plant during its operation. The goal was to verify the results of statistical analyses of fires sources and identify potential risk objects. The research was carried out using a non-contact method - a thermal imaging camera and a pyrometer. During the experiment, the surface temperature of machines and devices was monitored. As a result, based on the chosen temperature criterion (above 200°C), hot surfaces were identified, which pose a fire risk when in contact with fuel.

Fire modelling was carried out based on data obtained from statistical research and measurements in the engine room. Using the data, a scenario of a typical fire in a power plant of a passenger ferry was developed. Selected results of fire development visualization and parameter estimation were presented.

The impact of human behaviour on fire safety of an engine room was investigated. This included selected physical and mental overloads of crews, the impact of stress and the Covid-19 pandemic.

Critical correlations of technical and human factors influence fire risk in the engine room were identified.

2. Accident statistics and fire sources

According to the EMSA 2023 report, fires and explosions occurred more than 1100 times (7.2% of all 15 483 accidents) in 2014–2022 (European Maritime Safety Agency, 2023) and they were the cause of the majority of fatal accidents on ships in 2022 (Fig. 1). Over 45% of injuries were caused by collisions and crashes, 14.6 % of them by damage or loss of equipment, whereas 11.7% were the effect of fires and explosions (European Maritime Safety Agency, 2023).

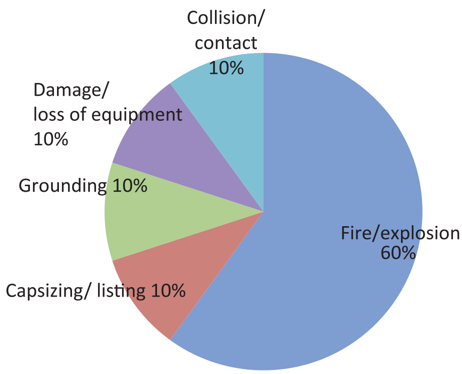

Figure 1. Fatalities in incidents involving ships, organized by casualty incident type in 2022
Source: (devised on the basis of European Maritime Safety Agency, 2023)

Fires and explosions are a significant cause of ship losses (15% over the last years) (European Maritime Safety Agency, 2023). Based on Allianz statistics, it amounted to 14% in the period 2013–2023 (104 incidents), while in 2022 it was 21% (Allianz, 2024).

Moreover, fire was found to be the most expensive cause of marine insurance claims. An analysis of almost 250,000 marine insurance industry claims has shown that fire accidents account for 18% of the value of all analysed cases (Allianz, 2023).

According to the EMSA 2024 report (European Maritime Safety Agency, 2024), human element was a direct cause of 58.4% of incidents (Fig. 2), while the percentage of contributing factors related to human element was over 80% (Fig. 3). In previous years, human factors have been also the primary type of accident event.

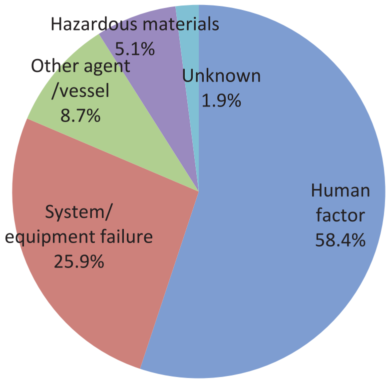

Figure. 2. Percentage of incidents involving the investigated marine accidents and incidents for the period 2014-2023, organized by types

Source: (devised on the basis of European Maritime Safety Agency, 2024)

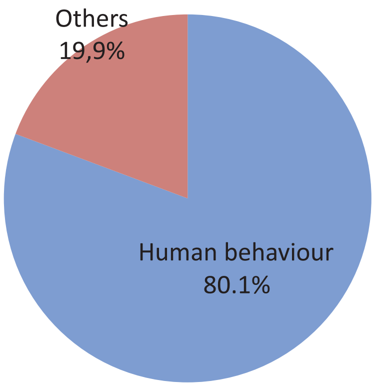

Figure 3. Percentage of contributing factors involving the human element for the period 2014-2023

Source: (devised on the basis of (European Maritime Safety Agency, 2024)

According to EMSA statistics (European Maritime Safety Agency, 2021, 2022), ca. 12% of fires originated in the engine department. Statistical data of the Det Norske Veritas (DNV) classification society shows that in previous years (2017–2024) it amounted to nearly 60%.

The primary reason (two-thirds) for their occurrence was failure in the flammable oil system, leakage of flammable materials onto a hot surface of the main or auxiliary engine or associated components such as turbochargers (Fig. 4), manifolds or cylinders (Det Norske Veritas, 2016 b, Gard, 2012; Mahajan, Watle, Larsen, 2025), which has not changed and is also recorded in current statistics as the main cause of the fire in the power plant.

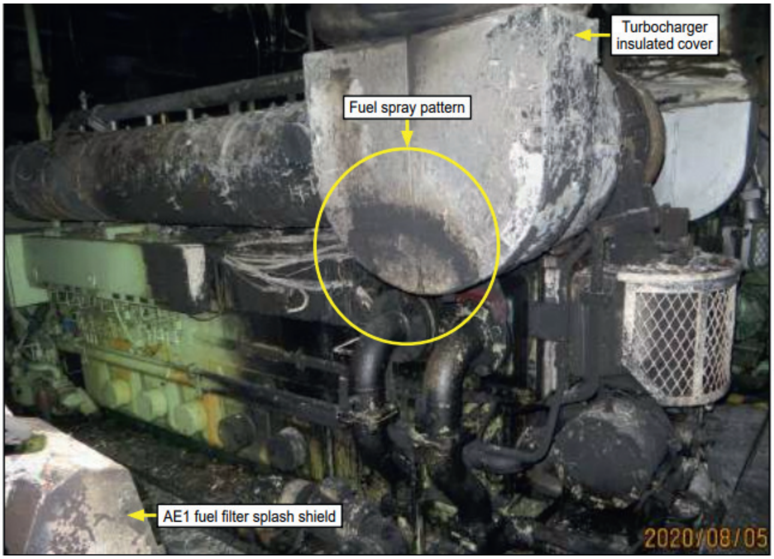

Figure 4. Post-fire fuel filter splash shield and turbocharger insulated cover
Source: (Red Insigne Group, 2023)

Figure 5 presents a leak simulation. This simulation depicts tests conducted during the fire investigation of the vessel Moritz Schulte, which suffered an engine room fire in 2020. The fire was caused by leaking fuel coming that came into contact with a hot surface.

Figure 5. Fuel filter leakage test
Source: (Red Insigne Group, 2023)

3. Identifying sources of leakages as the most important issue

The risk of fire on board of a ship is largely determined by the location of its origin. The ship power plant is a place where large amounts of combustible materials and many potential sources of ignition are continuously present in a restricted area. As mentioned, fuel oil leaks are most often the cause of fire outbreak, followed by oil-soaked insulation/lagging, excessive amounts of oil in engine room bilges, quick-closing valves on fuel and lube oil tanks being disabled in the open position, etc. All of the listed risk factors are associated with poor maintenance of the engine room and insufficient maintenance prior to leaks. The ability to maintain fire safety in the engine room was also affected by inadequate fire detectors, structural fire barriers, fire extinguishing systems and portable fire extinguishers, as well as inoperable fire pumps (US Coast Guard Port State Control, 2022).

Combustible materials in the engine room are mainly fuels and lubricating oils in tanks, fuel lines, bilges in machinery spaces, centrifuges, engine crankcases, fuel and oil pumps, and boiler burners. The total inventory of fuel and oils on board can be several thousand tonnes (Det Norske Veritas, 2016a, 2016b).

As fuel leakage onto hot surfaces is the most common fire scenario, identifying hot surfaces is a key fire prevention measure. Once risk factors are identified, they should be subjected to special surveillance.

Hot surfaces in a marine power plant, such as the engine block, indicator valves, exhaust manifolds, turbochargers, fuel injection pump housings, fuel inlet and overflow pipes of injection pumps and headlamp areas above the engine have been investigated on a seagoing vessel. Objects were classified as risky when their surface temperature was found to exceed 200°C. This is the limit set in regulations as a value above which surface insulation is required.

Measurements in the main engine area ranged from 320°C (for connection: bolted flange, exhaust manifold between exhaust valve and collective exhaust gas manifold), to 260°C (uninsulated plugged measuring cocks at the ME collective exhaust gas manifold). The uninsulated bolted flange at the exhaust gas outlet from the turbocharger was over 300°C, while the cylinder exhaust gas temperature was also 300°C.

The exhaust gas steam boiler area was identified as risky due to the high temperature of almost 300°C measured at the exhaust space inspection door during main engine operation.

The auxiliary engine of the generator set was also identified as a potential fire source. Temperatures in this area ranged from 320 to 480°C. The highest temperatures were recorded at the connector of the collective exhaust manifold to the turbocharger (over 480°C). Temperatures exceeding 300°C were observed on the surface of the exhaust gas manifold behind the turbocharger (340°C), the turbocharger exhaust side flushing stub (340°C), the turbocharger casing from the fore ship (320°C) and the bolt set connecting the turbocharger insert to the casing (300°C) (Krystosik--Gromadzińska, 2019, 2020).

4. Passive experiment of fire in engine room

Appropriate actions to improve fire safety depend on a thorough understanding of the phenomenon. Ship engine room fires are highly dynamic and risky. The duration of a fire in the engine room (pool fire) varies from few minutes to over a daytime. It may develop in the engine room or spread to other regions of the ship. The achieved temperature values may exceed 1000°C (Fig. 6). Representative parameters of a fire are temperature, heat release rate, flame height and fire duration.

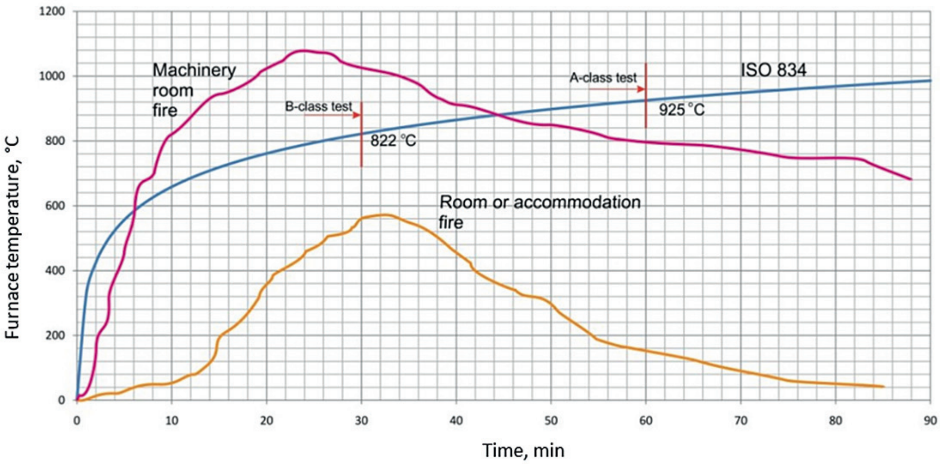

Figure 6. Temperature patterns: standard fire time-temperature curve according to standard ISO 834 (ISO, 1999) for a typical fire in the cabin of restricted use of combustion materials and in the machinery space of category A

Source: (Getka, 2011)

A passive experiment was conducted in an engine room to understand the development and spread of the fire. Selected fire parameters were analysed during the simulation of an engine room pool fire. The scenario envisaged that the fire started in the engine room of a small ferry, with the source being a fuel pool between the main and auxiliary engine. It was assumed that the combustible material was 12 kg of fuel from a leak (a 1 cm in diameter pipeline supplying fuel to the main engine, which consumes 30–50 l/h). Moreover, there was no high pressure at the leakage point, where fuel was delivered to the injectors. The simulation was executed on the assumption that all doors separating the engine room area were closed and the ventilation system turned off.

The simulation experiment programme involved dividing the machine room space into finite elements, assigning formal parameters, and identifying formal parameters as input data. The test was carried out for a specific fire scenario, assuming no supply of secondary fuel or air. The Pyrosim and SmokeView were used for modelling of the fire.

The representative parameters of a fire such as heat release rate, flame height, and fire duration have been calculated using formulas according to the United States Nuclear Regulatory Commission model (United States Nuclear Regulatory Commission, 2021). Fire parameters were calculated using the following formulas (United States Nuclear Regulatory Commission, 2021):

$$\dot{Q} = m^{"}\Delta H_{c,eff}(1 - e^{-k\beta D})A_{dike} \quad (1) \tag{1}$$

Where:

$\dot{Q}$ – pool fire release rate (kW)

$m^{"}$ – mass burning rate of fuel per unit surface area (kg/m²s)

$\Delta H_{c,eff}$ – effective heat of combustion of fuel (kJ/kg)

A_{dike} – surface area of pool fire (m²)

$k\beta$ – empirical constant

D – diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

$$H_f = 0.235Q^{2/5^{\cdot}} - 1.02D \tag{2}$$

Where:

H_f – pool fire flame hight (m)

$\dot{Q}$ – pool fire release rate (kW)

D – pool diameter (m)

Use was also made of the Thomas method:

$$H_f = 42D\ (\frac{m^{"}}{q_a}\sqrt{(gD)}^{0.61} \tag{3}$$

Where:

H_f – pool fire flame hight (m)

$m^{"}$ – mass burning rate of fuel per unit surface area (kg/m²s)

q_a – ambient air density (kg/m³)

D – pool diameter (m)

g – gravitational acceleration (m/s²)

To estimate pull fire burning duration, the following formula was used:

$$t_b = \frac{4V}{\pi D^2 \upsilon} \tag{4}$$

Where:

t_b – burning duration of pool fire (s)

V – volume of liquid (m³)

D – pool diameter (m)

υ – regression rate (m/s).

For the adopted input data, the temperature distribution in various planes was investigated at 1-second intervals. For example, the temperature distribution in the 9th second of the fire was presented (Fig. 7) in a plane perpendicular to the main engine and auxiliary engine, on the platform between the engines.

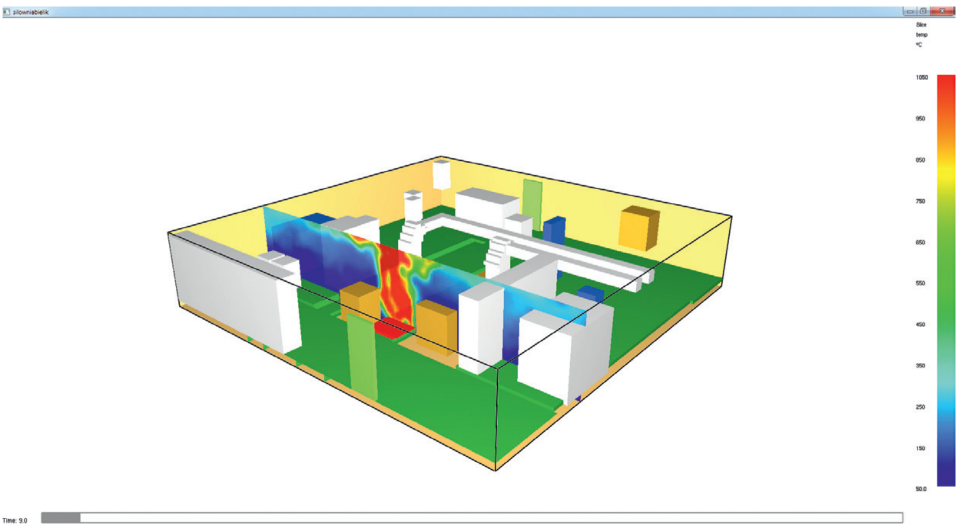

Figure 7. Visualization of a fire in the engine room of the Bielik vessel – temperature distribution
Source: (Krystosik-Gromadzińska, 2020)

The simulation showed a peak heat release rate of 3500 kW in the initial phase. The temperature rose rapidly during the simulated fire, exceeded 850°C above the fuel pool. The fire lasted approximately 200 seconds. Although the fire was intense, it self-extinguished after about three minutes due to insufficient oxygen, limited combustible materials, and heat absorption by the surrounding objects.

The simulation also modelled smoke spread during a passive experiment. Figure 8 shows a well-defined smoke column and ceiling layer at the 10th second.

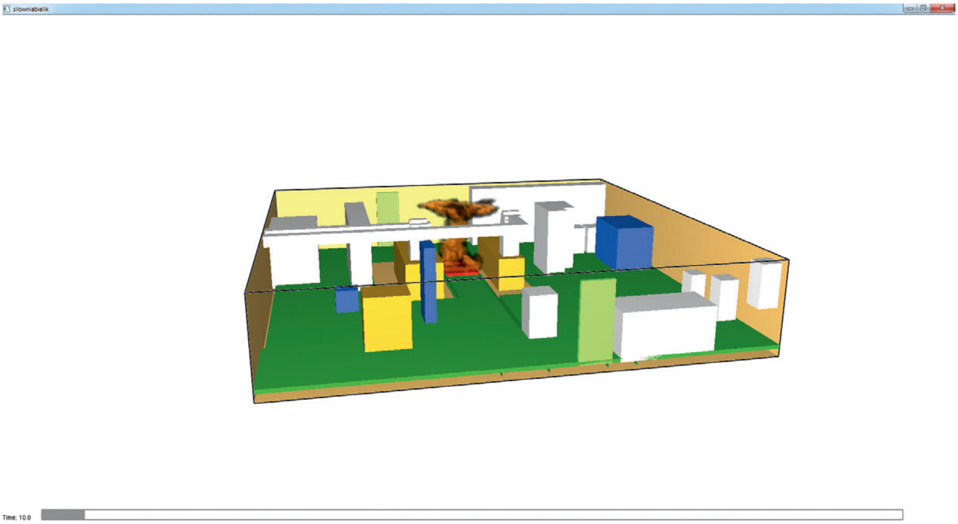

Figure 8. Visualization of a fire in the engine room of the Bielik vessel – smoke distribution
Source: (Krystosik-Gromadzińska, 2020).

The passive experiment provided a visualization of a fire in the engine room. The results of the fire simulation could serve as a valuable component of crew training, fostering a better understanding of the phenomenon and motivating crew members to adequately prepare for firefighting and, most importantly, fire prevention. The results of fire simulations could be incorporated into virtual reality training, giving trainees a virtual experience of fire origin and spread in their work environment. Such virtual experiences can significantly contribute to reinforcing positive safety behaviours.

5. Impact of working environment on the condition of the crew in terms of safety

Crew members are responsible for most casualties and accidents. Therefore, elimination of human factors can significantly improve fire safety in the power plant. Fire safety in the engine room depends not only on training but also on the physical and psychological condition of the crew, which in directly related to working and resting conditions.

To determine these relationships, research was carried out on working conditions in ship power plants. An ergonomic analysis of the ship engine room operators' workplace revealed many factors to which the crew members are exposed. According to respondents, occupational safety is primarily determined by high temperatures (over 50°C), noise level (over 100 dB), vibrations, humidity, insufficient lighting and air pollution. Moreover, work is generally executed in uncomfortable, non-ergonomic positions, and the tools are inadequately matched. Furthermore, the influence of ship rocking during stormy weather makes it much more difficult to safely fulfil the assigned duties. Other factors important for seafarers' well-being include changing time and climatic zones, family, social and cultural isolation, specific nature of work organization and hierarchy, different diet etc., as well as psychological factors, such as monotony, monotype, and high levels of stress particularly acute in managerial positions (Krystosik-Gromadzińska, 2018, 2020).

Stress is a significant factor impacting crew wellbeing, which can lead to undesirable behaviour that may affect safety. During a sea voyage, its effects are felt by all crew members, but ship management experiences were found to intensify stress due to responsibility for the safety of their subordinates, the ship and the cargo (Kroplewska, 2015).

Stress and overload on board can have serious consequences for the ship crew. Suicide is a major concern. The UK P&I Club reported that suicide was the leading cause of seafarer deaths, accounting for 15% of all fatalities at sea. As a solution, the CrewCare app was proposed. This tool may be used to improve seafarers' well-being (Maritime Cyprus, 2021).

A further important aspect of the human factor is the global problem of the Covid-19 pandemic, the effects of which are still ongoing. It significantly impacted ship crews, who were often forced to extend their contracts without the possibility of returning home. This resulted in increased stress levels due to uncertainty, additional mental stress and the lack of active rest, such as disembarking in the port during the loading operations. The problem has been analysed by Krystosik-Gromadzińska (Krystosik-Gromadzińska, 2022).

In summary, the human factor is a critical issue in enhancing ship fire safety. Physical and mental stress significantly contributes to human errors. In extreme cases, inappropriate crew conditions not only lead to impaired work efficiency, but even to suicide. Consequently, it is crucial to provide crews with good working and resting conditions, manage the team effectively, and foster a safety culture on board to prevent accidents, including fires, in a more effective way.

6. Correlations between technical and human factors in the context of fire safety in power plants

Statistical analysis, fire modelling, and ergonomic analysis are the main elements in a holistic analysis of fire safety in the engine room. They enable identifying factors that can be classified into three groups of key importance for fire safety in power plants.

The main technical factors, including uncontrolled release of combustible materials, unintentional exposure to ignition sources and undesirable human behaviour that contribute to the risk of engine room fire are presented in the table 1.

Table 1. Main factors contributing to risk in the engine room

Combustible material (CM)		
1.1. Liquid (CML) 1.1.1. Leakage, splashes or spray (CML1) of fuel (LO, HFO, others), oil (lubrication, hydraulic, thermal, others). 1.1.2. Waste (CML2): oily sumps, sewage disposal room, bilges. 1.1.3. Other (CML3): paints, solvents, cargo.	1.2. Solid (CMS) 1.2.1. Cargo. 1.2.2. Consumables. 1.2.3. Construction materials. 1.2.4. Decorative materials. 1.2.5. Electronic devices. 1.2.6. Waste. 1.2.7. Batteries.	1.3. Gases (CMG) 1.3.1. Cargo (CMG1): cargo vapour. 1.3.2. Ship operation (CMG2) during bunkering vapour, batteries storage, fuel vapour, bilge sediment vapour, during tank washing vapour, other ship operation vapours.
Ignition source (IS)		
2.1.Hot Surface (IS1) 2.1.1. Main engine: exhaust system, manifold, pipes, bellows and elbows, turbocharger, connections, bolted flanges, measurement and inspection equipment. 2.1.2. Steam boiler and burner: exhaust, inspection door 2.1.3. Auxiliary engine Exhaust: turbocharger, connections.		

2.1.4. Piping system in ER 2.1.5. Shield or flange screwed joints of pipes containing flammable agents. 2.1.6. Tank sounding pipes, air vents and level gauges. 2.1.7. Separator room. 2.1.8. Incinerator region. 2.1.9. Others: welding, frictions, radiators, other hot surfaces.	2.2. Electric (IS2): spark, arc, static electricity, short circuits, overloads, poor contact, distributor box, main switchboard, hot wires, electrical discharges.	2.3. Flame and spark (IS3) Acetylene igniter, etc.
Human behaviour (HB)		
3.1. Individual 3. 1.1. Physical overloads: static positions, overwork load, restricted work area, uncomfortable work stations, noise, vibration, temperature, vapours etc. 3.1.2. Mental overloads: poor stress compensation, monotony, restricted area, low quality food, sleep deprivation, lack of rest, separation form family and social life. 3.1.3. Communication: multinational crews, limited communication with family, poor communication with superiors.	3.2. Organizational: insufficient work organization, deficient management, lack of proper procedures and instructions, failure to follow procedures, lack of regular training at sea, lack of training in land-based training centres, outdated training methods, lack of cooperation.	3.3. Inspections: lack of regular inspections of all working machines, auxiliary mechanisms, devices, systems and installations and operating parameters, failure to record important operating parameters of ME and other devices, checking the engine load status, failure to conduct regular checks of the level of working media, lack of regular checks of the condition of engine room bilges, failure to record deviations, failure to explain the causes of deviations, failure to check and complete the ship's log incorrect operation, lack of knowledge of emergency procedures, lack of regular inspections of detection and fire-fighting installations and handheld equipment.

Source: devised on the basis of (International Chamber of Shipping, 2004)

Fire safety in the ship's engine room depends not only on the accumulation of flammable materials (CM, table 1) and sources of ignition (IS, table 1) in a small area, but also on the correct performance of maintenance and inspection activities by the crew (HB, table 1). However, if the physical and mental condition of the crew is not satisfactory, the probability of making mistakes is likely to increase. If the workstation is not adapted to activities performed and the working environment conditions are unbearable due to high temperature, noise, etc., there is a risk that the task would not be performed adequately. Growing fatigue and stress mean that the probability of human errors increases. There are a number of sources of fatigue and exhaustion on a ship and proper work organization does not always allow eliminating their effects (HB, table 1). In most cases, human inadequate behaviours result from failure to fulfil obligations, imprecise performance of activities planned during repairs or inspections, which directly stem from fatigue, the effects of stress, monotony and other factors affecting the mental and physical condition. Identification of potential fire sources in the engine room and behavioural factors allows analyses of their correlations and can be used to develop recommendations and, above all, to make crews and management aware of the fact that such a relationship does exist and directly affects the safety level.

7. Discussion and conclusion

Fires are typically caused by a combination of factors, including human and technical elements. To effectively manage risks, it is crucial to analyse not only the identification of these factors but also the relationships. A holistic evaluation of fire safety in marine power plants has led to the following conclusions:

1) Fires and explosions are major contributors to ship losses and are among the most expensive accidents, resulting in serious consequences.
2) Human behaviour is a contributing factor in 80% of casualties and accidents on board.
3) Engine rooms, with their concentration of combustible materials and ignition sources, are common starting points for fires and explosions. Those incidents often occur when combustible materials come into contact with hot surfaces. Engine room fires are particularly dangerous, with temperatures exceeding 1000°C reached, and generally last from a few minutes to several days.
4) Due to the high risk of fire, numerous areas in engine rooms require regular inspections. Thermal imaging was used when the ship was sailing to identify and document potential fire hazards in a specific engine room. These areas include main engine, auxiliary engines and steam boiler.
5) The crew must diligently supervise the above mentioned areas, prioritizing inspections of their technical condition. Those activities comprise verifying insulation, temperature control, and maintaining high standards of cleanliness to ensure early detection of fuel leaks.

6) Appropriate working conditions must be provided for the crew, to minimise the impact of aggravating factors such as noise, high temperatures, vibrations, poor lighting and others and keep them as low as possible. However, simply equipping crew members with protective measures, such as hearing protection or an air-conditioned room in the control room, may prove to be insufficient. The underlying issue often lies in the lack of conviction as regards the necessity of using such measures and disregarding the occupational health and safety recommendations. Therefore, behavioural audits should be carried out to monitor crew members, analyse attitudes, communicate conclusions and reinforce positive behaviours.
7) Crews should be equipped with tools that facilitate more effective inspections and monitoring of the developing situation during a threat. It is recommended that thermal imaging cameras, which function effectively in low-light condition and even smoke, be deployed. These cameras allow comprehensive inspections of relatively large areas within a short timeframe. Crew training should be delivered to demonstrate the usefulness of such tools. Enhancing staff competencies through participation in studies, training, and courses should be integrated into individual career paths. Furthermore, modern tools such as virtual reality, utilising models of engine room fires, should be incorporated into training to significantly improve crew competency.
8) Analysing hazard factors and working conditions in various ship regions revealed that the engine room presents a particularly challenging workplace. Those challenges include noise, high temperature, vibrations, insufficient lighting, limited work space, work overload as well as variable conditions influenced by weather conditions, directly contributing to human errors. An ergonomic assessment of engine room workplaces was carried out, identifying factors adversely affecting employees. Not only physical workload but also psychological stresses, which are particularly significant in maritime, were diagnosed.
9) A passive experiment has been conducted, allowing the modelling of fire temperature changes (reaching values exceeding 850°C), monitoring its development and spread, including the spread of combustion products. The experimental results can be incorporated into crew training based on the use of modern tools.
10) Correlations have been ascertained between technical factors and human behaviour in the context of engine room fire safety.

The conducted research entails certain limitations. Those limitations stem from the diversified equipment and working conditions in ship engine rooms, which can be even over 20 years old and vary given ship size and propulsion type. What is more, shipowners employ different human management models, duty division, and crew equipment with protective measures and tools, including those used for inspections. Consequently, it may turn out that the results of executed analyses may differ for various ships.

Future research comprises in-depth analyses and modelling of fires, as well as hazards recognition in engine rooms, including also those with non-conventional propulsion systems. Furthermore, ergonomic analyses of the work environment and the index of happiness for crews of different nationalities on ships of varying types and deadweight need to be carried out. Research is also planned concerning the effectiveness of deploying modern diagnostic tools for early fire hazard detection in engine rooms and the application of virtual reality in crew training.

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