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Review

Review and analysis of fire and explosion accidents in maritime transportation

Til Baalisampang [a], Rouzbeh Abbassi [b,**], Vikram Garaniya [a], Faisal Khan [c,*], Mohammad Dadashzadeh [d]

[a] National Centre for Maritime Engineering and Hydrodynamics, Australian Maritime College (AMC), University of Tasmania, Launceston, Tasmania, Australia
[b] School of Engineering, Faculty of Science and Engineering, Macquarie University, Sydney, NSW, Australia
[c] Centre for Risk, Integrity and Safety Engineering, Faculty of Engineering & Applied Science, Memorial University of Newfoundland, St. John's, NL, Canada
[d] Hydrogen Safety Engineering and Research Centre (HySAFER), Ulster University, Newtownabbey, Northern Ireland, UK

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ABSTRACT

The globally expanding shipping industry has several hazards such as collision, capsizing, foundering, grounding, stranding, fire, and explosion. Accidents are often caused by more than one contributing factor through complex interaction. It is crucial to identify root causes and their interactions to prevent and understand such accidents. This study presents a detailed review and analysis of fire and explosion accidents that occurred in the maritime transportation industry during 1990–2015. The underlying causes of fire and explosion accidents are identified and analysed. This study also reviewed potential preventative measures to prevent such accidents. Additionally, this study compares properties of alternative fuels and analyses their effectiveness in mitigating fire and explosion hazards. It is observed that Cryogenic Natural Gas (CrNG), Liquefied Natural Gas (LNG) and methanol have properties more suitable than traditional fuels in mitigating fire risk and appropriate management of their hazards could make them a safer option to traditional fuels. However, for commercial use at this stage, there exist several uncertainties due to inadequate studies, and technological immaturity. This study provides an insight into fire and explosion accident causation and prevention, including the prospect of using alternative fuels for mitigating fire and explosion risks in maritime transportation.

1. Introduction

The shipping industry is expanding globally, leading to an increase in worldwide shipping traffic (Hetherington et al., 2006; Tournadre, 2014; Yip). The growing number of marine vessels may lead to a rise in maritime hazards and accidents. Akten (2006) stated that shipping is, and always will be, full of risks despite increasing safety standards and improved technology. Celik et al. (2010) stated that the system complexity and automation, human error, human-centred system design, and potential design-based failures are different perspectives for ongoing shipping accidents. Due to this, international maritime authorities have made significant efforts to promote safety in the shipping industry (Hetherington et al., 2006; O'Neil, 2003) but despite this, there are still a high number of shipping accidents reported in recently published statistical reports (Baltic Sea Maritime Incidence Response Group (MIRG), 2017; Darbra and Casal, 2004; Eleftheria et al., 2016; Roberts et al., 2012). Shipping accidents by type are numerous, but common examples are collision or contact, capsize, foundering, breaking up, grounding, stranding, and fire or explosion (Abbassi et al., 2017; Akten, 2006). Broadly, human error, technical and mechanical failure, and environmental factors are common causes leading to shipping accidents but with different percentages (Karahalios, 2015; Uğurlu et al., 2015). The Major Hazard Incident Data Service (MHIDAS) (2002) database, considered eight types of possible causes of general accident, namely mechanical failure, impact failure, human error, instrumental failure, services failure, violent reaction, external events and upset process conditions. According to Allianz Global Corporate and Specialty (2017) foundering (sunk, submerged), wrecked/stranded (grounded), fire/explosion, collision (involving vessels), machinery damage/failure and hull damage have been the most frequent causes of losses at sea over the past decade (2007–2016).

Accidents are often assigned to a single category such as grounding,

* Corresponding author. Tel.: +1 709 864 8939.
** Corresponding author. Tel.: +61 29850 9224.
E-mail addresses: rouzbeh.abbassi@mq.edu.au (R. Abbassi), fikhan@mun.ca (F. Khan).

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fire or explosion, human error, collision and foundering. This type of categorization ignores the fact that often accidents are caused by more than one contributing factor or sequence of undesirable events (Baksh et al., 2016; Papanikolaou et al., 2007; Wagenaar and Groeneweg, 1987). Most literature relating to shipping accidents (Butt et al., 2013; Bužančić Primorac and Parunov, 2016; Roberts et al., 2013) have highlighted the causal factors for general shipping accidents but root causes of a particular event are often ignored. For instance, human error can lead to collision which in turn may cause fire and explosion. In this case, if there are no causal factors for human error as the root cause, then human error, collision and its subsequent events would not have occurred. In order to prevent the consequences of all these events, causal factors for human error are required to be addressed. This indicates that the determination of root cause and potential safety barriers of any accident type are vital in order to prevent accidents.

In the past, a significant number of shipping accidents involved fire and explosions (Akten, 2004; Roberts and Marlow, 2002; Roberts et al., 2012). For instance, Darbra and Casal (2004) found that 29% and 17% of accidents in seaports are caused by fires and explosions respectively. Bulk carrier casualties world-wide, taken from Lloyd's records between 1980 and 2010, confirm that fires and explosions caused 19% of accidents (Roberts et al., 2013). Weng and Yang (2015) found that the contributing factors in shipping accident mortalities resulting from fire/explosion accidents are, on average, 132% higher than from accidents where no fire/explosions were involved. According to the report presented by Allianz Global Corporate and Specialty (2016), about 10% of total losses, between 2006 and 2015, were caused by fire and explosion. From 2007 to 2016, foundering accounts for the highest percentage of losses (50.42%), followed by wrecked/stranded with 20.57% with the third highest contributor fire/explosion (9.95%) (Allianz Global Corporate and Specialty, 2017). The MIRG project (2017) stated that from 2000 to 2015, among different types of marine vessels in European waters, the largest percentage of ship fires and explosions occurred on cargo ships.

The actual number of fire and explosion accidents could be much higher than the published statistics because of underreporting issues of maritime accidents (Hassel et al., 2011; Schröder-Hinrichs et al., 2011). It is often found that the number of fatalities from fire and explosion accidents in shipping is comparatively higher than that of other types of accidents. Fire and explosion usually occur unexpectedly which provides little evacuation time for passengers or crew members (National Research Council, 1991).

This shows that the risk of fire and explosion in shipping vessels is high. The consequence of ship fire and explosion depends on the presence and amount of hazardous materials and the employed preventive and control mechanisms. In the absence of appropriate protection and response, even a small error that leads to a fire and explosion event has potential to cause loss of vessels, environmental pollution, injuries, and deaths due to the instantaneous nature of ship fires (Shichuan et al., 2012).

Uğurlu (2016) investigated fire and explosion events that occurred between 1999 and 2013 in tankers transporting hazardous liquid cargoes and identified 13 root causes and five causal factors being violation of entry permit (VEP), violation of work permit (VWP), lack of risk analysis (LRA), deficiency in safety management system (DSMS), and deficiency in planned maintenance system (DPMS). This study was conducted in three stages. In the first stage, significance level of the root causes was determined using Fault Tree Analysis (FTA), in the second stage, the causative factors underlying the root causes were determined and in the final stage, the relationship between the causative factors and root causes was determined. The author argued that hot work, electric arcs, static electricity, and combustible gas accumulation are the most significant root causes of fire and explosion accidents in tankers transporting hazardous liquid cargoes and VWP and LRA are the main causative factors of fire and explosion accidents.

In this paper, the contributing factors for fire and explosion accidents in maritime transportation are reviewed based on published full investigation reports and literature. Accident investigation reports prepared by different agencies such as National Transport Safety Board (NTSB), Danish Maritime Accident Investigation Board (DMAIB), Australian Transport Safety Board (ATSB), Federal Bureau of Maritime Casualty Investigation (BSU), Transportation Safety Board of Canada (TSB), European Maritime Safety Agency (EMSA) and Marine Accident Investigation Branch (MAIB) are considered. Publicly available fire and explosion related accidents in maritime transportation between 1990 and 2015 are grouped into five categories according to their main causes, namely human error, mechanical failure, reaction, electrical fault and unknown. The percentage of fire and explosion accidents caused by each causal factor is given in Fig. 1.

These accidents are further divided into different categories in order to compare the number of fatalities and number of accidents in maritime transportation as shown in Fig. 2. This indicates that fire and explosion still pose a risk to maritime transportation despite technological progress. In order to avoid fire and explosion accidents, a comprehensive review of all contributing factors is essential.

Additionally, in this study, potential preventative or mitigation measures are discussed for each type of contributing factor. Identifying sources of flammable materials and replacing them with less hazardous materials may play a positive role in mitigating fire and explosion risks in ship. Marine fuels are highly flammable. In this study, it is found that 31% fire and explosion events are caused by accidental releases of fuel or lubricating oil in the engine room. Due to this, it is worthwhile to review from a safety perspective flammability properties of alternative fuels. The effectiveness of alternative fuels in mitigating fire and explosion hazards is reviewed based on the comparison of their flammability properties. Therefore, this study would help identify contributing factors for fire and explosion events in maritime transportation and would seek to highlight potential preventive measures.

2. Fire and explosion accidents causations

The causes of fire and explosion in marine operations identified by Kwiecińska (2015), provided characteristics of basic fire causes and the influencing factors in ships. These are namely damage to electrical equipment and cables, damage to mechanical equipment, damage to ship's hull or its equipment, damage caused by external factors, damage occurring during maintenance work/repairs, and spontaneous ignition of cargo. The author has shown the interrelationship of cause-and-effect links leading to fires on ships and argued that spontaneous ignition of cargo is the strongest interaction with other factors. This shows that identifying interrelationships among various causal factors of a broad accident category helps to explore the underlying causes. Thus, in order to identify causal and root causes, contributing factors that were responsible for past fire and explosion accidents in shipping are

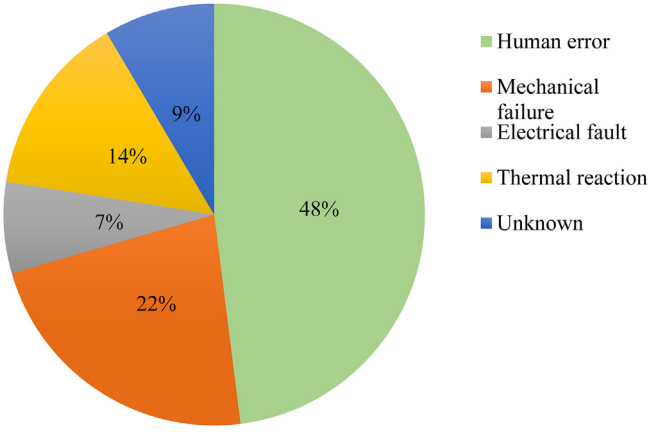

Fig. 1. Percentages of fire and explosion accidents.