Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen
 Published by Research Publishing, Singapore.
doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P4380-cd

X-Press Pearl Accident; Learning from one of the worst maritime disasters

Deshai Botheju

Wood Group, Technical Safety and Environment, Norway. E-mail: Deshai.Botheju@woodplc.com (or dbotheju@gmail.com)

Ajith de Alwis

University of Moratuwa, Department of Chemical and Process Engineering, Sri Lanka. E-mail: ajith@uom.lk

Kumuduni Abeysinghe

Vow ASA, Norway, E-mail: kumuprasa@gmail.com

Thushara Subasinghe

University of Moratuwa, Department of Chemical and Process Engineering, Sri Lanka. E-mail: thusharas@uom.lk

Abstract: The Xpress Pearl was a new-built container ship that was totally destroyed and sank due to an onboard fire and explosion event near the western coast of Sri Lanka in the Indian Ocean. This accident is regarded as one of the worst maritime pollution disasters to happen anywhere in the world. The accident released vast amounts of hazardous and noxious substances including various persistent pollutants. The huge quantity of plastic nurdles released in this accident will prevail in the ocean and the coastal environment for decades to come, thereby contributing to a significant micro-plastic pollution in the region. The event also unfolded a catastrophic socio-economic outcome, primarily due to the pollution inflicted on the sensitive and populated coastal area in the vicinity of the accident.

This paper discusses the plausible causes and series of mishaps that lead to this disaster, and consequent incident management failures which then magnified and escalated the initial event. The paper will also present the key lessons that must be extracted from this disaster in order to minimize the likelihood of similar events happening again. The first two authors had directly involved in advisory activities from the onset of the accident until the final investigations were completed by the Marine Environment Protection Authority of Sri Lanka (MEPA). Some details related to this accident are available to the public now, after several years since the disaster happened. The Xpress Pearl disaster must lead to wide and comprehensive changes in the regulations applicable to global maritime trade; particularly regarding the transportation of hazardous and noxious substances using ordinary container ships. Further, management practices associated with decision making procedures related to the handling of this kind of accidents must be reviewed.

Keywords: Exothermic reactions; Fire and explosions; Maritime accidents; Marine pollution; X-Press Pearl disaster.

1. Xpress Pearl disaster

Due to the strong growth of maritime transport during last several decades (UNCTAD, 2023), the risks of maritime accidents leading to large scale pollution events have also intensified. Hanjin Pennsylvania accident in 2002 (Kim, S. and Park, Y., 2005), Hyundai Fortune accident in 2006 (Lee, J. and Kim, J., 2008), MSC Flaminia accident in 2012 (König, D., 2014), and KMTC Hongkong accident in 2019 (Hand, M., 2019) are some of the events bearing certain similarity to X-Press Pearl accident. All these accidents involve onboard fires associated with hazardous cargo on container ships. However, the X-Press Pearl disaster stands out from these previous maritime accidents due to several unique characteristics including; massive plastic nurdle spill, proximity to a populated coastline, sensitive coastal ecosystem, the significant diversity of the hazardous cargo, and the total loss of the ship and its cargo.

The X-Press Pearl, a container ship carrying approximately 1500 containers, arrived at Colombo on the late hours of 19th May 2021. Awaiting entry to the port, it then anchored outside the harbor at about 9.5 NM (about 18 km) away from the shoreline. A fire incident onboard was reported at late hours in the following day, to which the Colombo port's fire service vessels promptly responded. Despite swift firefighting and early success, the fire was not able to be completely extinguished. Despite strenuous firefighting efforts, mostly using fire cannons on Ports Authority tugboats and the SL Navy ships, the fire began to escalate after several days, partly supported by monsoon winds and dry weather conditions. The continuous fire, followed by several explosions, led to the sinking of the ship along with its remaining unburnt cargo off the coast of Colombo, manifesting the largest maritime pollution event ever to occur in the region. Understanding the series of events that resulted in this disaster is vital for mitigating similar risks in future.

2. Propagation of the accident

On the morning of the 25th May, after 5 days of the fire initiation, a violent explosion was reported onboard the vessel. At that point, the vessel crew was evacuated with two (2) crew members suffering from burn injuries. Only 8 containers were initially reported to be thrown overboard as a result of the explosion. However, later evidence (based on debris washed ashore) pointed towards many more cargo being dislodged from the ship and ended up in the sea, as a result of this initial explosion or due to the ongoing fire. Within 24 hours after this first explosion, debris started to be found ashore along the coastline from Colombo (the capital city) to Negombo (another nearby township, 40 km north from Colombo). The initial debris washed ashore included a whole shipping container deformed clearly due to an explosion, many sacks of low density polyethylene beads (nurdles /pellets), some rolls of yarn, food items, etc. Soon the shoreline was covered with polymer beads and a gummy textured dark substance which is suspected to be self-polymerized resins (Figure 1).

By the 26th May, despite continued firefighting efforts, the fire intensified and escalated to engulf the whole ship from the Forward section to the Aft (Figure 2). The firefighting vessels had to retreat due to the intense heat.

Figure 1: First debris found ashore after the explosion onboard XPP.

Figure 2: X-Press Pearl on fire on 26th May 2021.

By the 27th May, the fire has largely consumed much of the flammable substances aboard the ship and the intensity of the fire reduced. The firefighting efforts were resumed with fire cannons, as well as with air drops of dry chemical packs. By this time, increasing amounts of plastic nurdles were found ashore and they were found even much further south from Colombo, such as in Hikkaduwa and Galle areas, along the western coastline of Sri Lanka. Also, many carcasses of dead fish and other sea creatures were found on the beaches, including a number of sea turtles. By the 27th May, the fire was largely gone and had been reduced to a pool fire deep down in the ship interior (possibly in the fuel tanks). By the 28th May, the fire had been mostly extinguished and only smoke plumes were visible. On the same day, at around 2300 hours' time, a second explosion was reported on the ship, but no additional intensification of fire was noticed. By the the 1st June, the fire had been extinguished, and the ship was sufficiently cool, allowing

salvors to go aboard the ship and to inspect it. On the 2nd June, attempts were made to tow the ship towards deep sea, and at the beginning of that attempt, a large section of the hull was disintegrated, and the engine room area was observed to be flooded. Shortly after that the ship started to sink. By the end of the day, the aft section of ship had been settled on the sea floor at a depth of about 21 m, while the forward section was still slowly sinking. The middle section had been completely submerged in water, while a pile of container rubble was still visible above the water level. The living quarter structure located at the aft continued to be visible above the surface due to its height (Figure 3). It was evident that the ship was now a wreck in the SL waters, that needed to be further dealt with.

Figure 3: Sinking of the X-Press Pearl.

3. Root causes

On the 11th of May, about 8 days prior to the arrival at Colombo ports, an acid leak had been observed in a container carrying 25 tonnes of nitric acid, when Xpress Pearl was at Hamad port in Qatar. Attempts of discharging this leaking container at Hamad port was rejected by the port authorities. A similar rejection happened when the ship was at Hazira, India, 4 days later (15th May). The continued leaking of acid can be the precursor to the subsequent fire that occurred 5 days later in Colombo.

There can be several exothermic chemical reactions responsible for the initiation of this primary fire (Botheju, 2021). The nitric acid itself does not burn, but as a strong oxidizer it can violently react with many organic matters as well as some metals (see Reaction 1).

Reaction 1:

$$C + 2HNO_3 \longrightarrow CO_2 + NO_2 + NO + H_2O$$

Reaction 1 is a highly exothermic reaction. This heat further accelerates the reaction rate. If the heat is not removed (e.g. by firefighting with a lot of water) the reaction can become a runaway reaction or in other words a “thermal explosion”. Mere use of a small amount of water can also worsen the situation due to the exothermic water dissociation of the concentrated acid (see Reaction 2).

Reaction 2:

$$HNO_3 + H_2O \longleftrightarrow H_3O^{(+)} + NO_3^{(-)}$$

Generation of nitrogen dioxide (NO_2) was evident during the first day of the fire initiation (i.e. 20th /21st May), as reddish-brown smoke was emanating from the ship (Figure 4). NO_2 is a toxic gas with pungent odor that causes severe air pollution, though it is not flammable. Meanwhile, nitric oxide (NO) is a colorless flammable gas.

Figure 4: X-Press Pearl after arriving at Colombo on 20th May 2021 (photo credit: Wikimedia Commons, “Isuruhetti”) .

The fire itself can also thermally decompose HNO_3 to generate NO_2 (see Reaction 3). Releasing oxygen (O_2) can provide oxygen for further combustion, even if the location is not well ventilated (e.g. deep down in the cargo hold, or inside a container).

Reaction 3:

$$4HNO_3 \longrightarrow 4NO_2 + O_2 + 2H_2O$$

As shown in Figure 5 (Vithanage, De Alwis, and Botheju, 2024), there was only one nitric acid container aboard the ship stored in the cargo hold number 2. This is very likely to be the place where the acid leak started. Some of the adjacent containers were filled with epoxy resin and high density polyethylene (HDPE) nurdles (beads). Also, the nearby containers had vinyl acetate, methanol, and lithium-ion batteries; all flammable and potentially explosion causing agents. In the cargo hold below the deck level, more methanol had been stored.

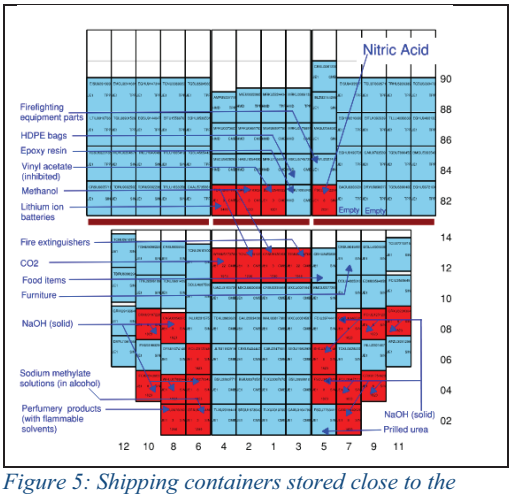

Figure 5: Shipping containers stored close to the leaking nitric acid container (figure extracted from Vithanage, De Alwis, and Botheju, 2024).

The epoxy resin itself is flammable; and if mixed with nitric acid, it will decompose exothermically, giving off more heat and starting a fire.

The reaction between nitric acid and methanol produces methyl nitrate, which is a strong explosive and also highly volatile (see Reaction 4).

Reaction 4:

$$CH_3OH + HNO_3 \longrightarrow CH_3NO_3 + H_2O$$

Lithium in the lithium-ion batteries can react with nitric acid to produce lithium nitrate and NO. The reaction is exothermic (see Reaction 5).

Reaction 5:

$$Li + HNO3 \longrightarrow LiNO3 + NO + H2O$$

Further, Li-ion batteries can rapidly catch fire and once started it is hard to extinguish such fires. Even if managed to extinguish, the fire could re-ignite once the firefighting /cooling is terminated.

The ship's cargo had several other flammable and combustible materials stored at different places. Some of them are mentioned below:

- Vinyl acetate: Flammable substance
- Aluminum smelting by products: These metal processing by-products can react with sea water to generate highly flammable and toxic gases such as hydrogen, acetylene, methane, ammonia and phosphine. This means even the fire water used in firefighting could have led to further escalation of the fire, if such water reached the locations where these Aluminum remelting by products were stored.
- Sodium methylate: Reacts with water generating methanol (which is flammable /potentially explosive).
- HDPE and LDPE bags: These are combustible polymer beads.

The ship's cargo contained many more non-specified organic liquids and various other combustible materials such as furniture, food items, automobile parts including tires.

Further, the ship had approx. 620 MT of heavy fuel oil and less than 50 MT of marine diesel for use in the ship's engines. A significant quantity of lube oils, and some quantities of fuel sludge were present.

3.1 Causes of explosions

As described previously, there were many agents onboard X-Press Pearl that could have created explosions. In addition to nitric acid's highly violent oxidation property (that could lead to thermal runaway type explosions), other agents such as methanol, vinyl acetate, aluminum remelting byproducts, and sodium methylate (in alcohol) could also have contributed to the occurrence of the first explosion. Among them, methanol and aluminum remelting byproducts can be identified as direct contenders. Note also that due to the very high congestion on the ship (which was packed with containers), a gas cloud explosion could have easily occurred when a flammable gas is accumulated within a partially confined space, such as below deck cargo holds, or even within a single container.

The 2nd explosion reported on the 28th May can be due to the extinguished pool fires in the ship's fuel tanks. It is a known fact that an extinguished or partially extinguished ventilation-controlled pool fire could lead to gas explosions.

4. Consequences of the disaster

As per the cargo load list, X-Press Pearl contained a large amount of different substances including a number of environmentally hazardous organic substances, such as acetyl cedrane used in perfumery products that is categorized as a substance posing acute and chronic toxicity to marine life. However, it is likely that many of such organic substances are disintegrated and burnt in the fire event thereby reducing the likelihood of releasing them to the marine environment. According to visual evidence, the fire temperature should have reached approximately 1500 deg C. Under such high temperature conditions, many organic substances should completely break down into harmless basic ingredients. However, any cargo stored close to the ship bottom could have been shielded from the fire heat due to submergence in accumulated firewater (that filled in the ship bottom).

The ship was reported to have close to 700 MT of fuels and lube oils. It can reasonably be expected that a significant part of this would have also been burnt in the fire. However, some unburnt fuel amounts could still have been trapped in the fuel tanks of the ship (which are either not ruptured open during the fire, or the pool fires at those deep-down locations in the ship were ventilation controlled and also possibly extinguished by firefighting) when the ship sank.

While the ship was still afloat during the fire, the bottom sections were evidently filled with a large amount of water (i.e. water used in firefighting, as well as the water leaking through the damaged hull) contaminated with various toxic and environmentally harmful chemical ingredients, potentially including many persistent and bio accumulative organic substances. As the ship sank, this cocktail of liquid chemicals (mixed with water) must have been released to sea. The observations made on the 2nd June indicated a yellowish substance floating near the ship, suspected to be originating from a sulfur stock transported on the ship. This is indicative of the release of liquid contents or other unburnt substances collected at the bottom sections of the ship. Nevertheless, the wave action and the sea currents should lead to dispersion and dilution of any chemical concentrations (including the release of any acidic or alkaline chemicals such as nitric acid and sodium hydroxide which were present onboard the ship).

The ship's cargo load list also indicates a large amount of scrap metals and lead ingots. These

heavy metals can cause considerable marine pollution, and cause long term harm to human health, as many of these metals can be slowly released (due to chemical and biochemical reactions) into seawater and then bioaccumulate and bioconcentrate along the food chains, eventually entering the human body via sea food consumption.

The fire has caused a substantial air pollution near the coastline of Sri Lanka. A large part of the fire could have propagated at relatively lower temperatures as evident from the prolonged black smoke emissions (even though there was a 1 – 2 days of high intensity fire duration). Such incomplete burning of plastics can release various harmful fumes including polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo furans; some of the most harmful and persistent pollutants. The smoke plume generated from the fire carried directly towards the shoreline, due to the prevailing weather conditions at the time. Therefore, the pollutants are basically scattered and settled on land. The smoke plume should have had many other toxic gases and components such as NO_2, NO, PH_3, CO, NH_3, VOCs, etc. and particulate matter.

A large-scale marine and beach pollution has happened due to the scattering of micro-plastics in the form of polymer beads (nurdles). It was reported that some dead fish were found with these polymer beads in their intestines. Also, a large amount of partially polymerized masses had been found in the sea as well as on the beach. The observed marine creature deaths could have been caused by the reduced dissolved oxygen levels in the water. Increased temperatures in the immediate locality of the ship would cause a reduction of oxygen levels. However, large temperature increases cannot happen much farther away from the burning ship as the mixing action of waves and currents quickly reduce the sea water temperature to ambient condition. In addition, chemical toxicity effects and slightly changed pH levels could also have contributed to some destruction of sea life near the location of the shipwreck. The large consignment of solid caustic (sodium hydroxide – NaOH) on X-Press Pearl might have had a role to play in explaining some fish and marine animal deaths reported later durations. The slow dissolution of the large amounts of solid caustic present onboard was a cause for concern.

5. Preventability

The leaking acid container did mean that either proper packaging or package securing (e.g. with a net inside the container) was not done in accordance with the IMDG code (IMO, 2018) and the CTU code (IMO/ILO/UNECE, 2014) or proper handling of the container did not happen.

When the acid leak was first noticed, the ship had requested both Hamad and Hazira ports to allow the leaking acid container to unload, but both ports had rejected the request. This cannot be considered as an act of goodwill and must be addressed as a matter of urgent attention in future formulations of international maritime low and the standards applicable to potentially hazardous situations onboard ships. On the other hand, if the situation was perceived as serious, the ship captain could have declared one of the above ports as the *place of refuge* and forced them to facilitate the ship with further assistance.

The next obvious decision the ship captain could have made was to dispose of the leaking acid container at sea. This is totally allowed according to the IMDG code (IMO, 2018) as well as MARPOL Convention (IMO, 1973). If the ship's master came to the judgment that a certain cargo was hazardous to the lives of the crew members, such goods could be disposed of in the sea. The safety of the crew always comes as the priority concern compared to any pollution risk. In this case, it is reasonable to believe that the onboard cranes had access to the relevant cargo hold

location and had capacity to lift the less than 30 MT acid container (it could have had to handle a few other containers before reaching the acid container). However, the ability to handle such operations under prevailing weather conditions is a decision that can only be made in accordance with the actual circumstances. Whether the ship captain had correctly understood the gravity of the situation was not clarified during the subsequent investigation.

The last remaining action that could have prevented a fire from occurring was to continuously cool the area subjected to the acid leak and simultaneously dilute the leaking acid with ample amount of water (until the leaking container can be removed from the ship). Whether this had been done rigorously was never clarified during the subsequent investigation.

The attempt to tow away the burnt and very delicate ship on the 2nd June should not have been made. It is obvious that a typical ship structure, after being subjected to such intense fire, becomes very weak and must handle with extreme care and precision. The ship should have been secured, the remaining cargo removed and structurally reinforced before towing it to a safe location.

6. Conclusions and recommendations

X-Press Pearl represents a unique marine accident that has led to extensive marine pollution. It has evidently caused a large environmental, human health, and socio-economic damage to Sri Lanka as well as to the surrounding region. The consequences will be spread over a long period of time.

Therefore, this accident should impact on some of the existing rules and guidelines applicable to international maritime trade. IMO must seriously evaluate the need for relevant changes. The affected countries, including Sri Lanka, must recognize their own measures to safeguard coasts and the waters from these types of events in future. To reduce similar risks in future, the following key measures are proposed:

- SL government must establish a single point authority to plan, respond, investigate, and manage aftermaths related to maritime and land-based catastrophes involving complicated chemical process and technical scenarios. The management and the regulatory structure of Norwegian Ocean Industry Authority can be a good example to follow. X-Press Pearl accident showcased the current weaknesses of existing management structures involving multiple parties that are difficult to coordinate and managed during a crisis situation. Alternatively, the above proposed management body can be a part of an Accident Prevention and Investigation Authority that may be entrusted with a wider responsibility of handling various other industrial incidents and accidents (such as transport accidents, aviation accidents, factory and refinery accidents, etc.). The structure of the US Chemical Safety and Hazard Investigation Board can be another good example to study in this regard.

- Apparently, there is a vast void when it comes to the legal basis of claiming environmental damage costs involving international parties. A parliamentary act should be drafted with proper attention given to the US OPA (oil pollution act) where NRDA (Natural Resource Damage Assessment) models are embedded in it.

- Enhance the capabilities and capacities to respond to similar events. Strategic technical facilities such as improved marine firefighting equipment, underwater ROVs, Underwater survey facilities, coastal surveillance aircraft, deep sea response vessels, etc. must be recognized and acquired. Sufficient stocks of oil spill dispersants, oil collecting booms, oil absorbing pads, firefighting agents etc. must be stockpiled.

- Establish a national pool of experts related to various disciplines and subdisciplines. Receiving expert opinions at urgent moments is a critically important aspect that can decide the eventual outcome of an industrial accident while it is still evolving. Information on resident and expatriate scientists and engineers must be collected, and the individuals must be contacted to establish such a resource pool.

Further, it must be mentioned that this article is primarily focused on the root and proximity causes of this disaster. There could be various other organizational, socio-technical, and cultural factors that may have indirectly or partially contributed to the eventual outcome.

References

Botheju, D. (2021). X-Press Pearl: What went wrong? The scientific basis. News article, available online: https://www.ft.lk/opinion/X-Press-Pearl-What-went-wrong-The-scientific-basis/14-719287

Hand, M. (2019). Undeclared dangerous cargoes believed to have caused fire, explosions on KMTC containership. SeatradeMaritime News article, available online: https://www.seatrade-maritime.com/cargo/undeclared-dangerous-cargoes-believed-to-have-caused-fire-explosions-on-kmtc-containership

International Maritime Organization (IMO). (1973). International Convention for the Prevention of Pollution from Ships (MARPOL).

International Maritime Organization, International Labour Organization, United Nations Economic Commission for Europe (IMO/ILO/UNECE). (2014). Code of Practice for Packaging of Cargo Transport Units (CTU Code).

International Maritime Organization (IMO). (2018). International Maritime Dangerous Goods Code, Volume I & II.

Kim, S., and Park, Y. (2005). Fire and Explosion Risks in Container Shipping: Lessons from Recent Incidents. Journal of Navigation, 58(2), 245-259.

König, D. (2014). The MSC Flaminia Incident and its Implications for International Maritime Law. Journal of International Maritime Law, 20(3), 185-198.

Lee, J., and Kim, J. (2008). Analysis of Container Ship Fire Incidents: A Case Study on Hazardous Cargo Mismanagement. Maritime Policy & Management, 35(4), 387-402.

United Nations Conference on Trade and Development (UNCTAD). (2023). Review of maritime transport 2023. Report, available online: https://unctad.org/publication/review-maritime-transport-2023

Vithanage, M., De Alwis, A., and Botheju, D. (2024). Maritime accidents and environmental pollution – The X-Press Pearl disaster. Causes, consequences, and lessons learned. CRC Press. Taylor & Francis Group.

Acknowledgement and disclaimer

Authors acknowledge the collaborative support from the Marine Environmental Protection Authority of Sri Lanka. Works of other colleagues from various institutions involved in the X-Press Pearl accident investigation are also to be recognized. A special gratitude is extended to Prof. Meththika Vithanage (University of Sri Jayewardenepura) and Veditha De Silva (University of Ruhuna).

The opinions and viewpoints indicated in this article, directly or indirectly, do not represent authors' organizations.