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Safe Transfer of Ammonia in Pipelines: An Analysis of Risk

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Abstract: Humanity is currently confronted with unprecedented environmental challenges, prompting an urgent shift toward the widespread adoption of clean energy. Among the diverse alternatives, ammonia stands out as a highly promising candidate due to its relatively high volumetric energy density, advanced technical readiness level, and well-established infrastructure with established standards. However, the safety of ammonia transport via pipelines demands particular attention, as several past accidents have shown. Given the inherent risks associated with ammonia pipeline accidents, a thorough safety analysis is essential, especially for densely populated countries like Singapore. While Singapore explores using ammonia, a detailed assessment of potential pipeline leaks is currently lacking. To address this, this study employed Computational Fluid Dynamics (CFD) simulations using Phast software. Simulations modeled ammonia leaks at various pressures and weather conditions, and the results highlighted the significant hazards of ammonia leaks, including toxicity and flammability. Notably, the potential hazardous zone resulting from these leaks could span up to 1,000 meters. Furthermore, the study proposes effective countermeasures based on insights derived from the simulations, offering valuable perspectives to enhance safety and efficiency in clean energy applications. These measures include the implementation of safety instrumented systems, among others. The results from this study lay the groundwork for future laboratory-based experiments aimed at improving the safety of ammonia pipelines.

Keywords: green energy, ammonia, risk analysis, pipeline safety, leakage simulation

1. Introduction

The world is grappling with the impact of climate change, a consequence of human activities that predominantly rely on fossil fuels for energy generation [1]. Considering the current rate of population growth and associated increases in energy consumption, it has been projected that the corresponding global energy demand will increase by at least 50% before 2050 [2, 3]. In response to this, various organizations have initiated proactive measures. The International Maritime Organization has set an ambitious decarbonization target, aiming to reduce CO_2 emissions from shipping by a minimum of 40% by 2030 compared to the 2008 baseline [4]. Simultaneously, the Paris Agreement, a collaborative effort among nations, seeks to limit the global average temperature increase to well below 2 °C (preferably below 1.5 °C) above preindustrial levels [5]. On a regional scale, Singapore has committed to a Green Plan 2030, which aims to curb greenhouse gas emissions and cultivate a more sustainable future[1]. In the United Kingdom, the aviation industry, under the government's Jet Zero plan, has pledged to achieve net-zero carbon emissions by 2050. Similarly, the United States and the European Union have set comparable goals, aiming for net-zero emissions in their aviation sectors by 2050[2].

Clean energy has attracted significant attention as a key method to achieve carbon neutrality. According to the International Renewable Energy Agency, it is projected that 90% of all decarbonization solutions in 2050 will involve renewable energy. This includes the direct supply of low-cost power, improvements in efficiency, renewable-powered electrification in end-use, and the production of green hydrogen [6]. However, several challenges must be addressed to fully realize the utilization of clean energy. Firstly, the issue of instability arises as clean energy sources like wind or solar power rely on weather conditions, coupled with the fluctuating demand from consumers throughout the day or year. This variability complicates the integration of clean energy as a primary energy source. Secondly, the unequal distribution of clean energy resources poses a hurdle, as varying energy demands in different regions necessitate efficient energy transmission to meet the dynamic demand [7].

To overcome these challenges, the development of energy carriers has played a crucial role. Energy carriers help mitigate uncertainty and inequality by smoothing out peak demands and filling gaps in energy supply, thus achieving a more balanced distribution across different regions [8]. Numerous clean energy carriers have surfaced, and they can be classified into various groups, such as liquid organic hydrogen carriers (LOHC), hybrid metals, hydrogen, ammonia, methane, and hydrogen capsules, among others [9]. Each category of carrier has its unique

[1]Singapore Green Plan 2030. https://www.greenplan.gov.sg/

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[2]Could airports make hydrogen work as a fuel? https://www.bbc.com/news/business-67371275

advantages and drawbacks. Some carriers, with long periods of historical use, benefit from comprehensive knowledge and established standards and regulations that govern their safe and efficient utilization. In contrast, newer carriers that have come to the forefront in recent years are still undergoing research that seeks to achieve lower production costs and more efficient synthetic methods with higher reliability, lacking existing infrastructure tailored to their needs, and encountering substantially higher utilization costs.

Among all the energy carriers, ammonia stands out as a promising medium for energy storage, paving the way for future CO_2-free energy systems. Namely, ammonia is an energy carrier as an alternative carbon-free fuel source without any CO_2 emissions, which carries high expectations [10]. However, it's important to recognize that the conversion process of ammonia can lead to the emission of nitrogen oxides (NOx), a greenhouse gas. Research and development efforts are underway to mitigate these emissions. For instance, the development of new combustor designs significantly reduces NOx emissions during ammonia combustion [11]. Additionally, a deeper understanding of ammonia combustion dynamics and chemistry paves the way for lower overall greenhouse gas emissions [12]. Through these technological advancements, we can potentially overcome challenges associated with ammonia, such as its limited flammable range and NOx formation. Furthermore, ammonia benefits from well-developed methods for production, storage, and short-term transport due to its established role in fertilizers and chemical production. This existing infrastructure facilitates a smoother transition toward utilizing ammonia as a clean energy carrier.

Ammonia possesses favourable characteristics, which promote its suitability to work as a clean energy carrier. In terms of physical parameters, ammonia is a transparent alkaline with a strong odor. Its boiling point under atmospheric conditions is about −33 °C; with moderate pressure (10 Bars), ammonia could remain in the liquid state under room temperature. As an energy carrier, ammonia gets a relatively high volumetric energy density of 17 MJ/L, which promises high transport efficiency. High auto-ignition temperature (AIT) of 650 °C is an advantage of ammonia, when compared with other potential energy carriers, for instance, hydrogen's AIT is 520 °C, methane's AIT is 630 °C, and propane's AIT is 450 °C [13]. The density of ammonia is 0.769 Kg/m^3, lighter than air's average density, which could benefit its safety as well, for it could diffuse by itself.

Thanks to its characteristics, such as high volumetric hydrogen density, low storage pressure, and long-term stability, ammonia is regarded as an advantageous option. More importantly, ammonia can be produced from various primary energy sources, encompassing renewables, fossil fuels, and surplus energy, particularly excess electricity from the grid [14]. Therefore, a few countries and companies wished to exaggerate the scope of ammonia usage, and some US states like California had issued relevant incentives for green fuels, including ammonia[3,4].

However, a significant challenge arises from the current insufficiency of existing pipeline infrastructure to facilitate the widespread distribution of ammonia. To illustrate this point, take the natural gas pipeline network in the United States, stretching approximately 3 million miles [15]. This is vastly more than the current ammonia pipeline network, which spans a mere 5 thousand miles across the USA [16]. The disparity in infrastructure scale emphasizes the imperative need for a significant expansion in ammonia pipeline construction. To transition to an ammonia-based energy system, it is estimated that over a million miles of new pipelines would need to be developed. According to Yang and Ogden's [17] findings, pipelines are far more cost-effective for all distances at large scales.

In developing ammonia transfer pipelines, the risk of ammonia leakage cannot be overlooked. Numerous existing regulations and codes categorize ammonia as a toxic chemical with relatively low permissible concentrations [18]. The US-National Fire Protection Association has designated it as a hazardous material, elevating its safety risk to a significant level [19]. It is crucial to note that an airborne concentration of just over 4 percent of ammonia has been demonstrated to cause the death of rats within 10 min [20]. As per the United States' National Library of Medicine, ammonia concentrations within the range of 2500–4500 ppm can prove fatal within roughly 30 min. Beyond this threshold, concentrations exceeding 5000 ppm can swiftly induce respiratory arrest [21].

Ammonia is also corrosive to several metals, including copper, brass, and bronze. Fortunately, it does not react with stainless steel, allowing for the safer transportation of ammonia through steel-based pipelines [22]. Despite so, stress corrosion cracking (SCC) due to a combination of tensile stress and exposure to a corrosive medium is still a safety concern. A case study involving a pipeline constructed with API 5L X52 steel shows that the pipeline experienced 20 leaks over a 13-year operational period due to SCC. According to Mora-Mendoza et al. [23], laboratory results indicated that approximately 50% of the pipeline length exhibited a high or very high probability of cracking failure.

On October 17, 2016, a catastrophic failure occurred in an ammonia pipeline near Tekamah, USA, leading to significant economic, environmental, and human losses. The incident timeline revealed delays in pressure drop detection and emergency isolation procedures, contributing to the severity of the leak. The cause analysis identified corrosion-related factors, emphasizing the need for meticulous material selection. Inspection and maintenance lapses, including a substantial distance between isolation valves, which allowed massive ammonia to remain in the pipelines (2587 barrels), exacerbated the consequences. The incident underscores the devastating consequences of inadequate maintenance and delayed responses, emphasizing the importance of stringent safety protocols for hazardous material pipeline operations [24]. On July 23, 2010, a significant ammonia leakage occurred near Nebraska, USA, during pipeline modification. The pipeline buckled and cracked during welding on the Thread-O-Ring fitting, causing the release of liquid ammonia and subsequent vapor clouds. The findings emphasized the inherent hazards of ammonia pipelines, which highlight the need for independent protection layers, including safety instrumented systems (SIS), and comprehensive management of change procedures along with hazard analysis before infrastructure modifications, coupled with enhanced emergency response training for personnel involved in such projects [25]. Both incidents underscore the critical importance of safety in ammonia pipeline transfers and the demand for in-depth study of ammonia leakage.

In the specific context of Singapore, to the best of our knowledge, there has not been a comprehensive risk study conducted on ammonia leakage from pipelines. This study aims to address this gap by examining the potential risks and mitigation strategies associated with ammonia leakage in pipeline infrastructure. Through simulations, we seek to enhance our understanding of the potential consequences of such incidents and

[3]New ammonia import infrastructure under development across Europe (and beyond). https://ammoniaenergy.org/articles/new-ammonia-import-infrastructure-under-development-across-europe-and-beyond/

[4]Potential as an energy carrier and beyond. https://www.cleantech.com/green-ammonia-potential-as-an-energy-carrier-and-beyond/

contribute to the overall safety and sustainability of future ammonia pipeline infrastructure in Singapore.

2. Methodology

This study utilized computational fluid dynamics simulations with DNV's Phast software to model potential ammonia leakage scenarios. Phast's strength lies in its ability to perform transient simulations. This allows us to capture the dynamic nature of an ammonia leak, where the concentration of ammonia in the surrounding environment will change over time. Using continuity, momentum, and energy equations, these simulations are crafted to offer comprehensive insights into the extent, dispersion, and severity of potential leakages, closely mirroring the conditions prevalent in Singapore. By comparing and simulating various weather conditions, including differences between daytime and nighttime scenarios, we can achieve a more refined and accurate presentation of the results.

In this study, we have referenced parameters from existing ammonia projects, such as temperature and pressure (18 bars), to simulate scenarios closely resembling real-world conditions. Weather data were sourced from the National Environmental Agency of Singapore, as shown in Table 1 [26], and the location chosen for the leakage simulation is Jurong Island, the western part of Singapore, known for its concentration of industrial activities, as shown in Figure 1.

To enhance the accuracy of the simulation, several assumptions were made. Firstly, to assess the potential impact of leaking ammonia on people, simulations were conducted in a scenario resembling a busy street in Singapore. In this context, the ignition source, such as moving vehicles and work activities, was assumed to be located 10 meters away from the point of leakage. Secondly, a concentration equivalent to 10 percent of the lower explosive limit (LEL) and the threshold limit value-time-weighted average (TLV-TWA) from American Conference of Governmental Industrial Hygienists (ACGIH) was considered [20]. Other assumptions include:

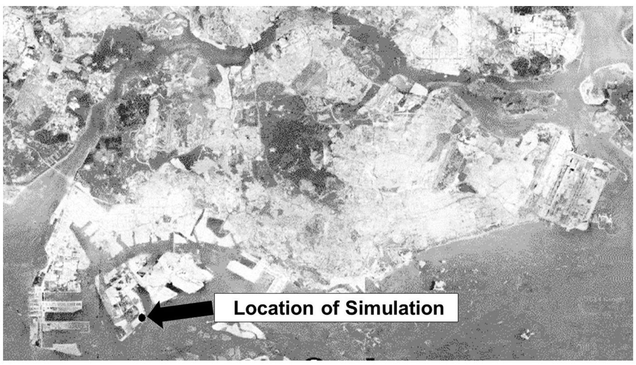
1) The ignition source was positioned 10 meters away from the leakage point, indicating that if the gas concentration reached 10 percent of LEL, a fire would occur. (Over 14000 ppm should be considered flammable, LEL is 140000 ppm) Redundancy measures were considered.
2) Concentrations exceeding TLV-TWA were deemed hazardous, with redundancy considered. No valid safety instrumented system was installed on the pipeline system, and the Basic Process Control System would not halt the flow of ammonia.
3) The leakage would persist until the pipeline was empty.
4) The total length of the pipeline was approximately 5 kilometers, which is assumed as a normal distance between isolation valves, while the leakage happened in the middle point of it.
5) The pipeline's internal diameter is about 200 mm. The leakage hole is about 2 mm in diameter, representing a realistic scenario of a small to moderate-sized breach in the pipeline. The hole size also reflects common defects or vulnerabilities in pipelines due to corrosion, wear and tear, or other factors.
6) The ground surface is composed of concrete as it is situated on land rather than water.
7) Ammonia concentrations exceeding the TLV-TWA (25 ppm) were identified as hazardous and dangerous for individuals, while concentrations over IDLH (300 ppm) are considered extremely hazardous.
8) The pipeline was an above-ground structure, and the leakage point occurred at a height of 0 meters.
9) The concentration of ammonia is even, and the pressure is stable within the pipeline at initial stage.

Table 1
Weather parameters used for simulation

Weather parameters (Singapore)		
Parameters	Day case	Night case
Atmosphere Stability	Class C	Class E
Wind Speed	3 m/s	2 m/s
Humidity	70%	90%
Ambient Temperature	306 K	297 K
Surface Temperature	311 K	300 K
Radiation Flux	1.2 KW/m2	NA

Note: The upper limit of radiation flux is 1.2 KW/m2

Figure 1
Simulated location of leakage, Jurong Island, Singapore



3. Results

The simulation of ammonia leakage from pipelines on Jurong Island yielded interesting insights. Firstly, Figure 2 illustrates the flammability range of the ammonia leakage cloud. In the simulation, conducted under conditions of either 277 K, 18 Bar, 36 Kg/s mass flow, or 277 K, 36 Bar, 36 Kg/s mass flow in the liquid state, the pool of leaked ammonia (in liquid state) is contained within a range of approximately 2 meters (shaded area in Figure 2). However, the flammable gas extends to about 14 meters during nighttime and 7 meters during daytime scenarios for the 18-bar pressure case. Meanwhile, higher pipeline pressure slightly expands the flammable zone from 14 meters to 16 meters in length. This highlights the potential for a fire or explosion if an ignition source is within 10 meters. Additionally, the maximum concentration of leaked ammonia, depicted in the figures on the left, shows that the concentration peaks within 10 meters. Furthermore, under higher pipeline pressure, the maximum concentration of leaked ammonia increases from less than 5000 ppm to 10000 ppm, nearly doubling the concentration.

Secondly, the results indicate that stable weather conditions may exacerbate the diffusion of the leakage, leading to more hazardous scenarios. This highlights the need for heightened awareness and preparedness in situations characterized by stable weather. Of particular significance is the observation that ammonia propagation can occur extremely rapidly, taking approximately 60 s. This swift dissemination poses a significant threat to individuals in proximity, emphasizing the urgency of effective emergency response measures. The rapid development is illustrated in Figure 3. Within the first

Figure 2
Footprint of flammable cloud under different pipeline pressure

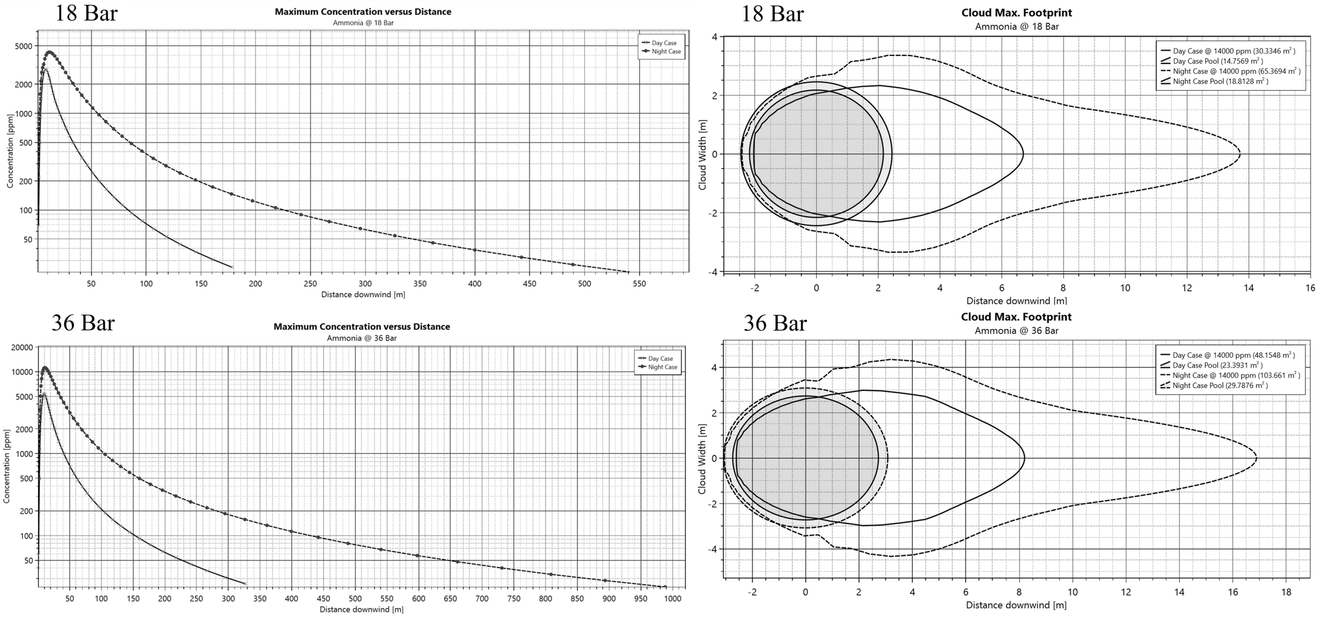
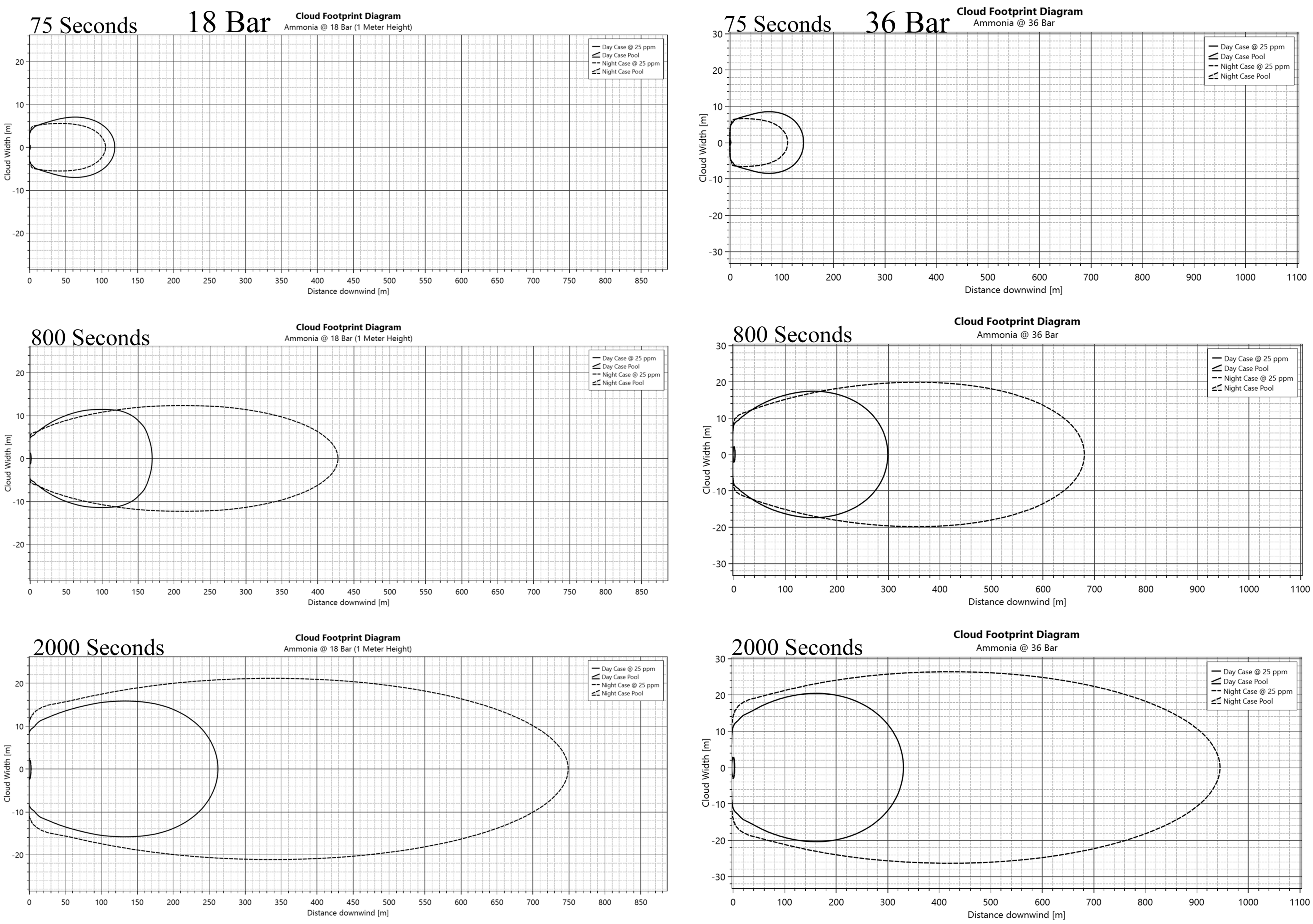


Figure 3
Toxic cloud expansion under different pipeline pressure



100 s, the ammonia hazard zone, characterized by its toxicity, extends to approximately 100 meters, with an even longer length observed for the night-time scenario. Subsequent developments in the hazards area reveal distinct trends. In the night-time case, the assumed stable weather conditions facilitate the expansion, covering a larger maximum hazard area. In contrast, the daytime case experiences suppression in the expansion due to unstable weather conditions, limited to approximately 100 meters in length.

Side view of the ammonia leakage cloud is shown in Figure 4. The results reveal that the height of the hazardous cloud is approximately 10 meters, indicating that individuals within the toxic cloud have no access to unpolluted air. Additionally, the side view's result also shows that the night scenario and higher-pressure pipeline case result in a relatively larger hazardous cloud.

The relationship between concentration of ammonia and time is illustrated in Figure 5, obtained through simulated image sensors positioned at distances of 1 meter, 5 meters, and 10 meters from the leakage point. At 10 meters, the peak concentration of ammonia is observed at approximately 600 s, while the closer proximity cases show dissimilar patterns. For areas closer than 10 meters, the concentration reaches its peak within seconds, indicating a lack of process safety time, with a fatal concentration of more than 30,000 ppm. The night scenario's peak concentration is almost 5 times higher than the daytime scenario, leading to higher risk of toxicity and flammability, while the higher pressure can also increase the concentration of leaked ammonia from 8500 ppm to 11000 ppm.

The shape of a jet fire can be influenced by both weather conditions and pipeline pressure, as depicted in Figure 6. Weather conditions, as illustrated, can impact the length of the jet fire, particularly under stable nighttime conditions, while the effect on width is relatively negligible. Moreover, higher pipeline pressures can exacerbate the situation, resulting in a prolonged jet fire.

The simulation yields several key findings. Firstly, the risk within a 10-meter radius of an ammonia pipeline leakage point is markedly high, as the released ammonia vapor poses both toxicity and flammability hazards. Secondly, within a 1000-meter radius, the toxicity levels from the leaked ammonia are substantial. Thirdly, areas located beyond 10 meters from the leakage point may provide a process safety time of less than 30 s. Fourthly, stable weather conditions, such as night-time, may exacerbate the diffusion of the leakage, leading to more hazardous scenarios. Fifthly, it's important to note that higher pipeline pressure could result in a larger hazardous zone concerning both flammability and toxicity. Sixthly, in the event of igniting leaked ammonia near the leakage point, a jet fire could ensue, spanning approximately 5 meters in length, representing a significant high-risk scenario. It's also worth noting that ammonia and humid air can form a

Figure 4
Side view expansion under different pipeline pressure

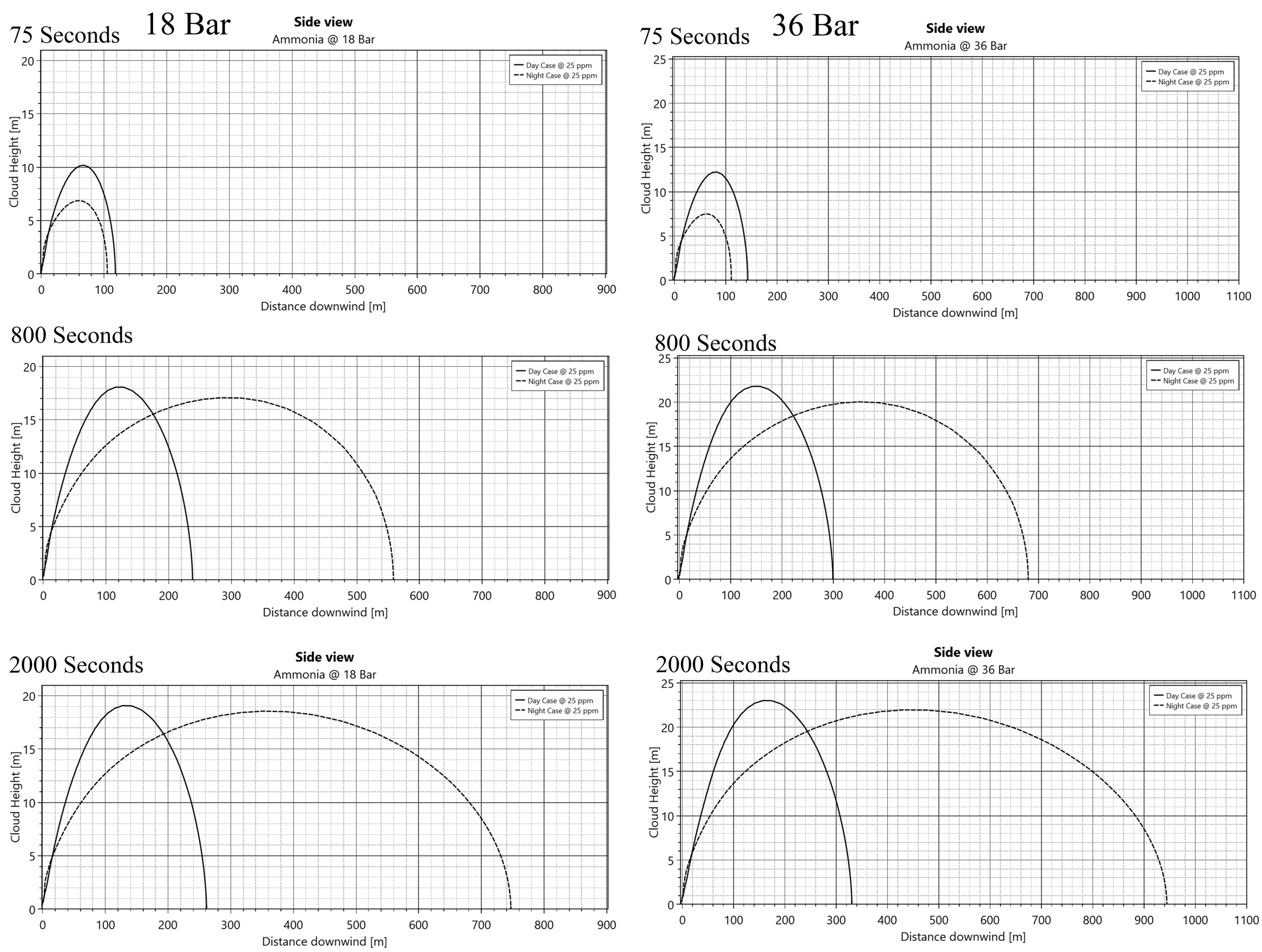
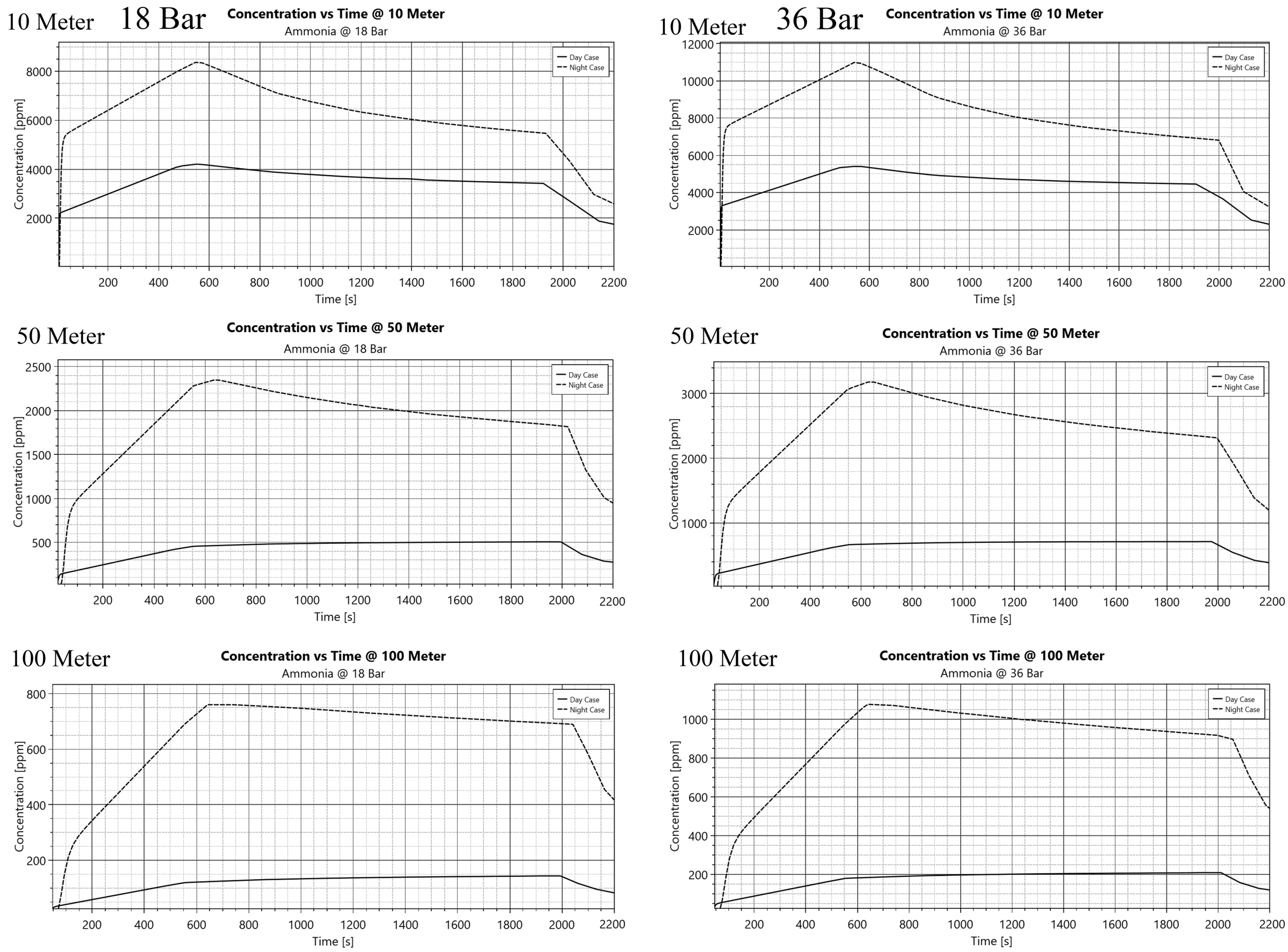


Figure 5
Concentration vs time at different distances under different pipeline pressure



mixture with higher density than ambient air, which could impact the diffusion of ammonia, causing the mixture to settle close to the ground. A phenomenon that has been observed in other studies [27, 28].

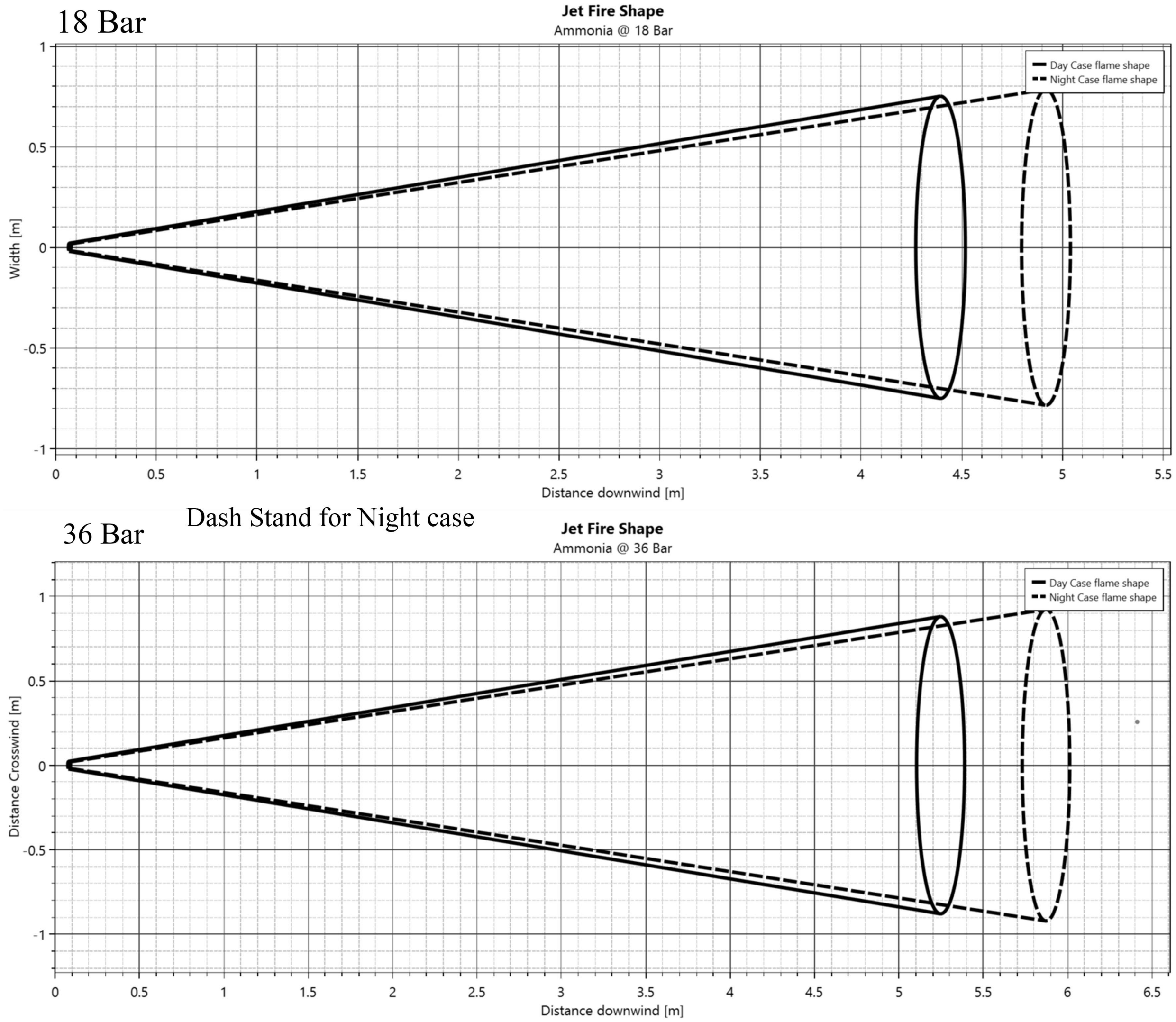
4. Discussions

Ammonia is increasingly recognized as a leading contender for future clean energy carriers, successfully balancing transport efficiency and technological readiness. However, the safety management of ammonia pipeline systems is crucial, given that significant leaks can have severe consequences. Our simulations show that ammonia pipelines should be considered extremely hazardous, with a heightened focus on ensuring their safety, particularly on Jurong Island due to its dense industrial activity. In Singapore, Jurong Island is home to numerous factories and a large workforce. A pressurized ammonia pipeline leak on the island could have catastrophic consequences, potentially affecting thousands of workers. However, the transportation of ammonia via pipelines is technologically viable and can offer cost savings with proper maintenance and adequate protection measures in place. Fortunately, the distinct smell of ammonia enables prompt detection of leaks, allowing for swift response measures to mitigate hazards. Furthermore, Jurong Island's lack of residential areas greatly reduces the risk of individuals being inadvertently exposed to ammonia poisoning while asleep. Although the simulation results show that reducing pipeline pressure can generally mitigate hazards by limiting the size of the hazardous cloud and slowing its expansion, it might not be operationally feasible in all circumstances. Based on the simulation findings, this study recommends implementing both passive and active control methods to enhance pipeline safety. Additionally, it identifies potential areas for future research aimed at developing ammonia-based energy systems, contributing to a cleaner environment.

Passive Control:

1) Material of Construction for New Ammonia Pipelines: The choice of material for ammonia pipeline construction plays a pivotal role in ensuring safe transfers. Stainless steel is often the preferred material due to its resistance to the corrosive properties of ammonia. Nevertheless, certain grades of carbon steel are considered suitable, particularly when the system undergoes meticulous maintenance and monitoring for potential corrosion.
2) Buffer Area: Simulation results indicate that maintaining a sufficient distance can effectively mitigate the hazards posed by an ammonia leakage in pipelines. The simulation suggests that, under stable environmental conditions, the hazard area of

Figure 6
Jet fire's shape from leakage point under different pipeline pressure



ammonia leakage could extend up to approximately 500 meters. Therefore, strategically situating pipelines away from residential or densely populated areas proves to be an effective measure to reduce potential risks.

3) To further enhance safety, the option of placing ammonia pipelines underwater or underground is worth considering. Ammonia, being a gas readily dissolved in water, implies that leaks from pipelines situated underwater or underground may pose reduced hazards, as a significant portion of the gas could dissolve into the surrounding water. Furthermore, given that the temperature at the bottom of the sea typically remains around 4 °C, constructing an ammonia pipeline underwater could capitalize on this natural condition. With pressures less than 4 bars, maintaining the liquid state of ammonia becomes feasible, potentially lowering construction costs and enabling the use of wider pipelines for transportation; however, it is essential to acknowledge the potential drawback of this method, which could lead to environmental concerns in marine ecosystems in the event of leakage.

Active Control:

1) Safety Instrumented System: Implementing SIS can enhance pipeline safety by providing additional layers of protection without having significant modifications to the existing system. Ensuring the effectiveness of the SIS requires in-depth analysis, including determining the required safety integrity level (SIL) through layers of protection analysis. This involves specifying each subsystem's devices, their risk reduction factor, considering the overall system's redundancy, and accounting for system structures. The following provides a brief overview of the basic workflow of the SIS.
2) Initiating Device Subsystem: An array of sensors can be integrated into the initiating device subsystem to prompt the activation of the SIS. These sensors may include mass balance, level indication, pressure drop, acoustic, seismic, and soil temperature systems. The strategic deployment of various sensor types, each focusing on specific parameters, enhances redundancy within the system. To achieve a superior SIL, it is recommended to combine multiple sensors from different

categories. This approach not only enables a comprehensive monitoring strategy but also substantially decreases the overall false alarm rate of the system.

3) Logic Solver Subsystem: The logic solver subsystem processes signals from initiating devices, such as analog signals. Decisions, such as whether to shut down an isolation valve, are made by the logic solver subsystem based on certain criteria. The performance of the logic processor is critical to the entire system. Therefore, it is essential to ensure systematic integrity and reliability of the processor, as the entire SIS depends on the logic solver system to make the right decisions in a timely manner.
4) Final Device Subsystem: The final device subsystem comprises various devices designed to perform specific functions ensuring process safety, such as emergency shutdown valves and alarm systems. Response time is a crucial consideration, ensuring it is shorter than the process safety time (PST). The PST of an ammonia leakage scenario, for example, as indicated in simulation results, is approximately 30 s.

5. Conclusion

Implementing the above-mentioned steps could be vital for ensuring safe transfer of ammonia in pipelines and a smooth transition to a cleaner, ammonia-based energy framework. However, it is important to recognize the limitations of the study. Firstly, the parameters of ammonia within the pipeline may have significant variations, influenced by factors such as pipeline elevation, fraction, and distance from the compressing station. To achieve more precise simulations and derive more specific results and conclusions, it's essential to tailor the simulations to the context of applications. Secondly, more risk factors should be considered, such as human errors, to better represent the hazards of ammonia leakage. Simulation serves as a valuable tool but has its limitations compared to real-world experimentation. Simulated leakage scenarios may not fully replicate actual conditions as factors like mesh quality and the chosen mathematical model can significantly influence results. Actual experiments on ammonia leakage would provide invaluable data for refining mathematical models, offering clearer guidance for policymakers and pipeline constructors.

This study provides valuable insights into the risks associated with ammonia pipeline leakage, emphasizing the urgency of safety measures. It identifies high-risk zones within a 10-meter radius of leakage points, where toxicity and flammability hazards are pronounced, and highlights substantial toxicity levels within a 1000-meter radius. The simulations also reveal a process safety time of less than 30 s in areas beyond 10 meters from the leakage point, highlighting the need for rapid response in the event of leaks. Additionally, higher pipeline pressure and stable weather conditions, particularly at night, may enlarge hazardous zones. There is also a potential high-risk scenario involving a jet fire spanning approximately 5 meters in length following ignition near the leakage point. These findings emphasize the importance of implementing both passive and active control methods to enhance ammonia pipeline safety. Whilst promising, given ammonia's hazardous nature, it's also important to explore other alternative clean energy sources. Among these, LOHC, hybrid metals, hydrogen, ammonia, methane, and hydrogen capsules have shown promising potential for cost reduction and transport efficiency enhancement.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The National Institute of Standards and Technology data that support the findings of this study are openly available at https://webbook.nist.gov/cgi/fluid.cgi?PLow=0.1&PHigh=100&PInc=0.1&Digits=5&ID=C7664417&Action=Load&Type=SatT&TUnit=C&PUnit=bar&DUnit=mol%2Fl&HUnit=kJ%2Fmol&WUnit=m%2Fs&VisUnit=uPa*s&STUnit=N%2Fm&RefState=DEF. The Cleantech Group data that support the findings of this study are openly available at https://www.cleantech.com/green-ammonia-potential-as-an-energy-carrier-and-beyond/.

Author Contribution Statement

Xuanchen Li: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization. **Siang Meng Ivan Sin:** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision, Project administration. **Sujith Bhaskara Panikkar:** Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision, Project administration. **Tzu Yang Loh:** Conceptualization, Writing – review & editing, Supervision, Project administration.

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