

MENENS WP2 - Regulatory Aspects

Underwater Venting of Methanol Vapours

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Summary

The transition to low carbon fuels in the maritime sector introduces new technical and safety challenges, including the safe handling of methanol as an alternative fuel. A specific challenge in this context is the safe management of pressure relief (i.e., venting) from inerted methanol fuel tanks. Such releases are infrequent and typically limited to abnormal or emergency situations, but may involve toxic and flammable vapours. Conventional design practice requires venting to open deck locations, which can impose significant layout constraints and extensive hazardous areas, especially on smaller vessels.

This study investigates underwater venting of methanol vapours as a potential alternative design solution. The objective is to assess whether this concept can provide a level of safety equivalent to that of conventional above deck venting arrangements. The scope includes an evaluation of regulatory requirements, a comparison of the safety characteristics of methanol and marine gas oil (MGO), and an assessment of the technical feasibility and associated risks of underwater discharge.

The results indicate that underwater venting can substantially reduce hazardous vapour concentrations in the vicinity of the vessel. Numerical simulations and laboratory experiments demonstrate that methanol vapour dissolves rapidly in water, with high absorption rates achieved even at limited submergence depths. As a result, the formation of flammable and toxic vapour clouds above the water surface can be significantly mitigated, potentially reducing hazardous areas on deck and offering greater design flexibility. However, the findings also identify important technical challenges, including hydrostatic back pressure effects on valve operation, the need to ensure continuous submergence of the outlet, risks of condensation and blockage, and long term issues related to biofouling and corrosion. Environmental considerations remain uncertain, particularly regarding local concentration peaks in seawater and their effects on marine organisms.

It is concluded that underwater venting is a technically credible and promising alternative for methanol fuel systems, but not yet a mature or fully validated solution. Demonstration of equivalent safety requires further full scale validation, improved understanding of environmental impacts, and the development of clear regulatory guidelines. With sufficient supporting evidence, underwater venting may contribute to overcoming key design barriers and facilitate the wider adoption of methanol as a marine fuel.

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Abbreviations

DNEL	Derived No-Effect Level exposure level below which no adverse health effects are expected
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
LC50	Median Lethal Concentration concentration of a substance in air or water expected to cause death in 50% of test organisms during a specified exposure period
LD50	Median Lethal Dose dose of a substance expected to cause death in 50% of test organisms under specified conditions
LEL	Lower Explosive Limit lowest concentration of a vapor or gas in air capable of propagating a flame
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
NOEC	No Observed Effect Concentration highest tested concentration at which no statistically significant adverse effects are observed
STEL	Short-Term Exposure Limit 15-minute time-weighted average exposure that should not be exceeded, used to limit short-term occupational exposure
TWA	Time-Weighted Average average airborne concentration over a specified reference period (typically 8 hours), used as a long-term occupational exposure limit
UEL	Upper Explosive Limit highest concentration of a vapor or gas in air capable of propagating a flame

1 Introduction

International shipping enables more than 80% of global trade and has long been regarded as one of the most energy efficient transportation sectors. Nevertheless, the maritime and offshore industry is responsible for close to 3% of global greenhouse gas (GHG) emissions [1] and over 25% of global toxic nitrogen oxide (NO_x) and sulphur oxide (SO_x) emissions [2]. These emissions largely result from the continued reliance on marine gas oil (MGO), marine diesel oil (MDO) and heavy fuel oil (HFO) as the primary energy carriers for propulsion and onboard power generation, in which HFO fuelled engines remain dominant, accounting for over 80% of total carbon dioxide emissions within the maritime and offshore sector. Without effective mitigation measures, emissions could rise substantially and approach 12–18% of the total allowable carbon dioxide emissions under the International Energy Agency (IEA) 450 ppm stabilization scenario by 2050. In comparison with 2007 levels, this corresponds to increases of up to 100% or more in absolute emissions.

In response, the International Maritime Organization (IMO) has adopted the objective of reducing CO₂ emissions by at least 20% by 2030 relative to 2008 levels, with a long term ambition of achieving net zero emissions by 2050 [3]. Meeting these targets requires a fundamental transformation of maritime and offshore power systems, focusing on optimizing energy conversion performance and reducing reliance on pollutant intensive maritime fuels.

One promising pathway is the adoption of alternative fuels with a lower carbon footprint. Among the most prominent candidates for maritime and offshore applications are hydrogen, methanol, and ammonia. Methanol is receiving increasing attention as a marine fuel because it can be used in slightly modified engines, offers potential for renewable production, and benefits from the sector's broad experience with handling methanol as cargo. At the same time, the use of methanol as a fuel introduces new safety considerations, particularly with respect to pressure relief from onboard fuel tanks.

1.1 Background

Methanol can be used as an alternative fuel for ships, such as the one shown in Figure 1.1. In current practice on board vessels operating on methanol, the fuel tanks are inerted and maintained as closed systems in order to prevent the formation of a combustible atmosphere inside the tank. The vapour space above the methanol liquid is filled with a gas blanket, typically consisting of nitrogen with a low oxygen content together with methanol vapour, and is maintained at a slight overpressure of ~ 102% - 110% of atmospheric pressure [4]. As a consequence of this inerted configuration, the release of toxic methanol vapour to the surroundings is also limited. Since the tank is integrated into the ship structure and, due to its typical scantlings and geometry, can withstand only a limited overpressure, a pressure vacuum (PV) valve must be installed to prevent excessive pressure build up.

The central issue is not venting itself, but the hazardous scenarios in which pressure relief from a methanol fuel tank becomes necessary. Relevant examples are blockage of the vapour return line during bunkering and heating of the tank in a fire adjacent to the fuel tanks. In such situations, the question is whether an alternative pressure relief (i.e., venting) arrangement can limit the resulting risks of toxic and flammable vapour exposure to a level that is acceptable for ship operations. The intended benchmark is a safety level that is at least equivalent to

that associated with conventional diesel tank venting, while also considering the prescriptive methanol venting arrangement in the interim guidelines as the current reference design. From this perspective, underwater venting is assessed as a possible design measure to achieve an equivalent level of safety under the governing risk scenarios.

The pressure increase in the tank must remain below the design pressure. Therefore, the nitrogen and methanol vapour mixture must be vented to a safe location when pressure relief is required. According to the interim guidelines, fuel tank vent outlets should normally be located not less than 3 m above the deck or gangway if they are within 4 m of gangways, and at least 10 m from the nearest air intake or opening to accommodation and service spaces and from ignition sources [5]. In addition, the area in the vicinity of the pressure vacuum outlet is classified as a hazardous area, which imposes constraints on layout, access, and equipment selection [5]. These requirements can significantly restrict ship design, especially on smaller vessels. For this reason, underwater venting has been proposed as an alternative arrangement in which the methanol vapour is discharged below the water surface.



Figure 1.1: The *Fugro Pioneer*, equipped for dual fuel operation on methanol and diesel (retrieved from [Fugro.com](https://www.fugro.com))

1.2 Aim

The aim of this study is to assess whether an alternative venting arrangement for methanol fuel tanks can provide a level of safety that is equivalent to that of conventional diesel tank venting. In this context, equivalent safety is considered in relation to the hazardous consequences associated with venting, rather than venting itself. The focus is therefore on the governing risk scenarios that may require pressure relief from a methanol tank, such as blockage of the vapour return line during bunkering or heating of the tank in an adjacent fire.

More specifically, this study investigates whether underwater venting can serve as a feasible alternative to the prescribed above deck venting arrangement. The assessment is centred on the extent to which this alternative can reduce the risks of toxic and flammable vapour exposure in to a level that is acceptable for ship operations and comparable to the safety level associated with conventional diesel venting arrangements. In this way, the study contributes to the broader question of how equivalent safety may be demonstrated for methanol fuel systems when deviation from prescriptive design requirements is considered.

2 Venting of Methanol Vapours

This chapter examines the venting of methanol vapours in maritime fuel systems. It first explains why venting may be required, then outlines the relevant rules and regulations, and finally introduces underwater venting as a possible alternative to conventional above deck arrangements. In this way, the chapter establishes the technical and regulatory context for assessing whether underwater venting can provide an equivalent level of safety.

2.1 Need for Venting

Fuel tanks are equipped with pressure and vacuum relief systems to prevent structural damage caused by excessive overpressure or underpressure. Overpressure may develop due to evaporation of the fuel following heat input, for example in a fire scenario, due to vessel motions such as sloshing, or during bunkering when liquid methanol is transferred into the tank. Underpressure may arise during fuel consumption or during cooling of the tank contents.

For methanol fuel systems, the need for venting follows from the way the tanks are operated. Since methanol fuel tanks are inerted in order to prevent the formation of a combustible atmosphere, the tanks are maintained as closed systems. During bunkering, current maritime and offshore practice is to handle the gas mixture through a vapour return line rather than discharge it directly to the surroundings, allowing the methanol vapour to be captured and condensed for reuse as fuel. Consequently, venting of methanol vapours is generally limited to exceptional or emergency situations in which pressure relief is required to protect the integrity of the tank, in contrast to conventional diesel fuel systems where tank venting forms part of normal daily operation.

In contrast to traditional maritime fuels such as MGO, MDO or HFO, whose vapours are typically vented directly to the atmosphere at deck level, methanol requires a more restrictive approach. This is primarily due to its properties and limited operational experience within the maritime sector. Methanol vapours are toxic when inhaled and is highly flammable [6, 7]. To mitigate risks to personnel, regulations therefore require that any vented methanol vapours are discharged at locations sufficiently remote from areas accessible to the crew.

2.2 Rules and Regulations

The primary international instruments governing marine pollution control and safety with respect to methanol vapour venting are MARPOL 73/78 [8] and IMO MSC.1/Circ.1621 [5], the Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel.

MARPOL 73/78 [8] does not contain fuel specific regulations for methanol or methanol vapour emissions. Vapour releases are addressed only indirectly through the general air pollution prevention principles of Annex VI. Consequently, detailed technical and safety requirements related to methanol vapour handling, venting arrangements, and hazardous area definition are governed by the IMO interim guidelines, which are based on the safety philosophy of the IGF Code for low flashpoint fuels, which is mainly tailored to LNG.

MSC.1/Circ.1621 establishes prescriptive requirements, which include:

- › **Pressure vacuum relief and vent system design**
 - **Section 6.3.4:** Pressure and vacuum relief valves should be fitted to each fuel tank to limit the pressure or vacuum in the fuel tank.
 - **Section 6.3.4:** Design and arrangement should prevent flame propagation into the fuel containment system.
 - **Section 6.3.4:** Where relevant, endurance burning certification is required for high velocity pressure relief valves, or alternatively certified flame arresters are required at the vent outlet depending on the arrangement.
 - **Section 6.3.5:** Shut off valves are not to be arranged either upstream or downstream of the pressure relief valves, except for specific temporary segregation arrangements subject to additional independent protection.
 - **Section 6.3.7:** Pressure relief valves should vent to a safe location on open deck and should be of a type that allows easy checking of valve function.
 - **Section 6.3.8:** The tank venting system is to be sized to permit bunkering at the design loading rate without over pressurizing the tank.
- › **Inerting and control of flammable atmospheres**
 - **Section 6.4.1:** All fuel tanks should be inerted at all times during normal operation.
 - **Section 6.4.3:** The atmosphere control arrangements are to eliminate the possibility of a flammable mixture existing in the tank during atmosphere change operations, including inerting and gas freeing.
- › **Vent outlet location and separation distances**
 - **Section 6.4.7:** Fuel tank vent outlets should be situated normally not less than 3 m above the deck or gangway when located within 4 m of such gangways.
 - **Section 6.4.7:** Vent outlets are to be arranged at a distance of at least 10 m from the nearest air intake or opening to accommodation spaces and service spaces, and from ignition sources.
 - **Section 6.4.7:** The vapour discharge is to be directed upwards in the form of unimpeded jets.

In addition to venting system design, the interim guidelines prescribe requirements for inerting and atmosphere control within methanol fuel tanks. Methanol is categorised as a low flashpoint fuel due to its flashpoint of approximately 12 °C, which is below the 60 °C threshold applied to conventional maritime fuels. To prevent the formation of flammable atmospheres, fuel tanks are required to remain inerted during normal operation.

- › **Gas freeing discharge options**
 - **Section 6.4.10:** During gas freeing operations, the interim guidelines specify that vapour should initially be discharged either through elevated high velocity outlets, or through outlets underwater.

Gas freeing operations involve sequential inerting or purging to reduce methanol vapour concentration, followed by controlled ventilation to restore oxygen concentration to atmospheric levels. Ventilation should be designed such that methanol concentrations in air remain below applicable occupational exposure limits, typically an 8-hour time-weighted average (TWA) of 200 ppm [6, 7]. As the lower flammable limit of methanol is approximately 6 volume percent (60,000 ppm), a space that is safe from a toxicity perspective is also safe with respect to ignition risk. Nevertheless, gas detection systems are required, as human odour perception thresholds for methanol are significantly higher than acceptable exposure limits.

› **Hazardous area classification around vent outlets for fire and explosion risk**

- **Section 12.5.2.3:** Hazardous area zone 1 includes areas on open deck or semi enclosed spaces on deck within 3 m of any fuel tank outlet, gas or vapour outlet, and other specified release points.
- **Section 12.5.2.4:** In addition, for tank pressure vacuum outlets, hazardous area zone 1 includes the vicinity within a vertical cylinder of unlimited height and 6 m radius centred on the outlet, and within a hemisphere of 6 m radius below the outlet.
- **Section 12.5.3:** Hazardous area zone 2 includes areas 4 m beyond the cylinder and 4 m beyond the sphere defined for zone 1 around pressure vacuum outlets, and other specified surrounding regions.

Equipment installed within these zones are required to be suitable for the applicable hazardous area classification. It is noteworthy that the hazardous distance definitions in the interim guidelines are independent of vessel size. As a result, even relatively small vessels may be subject to extensive hazardous areas surrounding methanol vent outlets.

These requirements create practical integration challenges, particularly for smaller vessels. For example, achieving a vent outlet height of 3 m while also maintaining a 10 m separation from air intakes, openings, and ignition sources can be difficult or even unworkable within limited deck layouts. In parallel, the extent of the hazardous zones defined around pressure vacuum outlets can constrain the placement of equipment and the routing of ventilation inlets and outlets.

2.3 Underwater Venting

To address the design and integration challenges identified in Section 2.2, underwater venting is considered as an alternative venting concept. In an underwater, i.e. subsea venting scenario, methanol vapour is released below the waterline such that it dissolves into the surrounding water. Methanol has a high solubility in water, disperses rapidly, and is biodegradable [9]. These properties make it less harmful to the marine environment than conventional maritime fuels. In principle, this may reduce the amount of methanol vapour released into the air above the water surface and thereby mitigate the formation of hazardous toxic and flammable vapour concentrations near the vessel. Nevertheless, when released into the water, part of the vapour may still evaporate from the water or emerge at the surface if the rise time is too short for complete dissolution.

If effective dissolution is achieved, methanol concentrations at deck level may remain below relevant flammability and toxicity limits, and the extent of hazardous areas on deck may be reduced accordingly. From a design perspective, this could mitigate several of the integration challenges associated with conventional above deck venting arrangements, particularly on vessels where the required vent mast height, separation distances, and hazardous area restrictions are difficult to accommodate.

The potential advantages of underwater venting include:

- › No need for tall vent masts or funnels
- › Reduced or eliminated hazardous zones on deck
- › Minimal risk of inhalation exposure to crew
- › Potential simplification of ship design, particularly for small vessels

At the same time, the concept introduces additional technical challenges. These include the back pressure associated with discharge below the waterline and the need to ensure that the outlet remains submerged under all relevant operating conditions. Moreover, the effectiveness of the concept depends on whether sufficient dissolution takes place before the released gas reaches the free surface.

The concept of underwater venting is not explicitly included in existing rules, regulations, or guidelines. However, IMO MSC.1/Circ.1621 states the following regarding alternative designs:

- › **Section 2.3.2:** Appliances and arrangements of methyl/ethyl alcohol fuel systems may deviate from those set out in these Interim Guidelines, provided such appliances and arrangements meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety to the relevant sections.
- › **Section 2.3.3:** The equivalence of the alternative design should be demonstrated as specified in SOLAS regulation II 1/55 and approved by the Administration. However, the Administration should not allow operational methods or procedures to be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment or type thereof which is prescribed by these Interim Guidelines.

In the context of the present study, this means that underwater venting cannot be justified merely as a different venting arrangement, but must be evaluated as an alternative safety measure for the governing hazardous scenarios that require pressure relief. The relevant question is therefore whether underwater discharge of the methanol nitrogen mixture can provide a level of safety that is at least equivalent to that of the prescribed above deck arrangement and, more fundamentally, equivalent to the safety philosophy applied to conventional oil fuelled systems. Underwater venting is therefore assessed here as a candidate alternative design, whose acceptability depends on demonstrating equivalent safety with respect to toxic and flammable vapour exposure.

3 Safety Characteristics

This chapter outlines the principal safety characteristics that determine whether underwater venting of methanol vapours can be considered a credible alternative to conventional above deck venting. The discussion focuses on the comparison between methanol and marine gas oil (MGO) in terms of toxicity, aquatic effects, flammability, explosion hazards, and solubility in water. Together, these properties govern both the potential consequences of a release and the extent to which underwater discharge may reduce hazardous vapour concentrations in the vicinity of the vessel. The chapter therefore provides the safety related basis for assessing the opportunities and limitations of underwater venting from both a personnel safety and an environmental perspective.

3.1 Toxicity

Methanol is classified as toxic if swallowed, toxic in contact with skin, toxic if inhaled, and as causing damage to organs. The acute toxic effects of methanol are associated with relatively high exposure concentrations, particularly through inhalation or ingestion. In contrast, methanol exhibits relatively low acute toxicity to marine organisms and other animals. Methanol is readily biodegradable and fully soluble in water, which promotes rapid dilution following release. As a result, methanol is generally considered to pose a lower environmental hazard in spill scenarios when compared to conventional marine fuels, provided that releases are limited in extent.

Tables 3.1, 3.2 and 3.3 summarize the toxicity limit values relevant to the comparison between methanol and MGO, including occupational exposure limits, derived no effect levels, and acute (immediate) toxicity values.

Table 3.1: Occupational exposure limit values for methanol and MGO

Property	Methanol	MGO	Unit
Time Weighted Average (TWA)	200 [6, 7]	-	ppm
Time Weighted Average (TWA)	260 [6, 7]	100 [10]; 200 [11]	mg/m ³
Short Term Exposure Limit (STEL)	250 [6]	-	ppm
Short Term Exposure Limit (STEL)	325 [6]	1000 [10]	mg/m ³

Table 3.2: DNEL values for methanol and MGO

End use	Exposure	Potential health effects	Methanol	Unit	MGO	Unit
Workers	Inhalation	Acute systemic effects	260 [7]	mg/m ³	-	
Workers	Inhalation	Long-term systemic effects	260 [7]	mg/m ³	68 [11]	mg/m ³
Workers	Dermal	Long-term systemic effects	40 [7]	mg/kg/day	2.9 [11]	mg/kg/day
Consumers	Inhalation	Acute systemic effects	50 [7]	mg/m ³	-	-
Consumers	Inhalation	Long-term systemic effects	50 [7]	mg/m ³	20 [11]	mg/m ³
Consumers	Dermal	Long-term systemic effects	8 [7]	mg/kg/day	1.3 [11]	mg/kg/day
Consumers	Oral	Long-term systemic effects	8 [7]	mg/kg/day	-	-

Table 3.3: Acute (immediate) toxicity values for methanol and MGO

Property	Comment	Methanol	MGO	Unit
Acute toxicity estimate	Oral, mixture	100 [7]	-	mg/kg
Acute toxicity estimate	Dermal, mixture	300 [7]	-	mg/kg
Acute toxicity estimate	Inhalation vapour, 4 h, mixture	3 [7]	-	mg/L
LD50 oral	Rat	1187–2769 [7]	>5000 [11]	mg/kg
LD50 oral	Rat	6200 [6]	-	mg/kg
LD50 dermal	Rabbit	17100 [7]	>5000 [11]	mg/kg
LD50 dermal	Rabbit	15840 [6]	-	mg/kg
LC50 inhalation	Cat, 6 h, vapour	43.7 [7]	-	mg/L
LC50 inhalation	Rat, 4 h, vapour and aerosol	-	4100 [11]	mg/m ³
LC50 inhalation	Rat, 8 h	22500 [6]	-	ppm
LC50 inhalation	Rat, 4 h	64000 [6]	-	ppm

Methanol and MGO pose risks not only to human health, but also to the aquatic environment. Aquatic toxicity is commonly assessed using indicators such as the LC50, and the NOEC, which represents the highest concentration at which no observable adverse effect is detected. Methanol generally exhibits relatively low acute toxicity to aquatic organisms, with reported LC50 values for fish and other freshwater species in the order of several thousands of mg/L. Nevertheless, adverse effects may already occur at substantially lower concentrations during prolonged exposure, as reflected by the reported NOEC of 23.75 mg/L for chronic freshwater exposure [12, 13]. In comparison, the reported diesel values are considerably lower, indicating substantially higher aquatic toxicity, although the source does not explicitly specify the type or grade of the conventional diesel fuel used [14]. Overall, this suggests that methanol poses a lower risk to aquatic life than diesel, while its rapid biodegradation and short environmental half life further reduce its residence time in the aquatic environment [9].

Tables 3.4 summarizes the toxicity limit values related to aquatic toxicity relevant to the comparison between methanol and conventional diesel fuel [14].

Table 3.4: Aquatic toxicity and related environmental values for methanol and conventional diesel fuel [14]

Endpoint	Comment	Methanol	Diesel Fuel	Unit
LC50	<i>M. micrura</i> (zooplankton), 96 h	4820 [12]	-	mg/L
LC50	<i>O. mossambicus</i> (Tilapia fish), 96 h	15320 [12]	-	mg/L
LC50	<i>B. sowerby</i> (worm), 96 h	54890 [12]	-	mg/L
NOEC	Freshwater ecosystem, chronic exposure, 90 d	23.75 [12]	-	mg/L
LC50	Rainbow trout, 96 h	20300 [13]	-	mg/L
LC50	Bluegill, 96 h	20300 [13]	-	mg/L
LC50	Fathead minnows, 96 h	29400 [13]	-	mg/L
LC50	<i>D. magna</i> (plankton), 24 h	-	1.78 [14]	mg/L
LC50	<i>O. mykiss</i> (Rainbow trout), 72 h	-	578 [14]	mg/L
Biodegradation rate	Instantaneous removal	11 [9]	-	%/day
Half life	In marine environment	6 [9]	-	days

Overall, methanol presents a more critical hazard from the perspective of toxic vapour exposure and personnel safety, whereas diesel fuel generally remains in the aquatic environment for longer and exhibits higher aquatic toxicity. Comparing the toxicity limit values therefore does not indicate that one fuel is uniformly safer than the other, but rather that the hazards differ in nature.

3.2 Flammability and Explosion

In addition to its toxicological hazards, methanol presents important flammability and explosion hazards. Methanol is classified as a low flash point fuel, meaning that flammable vapour air mixtures can form under ambient conditions. At 20 °C, the vapour pressure of methanol is approximately 13 kPa (3 vol% in air) and therefore lies well within its flammability range [6, 7]. In practice, however, such concentrations are only reached after a relatively long period, as the evaporation rate of methanol is limited.

Methanol vapour clouds are readily ignitable because methanol is highly volatile, has a low flash point, and can form flammable vapour air mixtures under ambient conditions. In addition, the SDS indicate that electrostatic discharge can ignite such mixtures [7]. Self ignition does not occur under normal conditions and requires temperatures above the autoignition temperature, which is approximately 455 to 464 °C [6, 7]. Nevertheless, the ease with which flammable methanol vapour mixtures can ignite justifies the previously defined safety distances around vent discharge points on deck. An overview of the principal flammability related properties of methanol and MGO is provided in Table 3.5.

Table 3.5: Flammability, explosion, and volatility related values for methanol and MGO

Property	Methanol	MGO	Unit
Flash point	11 [6]; 10 [7]	60 [10]; ≥ 60 [11]	°C
Autoignition temperature	464 [6]; 455 [7]	350 [10]; >2 50 [11]	°C
Lower flammability; explosive limit	5.5 [6]; 6.1 [7]	1.0 [10]; 0.6 [11]	vol.% in air
Upper flammability; explosive limit	36.5 [6]; 44 [7]	6.0 [10]; 7.0 [11]	vol.% in air
Vapour pressure at 20°C	12.8 [6]; 13.1 [7]	<0.04 [11]	kPa
Vapour pressure at 40°C	-	<0.04 [10]	kPa
Vapour pressure at 50°C	55.7 [7]	-	kPa
Initial boiling point or boiling range	64.72 [6]; 63.6–64.6 [7]	160–400 [10]; >180 [11]	°C
Lower explosive limit (LEL)	5.5 [6]; 6.1 [7]	1.0 [10]; 0.6 [11]	vol.% in air
Upper explosive limit (UEL)	36.5 [6]; 44 [7]	6.0 [10]; 7.0 [11]	vol.% in air

The difference in vapour concentrations that can develop above methanol and MGO under ambient conditions is primarily governed by their volatility. Methanol has a much lower boiling point and substantially higher vapour pressure than MGO, which means that it evaporates more readily and can therefore generate higher concentrations in air, expressed in ppm, at the same temperature [6, 7, 10, 11]. Consequently, although both fuels possess defined flammable ranges in air, methanol is generally more likely to approach such concentrations at ordinary temperatures because sufficient vapour is produced more easily. This also explains its substantially lower flash point in comparison with MGO [6, 7, 10, 11].

3.3 Solubility

Where MGO is practically insoluble in water [10, 11], methanol is fully miscible in water [7]. On this basis, the concept of underwater venting of methanol vapours is proposed as a potential mitigation measure for the impractical design requirements set by the interim guideline IMO MSC.1/Circ.1621 [5]. The equivalent level of safety associated with underwater venting has not yet been proved. Consequently, significant uncertainties remain with respect to the behaviour of methanol vapours released underwater and the associated risks.

Existing research has primarily focused on gas releases from ruptured pipelines, typically involving leakage points at substantial water depths. Moreover, this research has largely concentrated on gases relevant to the oil and gas industry, in particular methane. Limited

research is available on the release, dissolution, and dispersion behaviour of methanol vapours in water. To address this knowledge gap, TNO has conducted both numerical and experimental investigations.

A numerical study by De Boom [15] illustrates both the potential of the concept and the importance of the release conditions. For a venting depth of 0.9 m and an initial bubble diameter of 2 mm, the CFD results indicated complete dissolution of methanol before reaching the free surface. For a more conservative case, with an initial bubble diameter of 0.08 m and a venting depth of 0.5 m, methanol vapour was predicted to reach the free surface, with peak concentrations of approximately 800 ppm at 0.25 m above the water surface. These concentrations decreased rapidly with height, and at 0.5 m above the water surface only sporadic methanol particles were observed. Even in this conservative scenario, no harmful methanol concentrations were predicted at deck height [15].

Laboratory experiments demonstrated that underwater venting can lead to very high methanol absorption rates in the surrounding water. Reported tests covered vapour flow rates between 10 and 200 litres per minute, venting depths between 5 and 90 cm, and several nozzle configurations. The results indicated that more than 95% of the methanol could already be absorbed within the first 5 cm of water depth, while absorption levels of about 99% were reached after 15 cm and remained above 99% for venting depths below 40 cm, even at the highest tested flow rate [16]. During 20 minute test periods, no clear loss of absorption capacity was observed, which suggests that underwater venting is promising from a personnel safety perspective. Smaller bubbles were found to improve absorption, and the best performance was obtained with a porous hose, which generated small and relatively uniform bubbles and provided a large effective water column. Nevertheless, such a configuration may be less suitable in practical shipboard applications because of fouling and the availability of simpler alternatives. For that reason, full scale vent tests are still recommended to assess the applicability of underwater venting under realistic shipboard conditions, such as bunkering or fire scenarios, and to provide additional data for CFD model validation [16].

The available evidence therefore suggests that underwater venting may substantially reduce the formation of hazardous methanol vapour concentrations near the vessel, although further experimental validation remains necessary before equivalent safety can be established with confidence.

4 Technical Considerations

The application of underwater venting as an alternative to conventional above deck venting introduces several technical and operational considerations. These considerations relate to the basic functionality of the venting system, its reliability under normal and abnormal operating conditions, and its interaction with the surrounding environment. This chapter outlines the main issues that must be addressed before underwater venting can be considered a viable and equivalent safety solution.

› Hydrostatic back pressure and valve operation

- In an underwater venting configuration, the vent outlet is subjected to hydrostatic pressure. Consequently, the pressure vacuum valve must open against an additional back pressure that increases with water depth. If the outlet is located too deep below the waterline, the valve may fail to open at the intended set pressure, reducing the effectiveness of pressure relief. Conversely, if the outlet is positioned at very shallow depth, changes in draught or wave induced motions may cause the outlet to emerge above the waterline, causing the system to behave similarly to a conventional above deck vent.

› Condensation and liquid accumulation in the vent line

- As methanol vapour flows through vent piping, cooling may occur, resulting in partial condensation of the vapour back into liquid methanol. This liquid may collect at low points in the vent line or vent mast, potentially restricting flow or leading to blockage. The routing of the vent line and the thermal conditions along the pipe are therefore expected to play a critical role in ensuring reliable operation.

› Biofouling and blockage

- The submerged section of the vent line is exposed to the marine environment and may be subject to biofouling. Regular inspection, cleaning, or protective measures would therefore be required to ensure long term system reliability.

› Fire scenarios

- In fire scenarios, tank venting becomes critical to prevent excessive pressure build up and potential tank rupture. Experience from conventional fuel systems shows that large quantities of vapour may need to be vented, sometimes several hours after the onset of a fire. The system should not introduce additional failure modes that could compromise tank protection during emergency situations.

› Environmental

- Although methanol is biodegradable and generally exhibits lower acute aquatic toxicity than conventional marine fuels, its environmental acceptability cannot be assessed solely on the basis of acute toxicity values listed in Table 3.4 where reported values for diesel are considerably lower than for methanol. Nevertheless, uncertainty remains regarding the environmental impact of underwater vapour discharge, particularly with respect to local concentration peaks near the outlet and their possible effects on marine organisms. Further investigation is required to determine whether underwater venting can be considered environmentally acceptable under both normal and abnormal operating conditions.

5 Regulatory Gaps and Path Forwards

At present, neither MARPOL 73/78 [8] nor MSC.1/Circ.1621 [5] explicitly addresses the underwater venting of methanol vapour. The interim guidelines do, however, allow alternative arrangements provided that an equivalent level of safety can be demonstrated. This creates a regulatory opening for underwater venting to be proposed as an alternative design solution, provided that sufficient technical evidence is available to show that the associated risks are adequately controlled and that the overall safety level is at least comparable to that of conventional above deck venting arrangements.

In practice, underwater venting has already been implemented on a small number of yachts and other vessels. These projects were approved only after an extensive and complex design approval process, during which it had to be demonstrated that the proposed system offered an equivalent or higher level of safety than a conventional above deck venting system. While this proves that underwater venting is technically and administratively possible under current rules, the lack of explicit regulatory guidance makes the process slow, expensive, and unpredictable.

If specific regulations or standardized approval procedures for underwater venting are introduced, the approval process could be greatly streamlined. Such a development would make the approval process more transparent and predictable, thereby supporting broader adoption of the technology, particularly on small and medium sized vessels where conventional vent mast arrangements can be especially restrictive from a layout and integration perspective.

Knowledge gaps that still need to be addressed are the following:

- › **Methanol concentration in seawater after venting.** Although methanol is fully miscible in water and available studies indicate rapid absorption, further work is needed to quantify methanol concentrations that may arise in seawater directly after venting. This is important because the diffusion of methanol is reduced in saltwater, which may slow down the rate at which the discharged methanol is diluted and dispersed in the surrounding water [16].
- › **Exposure levels above the water surface under realistic operating conditions.** Existing laboratory and numerical studies indicate that underwater venting can strongly reduce methanol vapour concentrations above the free surface. However, additional validation at full scale is needed under representative on board conditions, including the influence of wind, waves, vessel geometry and relative position of the vent outlet. These data are necessary to confirm that hazardous concentrations do not arise in locations where crew members, air intakes, or ignition sources may be present.
- › **Long term maintenance requirements and operational reliability.** In addition to safety during the venting event itself, the practical performance of the underwater venting system over the service life of the vessel must be demonstrated. This includes the effects of fouling, corrosion, clogging, inspection accessibility, mechanical robustness, and the reliability of valves, piping, and outlet arrangements.

6 Conclusion

Underwater venting appears to be a promising alternative to conventional above deck pressure relief arrangements for methanol fuel tanks. The concept directly addresses one of the main integration challenges associated with methanol as a maritime fuel, which is the need to manage toxic and flammable vapour releases without creating impractical hazardous areas and exclusion zones on deck. The available numerical and laboratory evidence indicates that the rapid dissolution of methanol in water can strongly reduce the formation of hazardous vapour concentrations above the free surface, thereby offering a credible pathway to reduce crew exposure and design constraints associated with vent mast height, separation distances, and hazardous area classification.

Numerical investigations indicate that, for representative shallow release conditions, methanol may dissolve almost completely before reaching deck level, and laboratory experiments have shown very rapid absorption of methanol in water, with absorption rates above 95% already being achieved at small water depths and about 99% under a wide range of tested conditions [15, 16]. These findings support the view that underwater venting can be an effective risk mitigation measure, particularly for the abnormal or emergency scenarios in which methanol tank pressure relief is required.

However, important technical and operational challenges remain. These include the influence of hydrostatic back pressure on valve operation, the requirement that the outlet remains submerged under all relevant loading and motion conditions, the potential for condensation and liquid accumulation in the vent line, the long term effects of biofouling and corrosion, and the need to demonstrate reliable system performance in fire scenarios. In addition, further work is required to quantify methanol concentrations in seawater after discharge, to confirm exposure levels above the water surface under realistic full scale conditions, and to demonstrate long term maintainability and operational robustness. Although methanol is biodegradable and generally exhibits lower acute aquatic toxicity than conventional marine fuels, uncertainty remains regarding its environmental impact when discharged underwater, particularly with respect to local concentration peaks near the outlet and their potential effects on marine organisms. For these reasons, the concept is likely to be more readily applicable on vessels with limited draught variation, where the submerged outlet position and the associated back pressure can be controlled more reliably.

Overall, underwater venting should be regarded as a technically credible and potentially highly valuable alternative design solution for methanol fuel systems, but not yet as a mature prescriptive solution. To move from case specific approval toward broader regulatory acceptance, additional full scale validation and further development of approval criteria will be required. If this evidence base is established, underwater venting could provide a practical means of reducing one of the major barriers to wider methanol adoption in the maritime sector, particularly for vessels on which conventional above deck venting arrangements are difficult to integrate.

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