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Unconventional bunker fuels, a safety comparison

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Contents

Abbreviations

ALARP	As Low As Reasonably Practical
FSA	Formal Safety Assessment
GA	General Arrangement
HFO	Heavy Fuel Oil
IGF	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IACS	International Association of Classification Societies
IMO	International Maritime Organisation
LNG	Liquified Natural Gas
LSA	Life Saving Appliance
MEOH	Methanol
MGO	Marine Gas Oil
SDS	Standard Data Sheet

1 Introduction

There is a strong urge to replace conventional bunker fuels such as heavy fuel oil (HFO), marine diesel oil (MDO) and marine gas oil (MGO) by ‘fuels’ which do not give a net emission of greenhouse gasses or emit pollutants when combusted. Candidate fuels are methanol, dimethyl ether (DME), ammonia, pressurised hydrogen and liquefied hydrogen. Liquefied natural gas has already entered the maritime domain, albeit initially primarily for pollutant emission reasons. Introducing alternative fuels on board ships has many far stretching implications in terms of safety. Hence a need exists to familiarize with the most important safety aspects, measures and regulations associated with usage of these alternative fuels. This report is the result of a safety assessment on the usage of alternative bunker fuels, in the context of the Green Maritime Methanol (GMM) project.

Conventional safety regulations do not capture the safety requirements for alternative fuels because of their hazardous nature. This is covered by item 2.1 (Limitations in the use of oils as fuel) of regulation 4 (Probability of ignition), of Solas Chapter II-2 (Construction-fire protection, fire detection and fire extinction). This item states; ***Except as otherwise permitted (by this paragraph), no oil fuel with a flashpoint of less than 60 degrees*** *(Celcius ed.)* ***shall be used***. The reason for this prohibition is that volatile fuels, when spilled on board, may attain temperatures of up to 60 Celcius. When this happens they should not ignite if given an ignition source. Likewise gaseous substances can mix with air into a flammable gas-air mixture and are therefore also prohibited.

Fortunately, authorities are now willing to accept alternative fuels, even when they are considered hazardous, provided that a safety can be attained through dedicated design and operational measures which is equivalent to the safety of conventional fuels. Obviously the big issue is demonstrating equivalent safety.

Over the past two decades regulations have been developed for the application of low flash point fuels, mainly with a focus on natural gas. Currently these are now being extended with requirements for methanol. These regulations start with a preamble stating the functional safety goals of each regulation category. However, usually, the reasoning behind the specific regulations is not given. Therefore an attempt has been made to identify such reasonings and compare them with reasonings for conventional fuels. Such a comparison, in conjunction with the ideas of a formal risk based approach is believed to provide a tool for demonstrating equivalent safety. Although the need is there to do this for all candidate fuels, the effort reported in this document is restricted to methanol, because it is one of the most promising fuel alternatives. As reference fuels marine gas oil (MGO) and liquefied natural gas (LNG) were chosen. Occasionally HFO and Petrol (Gasoline) are referred to as well.

Chapter 2 is about how risk is dealt with, about the relevant physics and how design/ operational measures affect risk. Chapter 3 describes the idea behind the approach of equivalent safety. Chapter 4 gives an example of how the factsheets may be used. The last two chapters give a consideration about the idea of the factsheets approach and some recommendations.

2 First principles considerations for a risk analysis

2.1 Risk based approach

The safety of the design of ships fuelled by low flash point fuels is to be supported by a risk assessment. A convenient approach is the Formal Safety Assessment (FSA). This concept has been developed over many years and is now used in many industries. IMO also advocates this approach for the rule making process [1]. Moreover IMO's IGF code requires a risk assessment[1] when alternative fuels with low flashpoints are introduced [4]. The international association of classification societies has issued a recommended practice on how to conduct such an assessment [8].

In October 2018 the Dutch Safety Integrity Platform published an excellent 20 page best practice guide on risk assessment [2]. It explains how risk can be visualised and quantified through the use of a risk matrix. Because this document is relatively easy to understand, it is referred to in this section. The ideas are basically the same as the ideas described in the IMO document and the IACS recommended practice. It is noted that safety and risk are each other's opposite, high risk means low safety and vice versa. So a risk assessment is also a safety assessment[1].

The most important picture to have in mind when doing a comparative safety analysis is the risk matrix as shown in Figure 1 (copied from ref. [2]). It is noted that ref. [8] uses a very similar matrix.

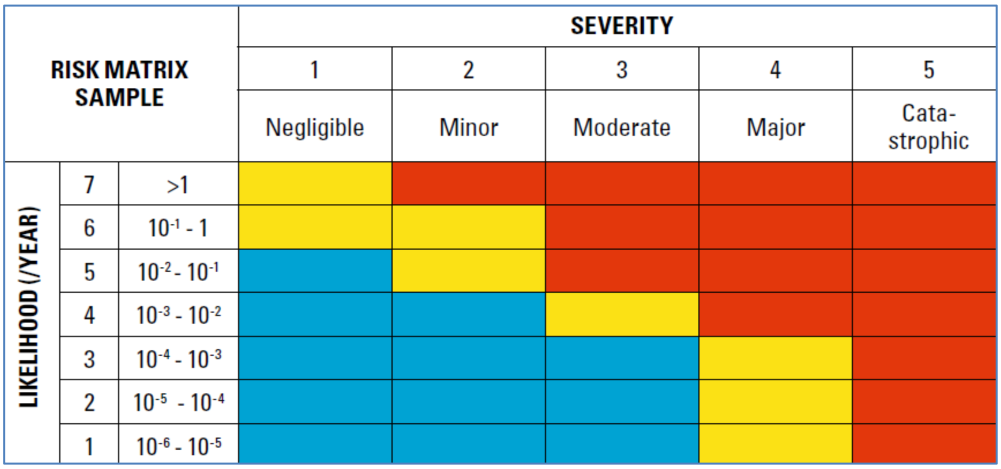


Figure 1 Risk matrix [2]

The colours in Figure 1 indicate the classification of the risk associated with an event/accident. The red area is considered *unacceptable*, the yellow area is known as the 'As Low As Reasonably Possible, *ALARP*' area, which means that if one can think of any improvement at 'reasonable' costs/ efforts, one must make the effort. The blue area is considered *tolerable*, i.e. safe enough (so NOT intrinsically safe).

[1] Formal Safety Assessment and Risk Analysis are treated as synonyms in this report. For puritans this is debatable.

Two factors determine the category of an event: likelihood and severity. Yearly likelihood (probability) ranges from 1 to 7, where 7 means that the event will take place at least once a year. 5 means that the event will take place once every 10 to 100 years. 1 means that the event is very unlikely, ones in 100.000 to 1.000.000 years. A somewhat intuitive interpretation is given in Table 1.

Table 1 Likelihood or probability as used in Figure 1 [2]

LIKELIHOOD CATEGORIES						
7 Very frequent > 1 /year	**6 Probable** 10^{-1} - 1 /year	**5 Sporadic** 10^{-2} - 10^{-1} /year	**4 Remote** 10^{-3} - 10^{-2} /year	**3 Improbable** 10^{-4} - 10^{-3} /year	**2 Very Unlikely** 10^{-5} - 10^{-4} /year	**1 Insignificant** 10^{-6} - 10^{-5} /year
Incident is very likely to occur on this location, possibly several times per year	Incident is likely to occur on this location	Incident has occurred on a similar location or within company	Incident is unlikely to occur within company and has occurred in industry	Incident is unlikely to occur on this location and has occurred in industry	Incident is highly unlikely to occur within company, but heard of in industry	Incident is highly unlikely to occur on this location, but heard of in industry

The severity of the consequences following an event is depicted in Table 2. It ranges from negligible effects (1) to catastrophic effects (5). From Figure 1 it is clear that catastrophic effects are never acceptable.

Table 2 Severity of consequences as used in Figure 1 [2].

SEVERITY CATEGORIES				
1 Negligible	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
Minor Injury, Medical Treatment Case with/or Restricted Work Case	**Serious Injury** or Lost Work Case	**Major or Multiple Injuries,** Reversible injury or non-disabling permanent injury	**Single Fatality,** Permanent disability	**Multiple Fatalities,** Up to 10 fatalities

The ultimate goal of FSA/ risk analysis is firstly to determine where the hazardous activity is positioned in the risk matrix and, when the result is unsatisfactory, take measures to shift this position to an acceptable location.

2.2 Risk analysis

In order to position a certain scenario in the risk matrix two types of analyses need to be done; a) determine the likelihood of incidents and b) determine the consequences of such the incidents. Both types of analyses may mean just a consultation of experts relying on their experience. It may also mean extensive desk studies and data collection via experiments. Either way, it demonstrates the importance of a good team of experts. Preferably, a risk assessment is a multi-discipline exercise and not a desk study. This ensures that as many aspects as possible are being looked into.

When addressing unconventional fuels, biological, chemical and thermodynamic properties of these substances are crucial for a proper understanding of the hazards. On top of that come integrity and robustness of the containment systems, the pipe lines on board, the bunker lines and the multitude of appendages. They must be able to ‘withstand’ the chemical and thermodynamic nature of the various fuels. Typical examples are brittle fracture of carbon steel, which is a hazard in case of cryogenic temperatures (below minus 100 Celsius) and sensitivity of common steels to corrosion when exposed to methanol. Containment systems should also be able to survive incidents such as ship collisions and fire exposure.

The goal of any risk analysis is to determine the position of the risk posing events in the risk matrix based on (scientifically) sound analyses. Both safety and design freedom are served through the ambition to apply first principles rather than to rely on prescriptive regulations.

3 The fact sheets approach

3.1 Equivalence

Since the ambition is to demonstrate equivalent safety of a new bunker fuel system, compared to existing bunker fuels, direct comparison of typical hazardous mechanisms between the new fuel and conventional fuels seems a viable approach. A practical way of comparing the safety/ risk of a novel fuel to existing fuels is by listing typical precautionary measures of both in a table and stating the associated hazard mechanisms alongside the precaution. In addition, the specific toxic, chemical and thermodynamic data of the fuels need to be compared. Throughout such comparative analyses the hazards, typical to people, the ship and the environment are the three focal points.

The process of making such a comparison is straight forward but requires a considerable effort. However the result is rewarding because it allows for a consistent and rational comparison between risks introduced by the new fuel and risks of a fuel with which the community is familiar. As said there are two important aspects;

a) risk in terms of probabilities and consequences,
b) first principles (statistics, physics, chemistry, biology).

See chapter 2 for some further explanation.

3.2 Methanol bunker fuel safety comparison factsheets

In order to investigate the viability of the approach outlined in section 3.1, a comparison has been made between methanol as the new bunker fuel and conventional bunker fuels such as HFO (Heavy Fuel Oil), MGO (Marine Gas Oil) and LNG (Liquefied Natural Gas) as the conventional bunker fuels. The choice for methanol was made because it fits in the on-going 'Green Maritime Methanol' project. LNG is included as conventional fuel because, when introducing this fuel, typical hazards were considered explicitly.

A categorisation was chosen for the comparison of safety measures, which is copied from IMO's IGF-code [4];

1. ship design,
2. containment,
3. materials,
4. bunkering,
5. fuel supply,
6. power generation,
7. fire safety,
8. explosion prevention,
9. ventilation,
10. electric installation,
11. control, monitoring and safety systems.

Regarding chemical/ thermodynamic, medical, environmental and precautionary data, the categorisation of the standard safety data sheets (SDS) was chosen.

Table 4 shows an example of a part of the comparison between methanol and LNG. The full data sheet is available as an additional deliverable to the GMM project. Only the category “containment”, and only two fuels are shown (methanol and LNG). The 2nd column (IGF category) refers to the main hazards addressed, the 3rd column states the reason(s) for a given regulation. The 4th and 5th column stipulate the regulations relevant to the respective fuels under consideration. The code between brackets refers to the source of the given regulation. The number of regulation/ information sources is restricted to those as listed in Table 3. These are considered the most relevant and appropriate.

Table 3 list of sources related to regulations and information

20190131 Concept Handleiding Risicoberekeningen Bevi 4.01.pdf
ADN_2019_E_Web.pdf
CCC 6-WP.3 - Report of the Working Group (Working Group) (1).pdf
Concept Handleiding Risicoberekeningen Bevi v4.1_0.pdf
IBC-Code International code for the construction and equipment of ships carrying dangerous chemicals.pdf
IGC-Code Int. Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (MSC.pdf
igf-code.pdf
iso-dts-18683.pdf
meth-2-booklet-2-PRINT-3-lowres.pdf
Methanol-Safe-Handling-Manual.pdf
MSC-MEPC 2-Circ 12-Rev 2.pdf
rec_no_146_pdf2946.pdf
Rules_for_the_Classification_of_Methanol_Fuelled_Ships__July_2019.pdf
SIL Platform - Risk Matrix Guide Oct2018 Final LR.pdf
SOLAS.pdf
SOLAS-Consolidated-Edition-2018.docx.pdf
STCW-Code Seafarers'' training certification and watchkeeping code - (MSC.180(79)).pdf

The document “*Concept Handleiding Risicoberekening Bevi*” is in Dutch and included here for future use. It is not referred to yet in the comparison sheets. The same remark is valid for *ADN_2019_E_Web*.

The *Methanol-Safe-Handling-Manual* is a publication by the Methanol Institute. The *Rules_for_the_Classification_of_Methanol_Fuelled_Ships__July_2019* is published by Lloyds Register. The rule set follows the development of the IMO guidelines for safety of ships using methyl/ethyl alcohol as a fuel, which is currently under development to reflect the latest development of the guidelines of the IMO sub committee CCC6/WP3. The *SIL Platform – Risk Matrix Guide Oct2018*, published by a Dutch foundation is included because it explains risk in an accessible fashion. The remaining sources are all published by IMO.

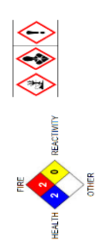
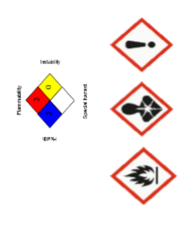
Table 4 Fuel safety comparison sheet, methanol - LNG, for category containment

		LNG	Methanol
IGF category / hazard	Reasoning behind regulation	Regulation	Regulation
Containment		***The goal according igf is to provide that gas storage is adequate so as to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil fuelled ship.***	***The goal according CCC 6 - 6.1 is to provide for a fuel containment system where the risk to the ship, its crew and to the environment is minimized to a level that is at least equivalent to a conventional oil-fuelled ship.***
Toxicity to humans, flamable/ explosive mixtures, blocking emergency escape routes, damaging safety/ escape equipment	No vapours on deck or below deck tolerated because of flamability and toxicity Tank location will imply no-go areas in vicinity, these must not impair routes and means of abandon ship	Containment arranged as to avoid dangers to ship persons and environment, in case of leaking (IGF - 6.2) - ship materials not exposed to cryogenic temperatures - flamable gas mixtures getting at ignition sources - gas mixtured intoxicating and asphyxiating personnel - hampering access to muster stations and LSA - reducing functionality LSA	
Toxicity, flamability	Avoid flamable, toxic or asphyxious vapours, after leakage, in spaces where people may enter		Tanks containing fuel: not located in accomodation or machinery space category A (CCC6 - 5.3.1)
Loss of bulk fuel, toxicity, flamability, asphyxiation, brittle fracture	Total failure due to single failure not acceptable	Pressure and temperature of fuel in tank under control (IGF- 6.2) back up required (IGF - 6.9.6)	Controlled venting required in fuel tank (CCC 6 - 6.3.1)
Damage to environment (ecology)	Methane is a severe GHG, so venting is not acceptable Any spill is not an issue from environmental point of view, methanol is bio degradable.	Operational venting not allowed (IGF - 6.9.1)	not considered hazardous to eco system
	Cold NG will heat up while decending from outlet and subsequently become buoyant so no vapour on deck / vapours will (hopefully) disperse within 3m and 10 m so they are not flamable, intoxicating or asphyxiating any more when the reach air in intakes	Pressure relief venting outlets 1/3B above weather deck, minimum height 6 m above weather deck	Fuel tank vent outlets: min 3m above deck or gangway, and min 10m away from nearest air intake (CCC6 - 6.4.7) Gas-freeing outlets also underwater allowed (CCC6 - 6.4.10)
No collateral damage	Precautionary shut down of systems should not increase the danger by disabling the ships manoeuvrability	Safety actions, e.g. emergency shut down, must not leave the ship powerless (IGF -3.2.3; 5.2.1.5; 6.2.3)	Safety actions should not lead to an unacceptable loss of power (CCC6 - 1.3.3; 3.2.3; 5.2.1.5; 6.2.3)
Leaking	community is used to 10 barg	Pressurized vacuum tank MARV 10 barg (IGF - 6.3)	Storage pressure hardly an issue
Loss of bulk fuel, toxicity, flamability, asphyxiation, brittle fracture	Similar design life to ship	Design life >= 20 years (IGF - 6.4.1.2)	- not found in CCC6 -
	Design for unresricted navigation Prevent loss of fuel tank due to dynamic load	Structural design of containment to be considered explicitly for North Atlantic (IGF - 6.4), accidental accelerations due to collision and fire loads (IGF - 6.4.1)	Design independend fuel tanks also for accidental loads (CCC6-5.4.3). -Nothing mentioned regarding North Atlantic in CCC6-
		Either detect deterioration of tank integrity timely or fail only after at least 20 years (IGF- 6.4)	
Leaking		Distinction between membrane tanks and independent tanks (IGF - 6.4.3)	no need for cryogenic storage, membrane tank not opportune
	avoid brittle fracture induced by low cryogenic temperature	Specific secondary barrier requirements amongst others: contain all potential leakages, icw insulation prevent lowering temperature of ship structure. (IGF - 6.4.4)	- not in CCC6 -
Damage to environment (ecology)		Requirements for thermal insulation (IGF - 6.4.13)	- not in CCC6 -
Loss of bulk fuel, toxicity, flamability, asphyxiation, brittle fracture		Mechanical design loads prescribe (IGF - 6.4.9)	- not in CCC6 -
		Sophisticated structural analysis required (IGF - 6.4.11)	- not in CCC6 -
	Prevent burst, only allowed to engage in case of emergency, e.g. collision or fire	Pressure relief valves required, dimensioning procedure prescribed (IGF - 6.7.3)	Pressure and vacuum relief valves required on fuel tanks (CCC 6 - 6.3.4), design and arrangement requirements are given (CCC6 - 6.3.4-6)
Flamability	Only for bunkering and supply lines, not for tank itself	Gas freeing and filling system required hence inerting systems required (IGF - 6.10.1)	
Flamability	Avoid the possibility of a flammable mixture existing in the fuel tank and avoid hazard due to dispersal of flammable vapour to the atmoshpere	no inerting requirements during nomal exploitation of ship, vapour pressure prevents air intake	-Fixed piping system for gas freeing and fill tank with fuel from a gas-free condition (CCC 6 - 6.3) - Gas freeing using water is allowed (CCC6 -15.4.2.3) - Inerting system within fuel storage system (CCC 6 - 6.4) - All fuel tanks, inerted at all times during normal operation (CCC6 - 6.4.1) 'Closed tank (ADN - 3.2.3.2)
Flamability	Due to regulation 6.4.1; all fuell tanks inerted all times.	Inert gas for gas freeing of fuel tanks may be provided externally to the ship (IGF - 6.10.4)	Inerting storage requirements (CCC6 - 6.5), inert gas permanently available on board (CCC6 - 6.5.1)
Flamability	No sparking electronics, controlled access only	Interbarrier spaces (i.e. cofferdam ?) qualified hazardous (IGF -12.5.2.1)	Cofferdams and pump rooms qualified hazardous(CCC6 - 12.5.2.1.1)

The full table can be accessed through the spreadsheet ***safetyfactsheets*** under tab. ***IGF categories safety measures***.

Table 5 shows an example of typical safety data sheet (SDS). Only the category hazard statements is shown. In this typical example, the table is restricted to HFO, MGO, gasoline (petrol) and methanol (MEOH). The full table is available through the spreadsheet ***safetyfactsheets*** under tab. ***SDS***.

Table 5 Safety Data Sheets (SDS), hazard statements

	HFO	MGO	Gasoline	MEOH
National Fire Protection Association (**NFPA**) Globally Harmonized System of Classification and Labelling of Chemicals **(GHS).**		 GHS02, GHS07, GHS08, GHS09		
Hazard Statements:				
H224: Extremely flammable liquid and vapour	-		H224	
H225: Highly flammable liquid and vapour	-			H225
H226: Flammable liquid and vapour		H226		
H301+H311+H331: Toxic if swallowed, in contact with skin or if inhaled				H301+H311+H331
H304: May be fatal if swallowed and enters airways		H304	H304	
H315: Causes skin irritation		H315		
H319: Causes serious eye irritation			H319	
H332: Harmful if inhaled	H332	H332		
H350: May cause cancer	H350		H350	
H351: Suspected of causing cancer		H351		
H361: Toxic to reproduction			H361	
H370: Causes damage to organs				H370
H373: May cause damage to organs through prolonged or repeated exposure	H373	H373	H373	
H410: Very toxic to aquatic life with long	H410			
H411: Toxic to aquatic life with long		H411		

The comparison sheets are under development and should be regarded as a living document, hence not all regulation/ information sources are currently referenced, although most of them are referenced implicitly through IGF and CCC 6-WP3. As the sheets develop, other references should also emerge in the sheets.

4 Application example

In this chapter, an example is provided by making a selection of a full, comprehensive safety equivalence exercise. The aspects that are addressed are (ecological) toxicity and flammability. Moreover only one category is considered, i.e. **‘*ship design*’**.

For the same reason an equivalence comparison is made only between methanol as the new fuel and marine gas oil (HFO/MGO) as the existing technology serving the same purpose.

4.1 System description

The new system is a methanol fuelled cargo ship. The ‘conventional’ system is an HFO/ MGO fuelled cargo ship. This example is brought in by Wagenborg Shipping.

Approximate dimensions of the ship:

Deadweight	10200	tonnes
Length over all	137.9	m
Breadth over all	15.87	m
Draught	7.98	m

The general arrangement of the ship to be converted is shown in Figure 2.

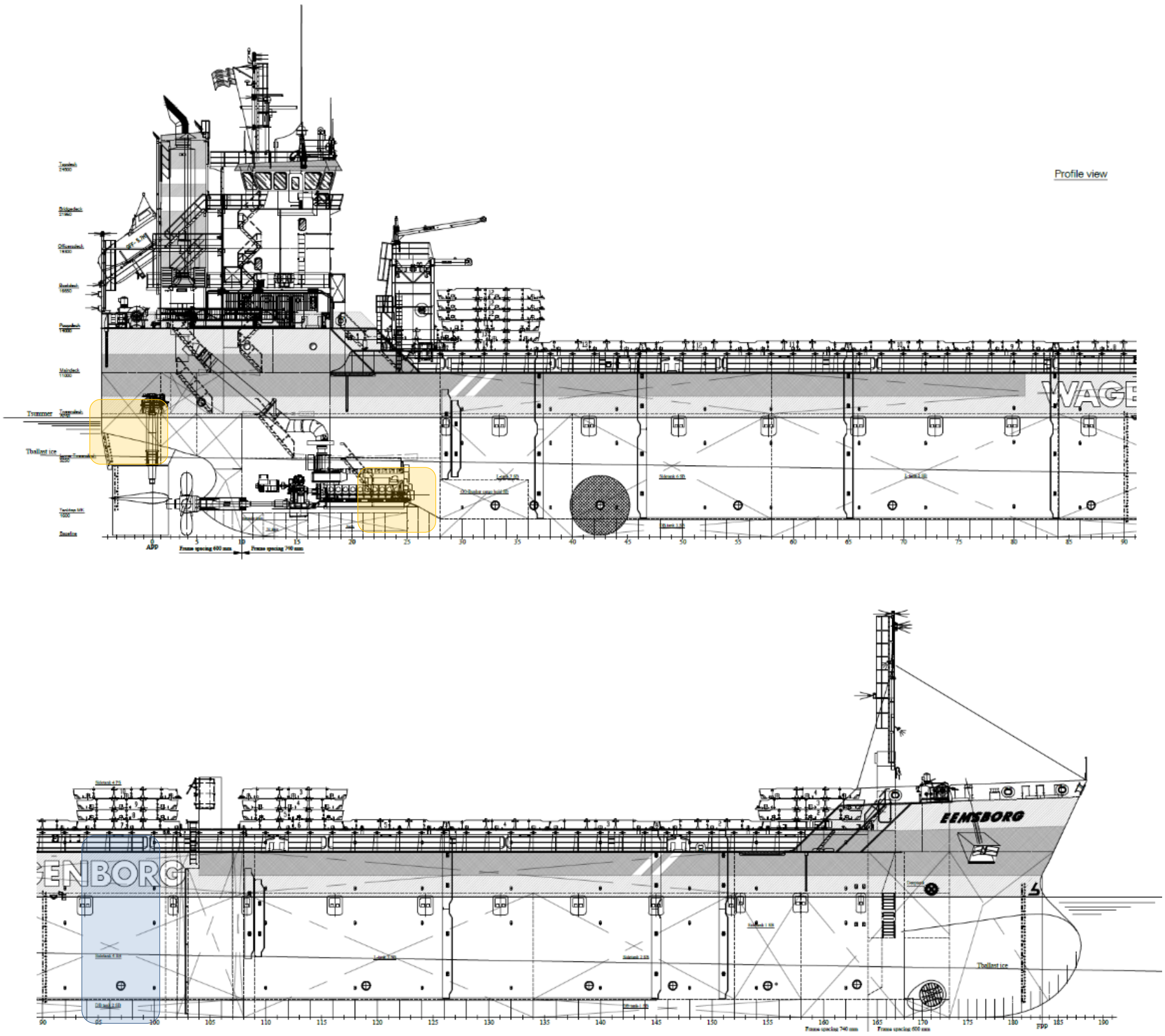


Figure 2 GA ms Eemsborg, sideview

Fuel capacities in the conventional design are HFO 881 m^3 and MGO 72.3 m^3. The HFO is located between frame 102 and frame 108 (shaded area blue), while the MGO is situated adjacent to the engine room (shaded area yellow).

Required fuel capacities for the new design are methanol 520 m^3 and MGO 289 m^3. In this example the HFO spaces are now used for methanol.

4.2 Equivalence probabilities and effects

Regarding safety measures the ***safetyfactsheets***, tab. ***igf categories safety measures*** is consulted. For this example only the ship design category is considered.

In the safety factsheet it is shows that for *methanol* a considerable list of requirements is in place. Most of these aim to avoid the development of flammable or toxic vapours. Development of vapours require spillage or leaking. The risk of leaking of methanol is compared to the risk of leaking of MGO to demonstrate the practical use of the equivalent risk approach.

The leakage of MGO is in the severity category (1) and assuming that it is in the *tolerable risk* region, the likelihood of spillage and leaking of this fuel is apparently *sporadic* i.e. (5) out of (7). This is indicated by the asterisk in fig 5. Having no better evidence and assuming containment, piping and handling to be similar to MGO (so no special measures), it seems reasonable to attribute the same likelihood to spillage of methanol. Consulting the standard data sheets (SDS, Table 5), consequences following a methanol spillage prove to be *moderate* (3) or even *major* (4). Hence in the risk matrix methanol bunker fuel ends up in the *unacceptable* area (red) (upper cross in fig. 5) if no measures are taken. So clearly from a safety point of view, methanol fuel, without additional measures, is not equivalent to MGO.

However measures as specified in Table 6 can be taken. most of them are aiming at providing a second barrier, e.g. double walled piping, cofferdams and arilocks. This implies that two barriers need to fail for a dangerous spill to occur. The probability of this to happen is equal to the probability of one barrier failing p squared p^2, i.e. $(10^{-2})^2 = 10^{-4}$. So through these measures methanol is shifted downwards in the risk matrix with respect to likelihood from *sporadic (5)* to somewhere between *improbable (3)* and *very unlikely (2)*, as shown in Figure 3. Note that the severity does not change.

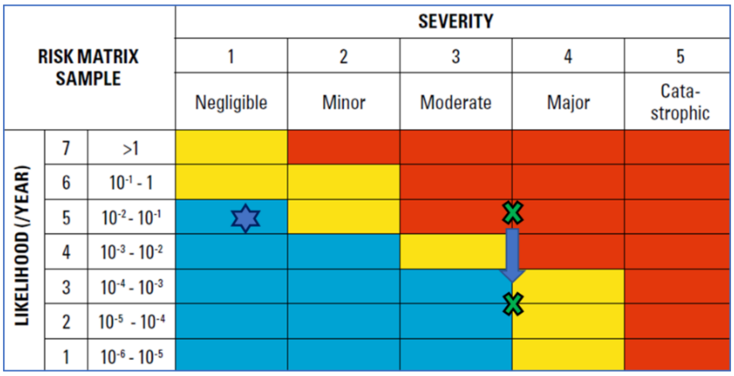


Figure 3 methanol and MGO in the risk matrix

Through these measures methanol bunker fuel has been *designed into* the tolerable risk region, albeit just. Methanol fuel is therefore now in the same risk category as MGO and HFO. Thus risk equivalence is demonstrated.

The reasoning above is an oversimplification of reality but it does illustrate the concept of equivalent safety. The regulations also prescribe accessibility of spaces vulnerable to leakage through a single wall. In such cases the number of persons present in such a space simultaneously is restricted. This is a measure which reduces the severity of a leakage, in this case the number of potential casualties.

Table 6 Extract from ***safetyfactsheets***, tab. ***igf categories safety measures***.

Hazard/ Risk addressed

		MGO UN 1202	Methanol
IGF category	**Reasoning behind regulation**	**Design**	**Regulation**
Ship design			***The goal CCC 6 is to provide for safe location, space arrangements and mechanical protection of power generation equipment, fuel storage system, fuel supply equipment and refuelling systems.***
damage due to ship collision, access for inspection	Collision protection/ room for inspection/ room for evacuation	piping no requirements wrt distance from shell LR	Piping 800mm from ship's side (CCC 6 - 5.7.1)
toxicity/ flamble mixtures	No leaking into other spaces in the ship		Piping not through accommodation (CCC 6 - 5.7.2)
damage due to collision	Collision protection/ room for inspection/ room for evacuation	tanks no requirements wrt distance from shell LR	Fuel tank 800mm from ship shell side/adjacent space(LR MF - 5.3.3)
	Offer design freedom (LNG)		
			If, explosion in space with potential source of release and ignition source, no progresssive flooding may occur (CCC6 - 4.3.1)
	- 2nd barier against leaking into other spaces in the ship - Added layer of gas and liquied tightness protection against external fire, toxic and flammable vapours between fuel tank and other areas of the ship (CCC6 - 2.2.3)		- Integral fuel tanks to be surrounded by a cofferdam except when surrounded by: (LR MF 5.3.6) ' pump room ' bottom shell plating'
	no toxic/ asphyxatious vapour in spaces where peaple are likely to enter		- Fuel tanks surrounded by cofferdam except for: (CCC6 - 5.3.2) (CCC6 - 11.4.3) ' surface bound by shell plating below lowest possible waterline ' other fuel tanks containing methanol ' fuel preparation space'
	No vapour ot vapour-air mixture into other spaces in the ship	air locks not required	Air-locks required for acces to hazardous spaces (LR MF - 5.6.1) Air-locks required for acces to hazardous spaces (CCC6 - Annex1)
	No vapour ot vapour-air mixture into other spaces in the ship, possible to hoist injured person from the bottom of cofferdam. This requirement is not found for LNG.		Acces from open deck to fuel tanks and cofferdams (LR MF) (CCC6 - 5.11.3)
	Avoid spillage into accommodation etc., vapour is heavier than air, so it sinks	tanks not above adjacent of below accomodation and service spaces and control stations LR Ships	Tanks and fuel piping not above adjacent or below accomodation, service spaces and control stations (LR MF - 5.3.10 & 7.2.14)
	Contain any spillage		Independent fuel tanks located on open deck, surrounded by coamings. Or fuel storage hold spaces (LR MF - 5.3.5)
	Practical reasons, enough space for passer by. See also methanol. Min distance: practical reasons, enough space for passer by, max distance: ?? maybe to avoid loss of excessive underpressure in the hazardous space (and prevent fals audibible/visual alarms due to pressure loss) , see also (CCC6 - 13.3.10)	doors to airlocks n. a.	Air lock: door to door distance between 1.5m and 2.5 m (LR MF - 5.6.3) (CCC 6 - 5.12.1)
			Area around independend tanks sufficient for maintenance inspections, evacuations and rescue operations (LR MF - 5.6.15)
	to allow evacuation and rescue (stretcher access)		horizontal hatches at least 600x600mm for the evacuation of injured person LR MF
	to allow for evacuation and rescue		vertical hatches atleast 600x800, not heigher than 600mm from deck LR
		iner gas not required	inert gas system required (LR MF 6.8)
	because of corrosion and lubrication issues in engines, by no means trivial	engine conventional	engine with special properties LR MF
		no double walled piping	drainage of annular space double walled piping LR MF
	avoid flamable vapours		exhaust fitted with purge/inert system LR MF
	no cones required ADN 3.2.3 Avoid spills in the water in case of a crash, however this is not harmfull for the environment. Is a crash a 'potential ignition source'? If that is the case it is also to avoid explosion / fire		No fuel tank forward of forepeak and aft of the afterpeak (CCC6 - 5.3.3)

Regarding safety data for both fuels the ***safetyfactsheet*** tab. ***SDS*** is consulted. For the sake of this example only the section on physical properties is considered.It shows that methanol has a low flash point of 9.7 °C, whereas MGO and HFO are above 55 and 61 °C respectively. The flash point is the minimum temperature at which the vapour of a liquid ignites when exposed to ignition sources. The flammable gas mixture will be present because of the high vapour pressure of methanol (determines volatility) and the flammability range of 6-36vol% in air [9]. Since temperatures on board can easily exceed 9.7 °C , this implies that methanol can develop into a flammable gas mixture with air when there is no proper ventilation. This hazard is aggravated by the property of methanol vapour being slightly heavier than air. It causes vapours to sink into compartments allowing it to develop into a flammable gas mixture. With this knowledge the measures as described in the tab ***igf categories safety measures,*** can be understood, since physical properties are impossible to change, the probability of leaking events needs to be engineered downwards. Also, in case of leakage, vapours must be ventilated out of and away from the ship.

Table 7 Extract from ***safetyfactsheets*** excel sheet, tab ***SDS***.

	HFO	MGO	MEOH
Physical properties:			
Flash point	≥ 61°C	>55 °C	9.7 °C
Lower Explosion Limit Upper explosion limit		none	6 % 50 % (V)
Minimum ignition energy mJ		-	0.14
Vapor pressure (20 °C) (kPa)	< 1.0	< 1	12.9
Relative vapor density at 20 °C	6		1.1
Solubility in water	Insoluble	Insoluble	Soluble
relative density vapour air mixture (20 °C)		-	1.01

It is noted that this example only addresses the category ship design in conjunction with flammability. Should ecological toxicity also have been considered, the results would have turned out in favour of methanol because it is bio degradable. The aim of this Chapter is however not to provide solid results but to provide an insight (and to create an understanding of) a comprehensive safety equivalence exercise.

5 Discussion

In this document the example of hazards of fuel leaking has been chosen to advocate the use of a risk matrix for demonstrating equivalent safety. There are however various failure mechanisms which can be considered. Obviously other failure mechanisms must also be addressed in case of a full analysis. In general those mechanisms may require more sophisticated approaches.

There is the mechanism of vented vapours entering the spaces in the ship. The source of vented or leaked methanol needs to be clear as it defines the behaviour of this hazard. For example, liquid methanol will possibly spray or cause pools, depending on the pressure and flow, and evaporate to form toxic or flammable mixture if not sufficiently ventilated. The regulations state minimum distances between venting outlets and space entrances/ air intakes. Technical evidence supporting the choice of the actual distances is difficult to generate. It would probably require CFD calculations and physical testing, either in a wind tunnel or full scale. Current safety zone distances are decided by experts to the best of their knowledge. These minimum distances pose severe restriction on the ship design. It may be attractive to further investigate these because a better understanding of air/ vapour flows may give opportunities to alleviate these very restrictive distances.

Another mechanism which deserves further investigation is tank leakage. Above the ballast water line a safe distance between tank and ship shell is required, while below the ballast waterline there is no such requirement (CCC6 5.3.2). Here also it is not straight forward to generate supporting technical evidence. Leakage below the ballast waterline is regarded as not so hazardous because methanol is not toxic to aquatic life (H411 in SDS), moreover, since methanol has a density of 0.8 tonne/m^3, sea water will enter the tank rather than methanol escaping the tank. Above the ballast water line however methanol will escape from the tank and a pool will develop on the waterline. Above this pool, a vapour/air mixture will develop causing a flammability, asphyxiation and intoxication hazard. It is worthwhile to further investigate the actual mechanisms associated with methanol escaping above the water line. It may very well be the case that the pool dissolves quickly in the water while any vapour disperses rapidly. If it can be demonstrated that after an methanol egress a hazardous situation exists only for a (very?) short period, it might be considered to lift the safe distance above the ballast water line. This again would substantially increase the design flexibility for the naval architect.

6 Conclusions and recommendations

Demonstrating that novel technologies are possible at a safety level ‘equivalent’ to existing technologies serving a similar purpose, can be done in a convenient way by applying the concept of risk. For this purpose two aspects can be taken into consideration: probability and severity. In this report the introduction of methanol as bunker fuel is taken as an example, which is compared to marine gas oil. In this example, the scope was limited and extensive efforts have been made to assess all corresponding safety regulations and guidelines. In a full analysis three areas must be covered; people, environment and property. Moreover all conceivable hazardous events must be investigated.

Ample guidance is given by the authorities with respect to which framework is most suitable for demonstrating equivalent safety of a new technology, with the final goal of attaining approval from the authorities. Entrepreneurs who introduce new technologies must realise that they are themselves responsible for generating and interpreting the technical evidence. Statutory authorities should be provided with such evidence including an assessment which must be sufficient to enable them to judge safety implications.

7 Signature

TNO, Delft, November 2020

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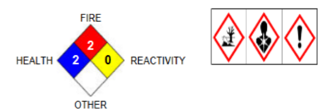
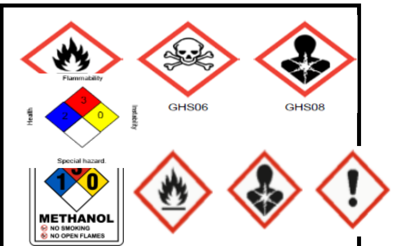
8 References

[1] IMO, MSC-MEPC.2/Circ.12/Rev.2, REVISED GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA) FOR USE IN THE IMO RULE-MAKING PROCESS, http://www.imo.org/en/OurWork/Safety/SafetyTopics/Documents/MSC-MEPC%202-Circ%2012-Rev%202.pdf
[2] A CONCISE BEST PRACTICE GUIDE ON RISK ASSESSMENT, https://www.nen.nl/Home-EN/SILPlatform.htm
[3] IMO, SOLAS 2018 Consolidated Edition, (freely available through Icelandic Transport Authority), https://www.samgongustofa.is/media/english/SOLAS-Consolidated-Edition-2018.docx.pdf
[4] IMO, IGF-Code, https://puc.overheid.nl/nsi/doc/PUC_80736_14/1/
[5] IMO, CCC 6/WP.3, 12 September 2019, Annex 1, DRAFT INTERIM GUIDELINES FOR THE SAFETY OF SHIPS USING METHYL/ETHYL ALCOHOL AS FUEL
[6] https://en.wikipedia.org/wiki/NFPA_704#Codes
[7] Methanol Institute, Methanol Safe Handling and Safe Berthing, Technical Bulletin, http://www.methanol.org/wp-content/uploads/2016/07/meth-2-booklet-2-PRINT-3-lowres.pdf
[8] Risk assessment as required by the IGF Code - Aug 2016, Rec 146, http://www.iacs.org.uk/publications/recommendations/141-160/
[9] Methanol Institute, Methanol Safe Handling Manual, https://www.methanol.org/wp-content/uploads/2020/03/Safe-Handling-Manual_5th-Edition_Final-pdf-1-580x750.jpg

APPENDIX 1: SAFETY SPREADSHEET

	HFO	MGO	MEOH
National Fire Protection Association (**NFPA**) Globally Harmonized System of Classification and Labelling of Chemicals **(GHS).**		 GHS02, GHS07, GHS08, GHS09 	
Hazard Statements:			
H224: Extremely flammable liquid and vapour	-		
H225: Highly flammable liquid and vapour	-		H225
H226: Flammable liquid and vapour		H226	
H301+H311+H331: Toxic if swallowed, in contact with skin or if inhaled			H301+H311+H331
H304: May be fatal if swallowed and enters airways		H304	
H315: Causes skin irritation		H315	
H319: Causes serious eye irritation			
H332: Harmful if inhaled	H332	H332	
H350: May cause cancer	H350		
H351: Suspected of causing cancer		H351	
H361: Toxic to reproduction			
H370: Causes damage to organs			H370
H373: May cause damage to organs through prolonged or repeated exposure	H373	H373	
H410: Very toxic to aquatic life with long	H410		
H411: Toxic to aquatic life with long		H411	
Precautionary Statements:			
P210: Keep away from heat, sparks, open flames, hot surfaces. -No smoking.	-	P210	P210
P233: Keep container tightly closed.			P233
P240: Ground/bond container and receiving			P240
P241: Use explosion-proof electrical, ventilating, lighting equipment			P241
P242: Use only non-sparking tools.			P242
P243: Take precautionary measures against static discharge.			P243
P260: Do not breathe dust / fume / gas / mist / vapors / spray.	P260	P260	P260
P264: Wash exposed skin thoroughly after handling.			P264
P270: Do not eat, drink or smoke when using this product.			P270

P271: Use only outdoors or in a well-ventilated area.			P271
P273:Avoid release to the environment.		P273	
P280: Wear protective gloves / protective clothing / eye protection / face protection.	P280	P280	P280
P301 + P310: IF SWALLOWED: Immediately call a POISON CENTER or doctor / physician.	P301+P310	P301+P310	P301+P310
P303+P361+P353: IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.			P303+P361+P353
P304+P340: IF INHALED: Remove person to fresh air and keep comfortable for breathing.			P304 + P340
P330: If swallowed, rinse mouth			P330
P331: Do not induce vomiting.	P331	P331	
P361+P364: Take off immediately all contaminated clothing and wash it before reuse.			P361 + P364
P370+P378: In case of fire: Use carbon dioxide (CO2), powder, alcohol-resistant foam to extinguish			P370 + P378
P403+P235: Store in a well-ventilated place. Keep cool.		P403+P235	P403+P235
P405: Store locked up.			P405
P501Dispose of contents/container in accordance with local/regional/national/international regulations	P501	P501	P501

Physical properties:			
Flash point	≥ 61°C	>55 °C	9.7 °C
Lower Explosion Limit Upper explosion limit		none	6 % 50 % (V)
Minimum ignition energy mJ		-	0,14
Vapor pressure (20 °C) (kPa)	< 1.0	< 1	12,9
Relative vapor density at 20 °C	6		1,1
Solubility in water	Insoluble	Insoluble	Soluble
relative density vapour air mixture (20 °C)		-	1,01