Journal of the Korean Society of Marine Engineering, Vol. 41, No. 10, pp. 992~1005, 2017
J. Korean Soc. of Marine Engineering (JKOSME)
https://doi.org/10.5916/jkosme.2017.41.10.992
ISSN 2234-7925 (Print)
ISSN 2234-8352 (Online)
Original Paper

Fire, explosion and safety Hazard identification (HAZID) of the entire methanol dual fueled system and ship

Hamid Etemad[1] · Jae-Hyuk Choi†

(Received October 17, 2017 ; Revised October 31, 2017 ; Accepted November 22, 2017)

Abstract: This study has evaluated the scope of the Hazard Identification (HAZID), focusing in-particular an analysis of the causes and consequences of hazards scenarios for entire methanol fuel system on methanol fuelled carrier. The main categories of hazard scenarios are: fire and explosion initiated from the methanol system, fire and explosion not methanol initiated, dropped objects, collisions, grounding, foundering and occupational accidents. We identified total 27 hazards and failures and proposed total 15 recommendations in term of design and operation with the division in high prioritization which prevent failures or reduce the effects of possible failures. The main result from the HAZID showed that the estimated HAZID increase is mainly due to design of the methanol system and operation, followed by materials and equipment and impact/dropped objects. HAZID study has been conducted for the methanol fuel system on 38,000 DWT methanol carrier in order to ensure that any risks arising from the use of methanol fueled affecting the structural strength and the integrity of the vessel's main safety functions are addressed. While methanol marine fuel is a relatively new application, HAZID provide standards and regulations for the use of methanol marine fuel that minimize risk to people and the environment. The HAZID show that no single failure can lead to a critical situation that will affect the structural strength and the integrity of the vessel if the recommendations are implemented. The HAZID results confirm that there is no major HSE showstoppers to carry out construction and conversion on vessel using dual fueled. This study has not identified any showstoppers, and in addition the equivalency is both feasible and suitable for its expected application complying with IGF Code and IMO MSC.1/Circ.1455, items 4.10.1.1 and 4.10.1.2.
Keywords: Methanol fuel system, HAZID, IGF code, IMO MSC.1/Circ.1455, fire and explosion, hazard and effects

1. Introduction

Utilization of alternative fuels such as methanol has rapidly grown and seen as a viable alternative to heavy fuel oils/marine diesel oil due to several factors such as the properties, economic and environment circumstances and its business is becoming mature phase **[1][2]**. In addition to that benefits, the engine is successfully certified as IMO Tier3 compliant **[3]**, using methanol, without the need of secondary exhaust gas treatment systems, such as selective catalyst reduction and/or exhaust gas recirculation, the engines are capable to burn MDO and low flash point fuels such as methanol with uninterrupted operation. Methanol as a fuel for ships is interesting for ship's operators because methanol does not contain any Sulphur **[4]**. For ships operating in IMO emission control areas (ECA), methanol could be a feasible solution to meet the sulphur requirement **[4]**. Already in 2013, IMO has decided to adopt the Energy Efficiency Design Index (EEDI) as a mandatory instrument for ships built after January 2013 to limit CO_2 emissions. This will influence the engine market and technical solutions faster than we had anticipated at first. Here, alternative low carbon fuels, such as Methanol, will in the future be serious candidates to fuel oil in-order to lower EEDI. By nature, methanol generates less CO_2 emissions during combustion than fuel oils **[4]**.

Over the past decade there has been a trend towards implementing progressively more stringent regulations aimed at reducing emissions that are harmful to human health and contribute to global warming. From the regulatory standpoint, marine methanol is a future-proof fuel that could comply with the most tightly specified emissions reduction legislation currently being considered. Methanol is characterised by having a low cetane number, and the self-ignition quality is therefore poor **[5][6]**.

† Corresponding Author (ORCID: http://orcid.org/0000-0003-0092-883X): Division of Marine System Engineering, Korea Maritime and Ocean University, 727, Taejong-ro, Yeongdo-gu, Busan, 49112, Korea, E-mail: choi_jh@kmou.ac.kr, Tel: 051-410-4257
1 Graduate School of Korea Maritime and Ocean University, E-mail: hamidetemad@kmou.ac.kr, Tel: 051-405-4258

Methanol has been shipped globally, handled and used in a variety of applications for more than 100 years. From a health and safety perspective, the chemical and shipping industries have developed procedures to handle methanol safely **[7].** There is ample experience in handling and transporting methanol as a chemical, both in tank trucks and bulk vessels. For example, methanol was the dominant bulk liquid handled in Finnish ports in 2008 and 2009 and is in general a very common chemical transported in ports around the Baltic Sea **[8]**. To cope with the demand of the methanol market with flexibility, this paper has newly and unique assessed and developed HAZID addresses all areas that need special consideration for the usage of the methanol fuel as low flashpoint fuel to become a global fuel choice.

The first version of the IGF Code addresses only LNG (methane). The IMO has been tasked to develop the second version of the Code, addressing methyl/ethyl alcohol and other low-flashpoint fules such as low flashpoint diesel, therefore according to SOLAS Reg. 1/5 and in order to comply with mandatory international regulations, IMO MSC./Circ.1455 alternative design and equivalent arrangements addressed on this study as an equivalent according to SOLAS 11/2, Reg.4.2.1 and SOLAS II-1. The flashpoint of methanol is below the minimum flashpoint for marine fuels specified in SOLAS. Methanol driven merchant vessels can be set into service via the alternative design approach covered by the IGF code. In this study, The IMO MSC./Circ.1455 alternative design and equivalent conditions have been met, and the alternative and/or equivalency was found feasible and suitable for its expected application. The goal of these alternative design and equivalent arrangement is to provide criteria for the arrangement and installation of machinery for propulsion and auxiliary purposes, using methanol as fuel, which will have an equivalent level of integrity in terms of safety, reliability and dependability as that which can be achieved with a new and comparable conventional oil-fuelled main and auxiliary engine. It is assumed that the vessel will run on methanol while performing cargo operations **[9]-[15].**

This analysis is the concept HAZID and based on by applying innovative thinking, maritime industrial experiences and the design concept of the vessel which is a typical methanol carrier operating between Korean port/Busan and Iranian Port/Bandar Abbas.

2. Vessel design concept and overview

The vessel's design data is shown in **Table 1**. The deadweight is about 38,000 tone on draught of 11.00m. Design speed (suitable service speed) is about 17 knots. Endurance for using gas fuel is set to 11,200 NM for one round trip between Iran/Bandar Abbas and Korea/Busan. In addition, endurance for emergency (using diesel oil) is estimated to be 5,600 NM.

Table 1: Design data of methanol carrier with methanol liquid fuelled 38,000 M^3 –ship design data compared to the reference ship 38,000 M^3 methanol carrier.

	Conventional fuel oil design	Dual fuel design
Length x Breadth x Depth	170.00 x 30.00 x 18.00 m	170.00 x 30.00 x 18.00 m
Main engine	low speed diesel fuel engine	low speed dual fuel
Alternator/ Generator	3x diesel generators	3 x dual fuel generators
HFO	2,000 m^3	500 m^3
DO/MGO	300 m^3	300 m^3
Methanol	-	2,500 m^3

The vessels slop tanks, or methanol fuel storage tank system will be filled from the cargo manifold. This design feature is an important aspect of the total fuel system, especially with respect to fuel contamination. The slop tanks, one on the starboard and one on the port side of the vessel, with a total capacity of about 2,500 m^3, will be used as methanol fuel tanks. The slop tanks are placed according to **Figure 1** general arrangement, methanol fuel tank arrangement and system.

The fuel service tank, with a capacity of about 80 m^3, is placed on the upper deck on the port side of the vessel as indicated **Figure 1**. The tank is protected towards the ship side by the methanol fuel supply room. Methanol is transferred by a submerged hydraulic pump from the slop tank to the service tank. All the connections to and from the service tank are shown in **Figure 1**.

The low flashpoint fuel supply system (LFSS) is locating in the methanol fuel supply room on the port side of the ship, towards the ship side at the same longitudinal location as the methanol service tank, as indicated in **Figure 1**, and including the supply unit, circulation unit and the fuel valve train. The supply and circulation units are locating in the methanol fuel supply room and constitute the LFSS. These units are designed, and include pumps, filters, and necessary safety systems.

The main engine uses temperature conditioned methanol at a fixed supply pressure and varying flow depending on the engine load. The LFSS will supply this fuel to the engine while complying with the requirements described regarding temperature, flow, pressure and ramp-up capabilities.

The fuel is taken from the service tank containing liquid fuel and boosted to a pressure close to the supply pressure, about 8.0 bar. The fuel is then circulated by the circulation pump, and the pressure is raised to the engine supply pressure, about 10.0 bar.

The delivery pressure must ensure that the fuel will stay liquid, and no cavitation will be generated at the temperatures to which the fuel is exposed until injection.

The flow of fuel in the circulation circuit should at all time be higher than the fuel consumption of the engine. A typical circulation factor is 2-3 times the fuel consumption. To ensure the fuel delivery temperature, a heater/cooler is placed in the circulation circuit. It is recommended to connect this through a secondary cooling circuit to the LT cooling system.

The methanol fuel system has its own draining system to handle spills as well as different emergency situations and in cases where the system needs emptying before switching over to fuel oil mode. The draining system is a combination between gravity draining and purging with nitrogen, which is an own system. Each unit described, such as the fuel valve train has its own delivery system of inert gas (Nitrogen) for purging.

The fuel valve train is designed and provided and connects the LFSS with the engine through a master fuel valve (MFV) arranged in a double block and bleed configuration. For purging purposes, the valve train is also connected to a nitrogen source. Typically, the valve train will be placed outside the engine room above the weather deck to avoid the need for double safety barriers. From the valve train, the fuel is fed to the engine in a double walled ventilated pipe through the engine room. The fuel valve train is locating in the methanol supply room. From the fuel valve train, the fuel is fed to the engine first in a single walled pipe on open deck and in a double walled ventilated pipe through the engine room. The supply piping from the fuel valve train to the main engine is shown schematically in **Figure 1**. The supply piping is divided into two main parts, namely above and below deck. The methanol fuel line on open deck is suited with single piping and with double piping below deck.

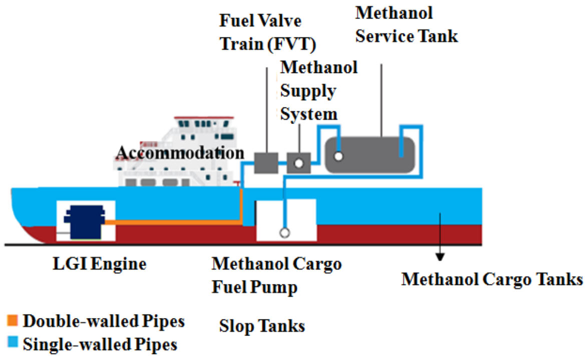

Figure 1: General arrangement, methanol fuel tank arrangement and system

The ventilation system is totally dedicated ventilation system for the methanol fuel system. The dedicated ventilation system for the methanol fuel system consists of separate ventilation system for the cooling oil system, double wall piping, covering the main methanol supply and purge return lines below deck, with mechanical extraction ventilation with 30 air changes per hour. The nitrogen system is provided by a nitrogen generator in the inert gas delivery unit, with a minimum supply pressure of 10 bar. The delivery lines distribute the inert gas to all units in the methanol fuel system.

The engine is using temperature conditioned methanol at a fixed supply pressure and varying flow depending on the engine load. The LFSS supply this fuel to the engine while complying with the requirements described regarding temperature, flow, pressure and ramp-up capabilities. A different system layout could be chosen for this task. Purge return system (PRS) on methanol fuel engine is arranged because of the low flashpoint methanol fuel, there are a number of operation scenarios where the fuel piping will have to be emptied and inerted. For the methanol engines, the fuel piping on the engine and in the engine room is arranged so that the liquid fuel can purge it and thereby return it to the fuel service tank. After the methanol fuel has been returned to the service tank, full purging and inerting are conducted for the double wall piping system.

If methanol operation is expected to be stopped for a longer period, e.g. during short harbour stays, the procedure for switching to standby mode is used. However, the low flashpoint fuel supply system (LFSS) is switched off when the procedure finishes. Major servicing work involving lifting equipment over the supply lines is not recommended in this mode. The reason being that the supply lines in the engine room and on the engine are methanol filled. In a complete shutdown of the liquid gas system, all piping is emptied from methanol fuel and the low flashpoint fuel supply system (LFSS) and ventilation is turned off. Shut down philosophy and redundancy consideration has been given. In general engine shut down philosophy will comply with the international rules and regulations.

3. Analysis basis and methodology

The Hazard Identification (HAZID) is a structured approach and exercises where documentation/drawings and a set of guidewords form basis for identifying hazards involved with an operation or the use of equipment and/or systems. HAZID's are commonly used throughout the maritime industry for all types of safety and risk assessments **[16]-[19].**

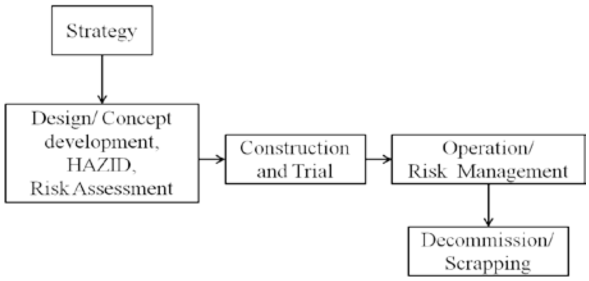

Figure 2: The lifecycle of a vessel from construction strategy to scrapping **[1]**

Figure 2 shows vessel's lifecycle. The focus for the HAZID assessment is the methanol fuel system and liquid gas engines (LGI) encompassing the following sequence of operations during the lifecycle of a vessel from construction strategy to scrapping:

(1) Construction/installation including testing and sea trials.

(2) Operations (Loading/offloading of cargo, voyage, bunkering, docking, maintenance, lay-up/Idle).

(3) Decommissioning/scrapping

Safety of ship propulsion during voyage and maneuvering to avoid blackout has been taken in to account. The following hazard guidewords used as a basis for the Hazard Identification (HAZID) study **[1]**:

Fire or explosion hazard, fire/explosion – methanol initiated, fire/explosion – not methanol initiated, other hazards generated by materials and substances, leakage of methanol causing loss of structural integrity, mechanical hazards, electrical hazards, thermal hazards, hazards generated by malfunctions, collisions, dropped object, grounding, foundering, environmental hazards, pollution, occupational accidents, hazards generated by neglecting ergonomic principles, and hazards generated by erroneous human intervention **[20].**

For each hazard causes/treats/initiating events, consequences, and controls (preventive and mitigating) are identified and recorded in the HAZID findings and results, following bow tie hazard and effect model in **Figure 3**.

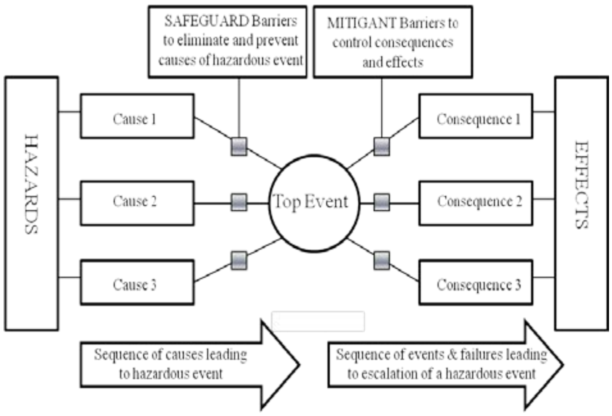

Figure 3: Bow tie hazard and effect model **[21]**

The diagram and model in **Figure 3** is shaped like a bow-tie, creating a clear differentiation between proactive and reactive hazards and effects. The hazard and top event always appear together in the centre of the bow-tie diagram.

Over-pressurisation could be a cause of loss of containment/tank of a hydrocarbon carrying methanol fuel. Causes appear on the left-hand side of the bow-tie diagram. Causes should be independent of each other and should lead to the top event directly. Causes should not be failures of equipment as this is in fact a barrier failure.

A consequence results in loss or damage. It is common to think of consequences as impacting on people, the environment, assets, business and reputation. More safeguards/barriers are put in place to try and stop the top event from developing into the consequences. Consequences appear on the right hand side of the bow-tie diagram. Preventive barriers (also called safeguards) appear on the left of the diagram and are designed to prevent the top event from taking place. Mitigation barriers appear on the right of the diagram.

The main focus of HAZID study was the conceptual design of the methanol fuel system. The study considered the system starting from the pumping of liquid methanol from the methanol cargo tanks to fuel tanks and followed the liquid/gas through the system to the engines.

The fuel supply system for the concept vessel is evaluated with respect to as low as reasonably possible (ALARP). The ALARP principle is based on the concept of implementing risk reduction measures if their respective costs are not disproportionately high as compared to their attained benefits. This HAZID study will thus assist ensuring safety equivalency with comparable ships using conventional fuel.

One failure in a component is considered separately, and it is assumed that all other components work properly. Generally hidden failures are not considered. Hidden failures which may be caused by nonidentifiable malfunctions of a component are kept in consideration as far as possible. In addition are external influences, such as fire, collision, grounding or other impact damage affecting the methanol system, assessed separately.

External influences are thereby defined as a separate system, with sub-components such as fire, collision etc. The HAZID table is adapted to fit a system component with its functions, failures, effects, controls, causes and actions, which are not directly transferrable to fit the effect from external influences. A logical transformation of some of the columns in the HAZID study is therefore made and is presented in **Table 2**.

The analysis focussed on the identification of hazards caused by methanol leakages affecting the structural strength and the integrity of the vessel. The methanol fuel system is operating within its design limitations. Attention was given to single point failure and regular inspection and maintenance is stipulated. The methanol fuel system is operated by an experienced crew.

An assessment of the methanol fuel system was conducted systematically for normal operation (voyage) according to the following subsystems:

(1) Manifold system (flanges, valves, piping on deck to inlet of methanol fuel storage tank, crossover connections, swing bends)

(2) Methanol fuel storage tank system (submerged pumps, filters on line to methanol fuel service tank, Inlet valves to methanol fuel service tank)

(3) Methanol fuel service tank system (methanol fuel service tank, inert gas inlet, drain to slop tank, engine purge return filters, low flashpoint fuel supply system, pressure and temperature indicators,)

(4) Low flashpoint fuel supply system (pipe connection from methanol fuel service tank, inlet valve, filters, valves, pressure indicators, pump, mixing tube, heating exchangers, 3-way valve, cooling pump, piping system for water and glycol, fuel gas system connections)

(5) Draining system for the methanol fuel supply room (safety relief valves, non-return valves, inert gas piping/valves)

(6) Fuel valve train (all items on main fuel line, valves, methanol fuel system valves, inert gas system valves)

(7) Supply piping to main engine (piping on open deck, piping below deck).

(8) Drain system – purge return piping (general action suggested: consider separate safety relief line with no obstacles (e.g. non-return valves, etc.).

(9) Ventilation system (dry air supply, valves, starting air system valves, ventilation fan, outer pipe, flow switches and gas detectors

(10) Nitrogen system (N_2 generation, N_2 line, manual shutoff valves).

(11) External influences (fire, collision or grounding, mechanical damage, blackout, opening of methanol fuel system for inspection/maintenance, loss of control air).

In general, for a safety analysis different operation conditions should be examined, to identify possible system weaknesses. For this analysis it was assumed during the HAZID study that all critical failures according to methanol leakage might occur during normal operation. There are two methanol fuel mode stop operations such as stop gas operation and stop for complete shutdown of liquid gas system.

It is assumed that during the start-up, shutdown procedure of these two operations or emergency shutdown (ESD), the risk for a leakage is equal or lower to the risk during normal operation. Only normal operation has therefore been considered during this HAZID study.

4. Findings and Results

The identified hazards and failures have been summarized in **Table 2**.

Figure 4 classified and ranked main hazards and causes. Total 27 hazards have been identified on the subsystems of the methanol fuel system which ranked with respect to design (18), operation (5), materials/ equipment (2), impact and dropped objects (2).

The HAZID was carried out in two steps: first with the system as designed (initial rating) and in a second revised step taking the given recommendations under consideration to mitigate and reduce the HAZID and risk.

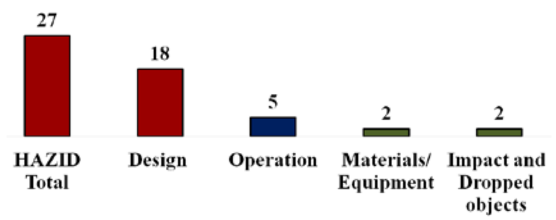

Figure 4: Classifying and ranking main hazards and causes

Table 2: Methanol carrier hazard identification (HAZID)

ID	Hazard	Cause	Consequence	Safeguards
1	Loss of control air	Mechanical damage	Loss of valve control	1.All remote operated valves go to "fail to safe" state 2.Flow switches and pressure sensors with alarms and automatic shutdown control air provided.
2	Corrosion of Methanol fuel system	N/A	Corrosion is prevented by current control measures	All components exposed to methanol are of proper steel grade (stainless steel)
3	Improper/not acting to procedures for opening of methanol fuel system for inspection/ maintenance	Human error	Intoxication to personnel	1.PPE (personnel protective equipment) 2.Operational manuals covering all methanol sub-system
4	Blackout	1.Human error 2.Mechanical failure	"UPS for remote valve system" (UPS) will ensure power supply to all critical systems. If UPS fails, valves will go to "fail to safe" position.	1.UPS for remote valve system 2.Valves goes to "fail to safe" position 3.Trapped methanol will be ventilated by bleed valves 4.Backup supply of nitrogen and control air in buffer tank and reservoirs of adequate capacity
5	Mechanical damage and impact damage (such as dropped objects, etc.) to the methanol fuel system in the engine room	1.Human error 2.Mechanical failure	1.Liquid release 2.Flammable gas dispersion with possible subsequent effects; flash fire, pool fire, jet fire, explosion. Cryogenic effects; brittle fracture of normal ship steel 3.Impact damage will be prevented by current control measures	1.Procedures ensuring that no methanol is in the system while doing heavy lifting operation in the ER 2.Methanol pipes located under deck where possible 3.Double wall piping 4.Tanks are placed in areas where they are not exposed to falling objects from crane
6	Mechanical damage and impact damage to the service tank	1.Navigational error 2.Human error 3.Mechanical failure	1.Liquid release 2.Flammable gas dispersion with possible subsequent effects; flash fire, pool fire, jet fire, explosion. Cryogenic effects; brittle fracture of normal ship steel 3.Impact damage will be prevented by current control measures	Service tank is located far away from any crane operations

7	Collision or grounding affecting methanol fuel system	1.Navigational error 2.Human error 3.Mechanical failure	Fuel system and storage tanks are protected by current control measures	1.Methanol fuel supply room is safeguarded by 2960 mm from ship side 2.Methanol service tank is protected by the methanol fuel supply room, closer to mid- ship 3.All piping is located close to the centreline, in accordance to rules and regulations (e.g. more than 760 mm from the ship side) 4.Methanol storage tanks are protected by double side and double bottom in accordance with the IGC and IGF codes. 5.In the possible event of a leakage methanol is dilutable in water
8	Fire affecting the methanol fuel system in the engine room	1.In tank explosion of cargo tanks 2.Fire in the methanol fuel supply room 3.Ignition of spills on deck 4.Fire in accommodation block	Heat ingress to methanol fuel system and possible ignition, or pressure build-up and rupture. Pressure increase prevented by the control measures.	1.Inherently gas safe engine room 2.engine room separated from cargo area by cofferdam and conventional fuel tanks 3.A60 Fire insulation towards accommodation 4.Engine room fire detection and firefighting system 5.Water spray system 6.Deck foam system 7.Inerting of cargo tanks and service tank 8.Pressure alarm on service tank 9.The methanol fuel supply room is elevated over deck 10.Safety relief valves in the fuel supply system 11.Fire detection in the ER and automatic shutdown with purging and draining
9	Fire affecting the methanol fuel supply room	1.Cargo tank explosion 2.Fire in the methanol fuel supply room 3.Ignition of spills on deck 4.Fire in accommodation block	Heat ingress to methanol fuel system and possible ignition, or pressure build-up and rupture. Pressure increase prevented by the control measures.	1.Water spray system 2.Deck foam system 3.Inerting of cargo tanks and service tank 4.Pressure alarm in system 5.The methanol fuel supply room is elevated over deck 6.Safety relief valves in the fuel supply system 7.Fire detection in the methanol fuel supply room and automatic shutdown 8.Location of tank in Hazardous zone 1 (EX zone)

10	Fire: Fire affecting the service tank	1.Cargo tank explosion 2.Fire in the methanol fuel supply room 3.Ignition of spills on deck 4.Fire in accommodation block	1.Heat ingress to tank and possible evaporation of methanol. 2.Pressure increase prevented by PV valve and pressure alarm.	1.Water spray system 2.Deck foam system 3.Inerting of cargo tanks and service tank 4.PV valve on service tank 5.Pressure alarm on service tank 6.Fire detection in the methanol fuel supply room Location of tank in Hazardous zone 1 (EX zone) 7.Consider the location of the controls for the sprinkler system and the foam system 8.Consider fitting redundant PV valves
11	Blockage: 1.Manual shutoff valves for Integrity Control of purging sequence 2.Safety relief valves Fail to open	1. Human error 2.Mechanical failure	1. - Loss of nitrogen supply 2. - Blockage of the safety relief line	1.Pressure transmitters, with alarm and automatic shutdown 2. 2.1.Pressure transmitter, with high pressure alarm and automatic shutdown 2.2.Pressure transmitter, with high pressure alarm and automatic shutdown 2.3.Level switch, if liquid is detected drain pumps will start automatically The other safety valve will act as backup safety valve 2.4.Pressure regulating valve will function as pressure relief
12	N2 Leakage: 1.Transfer of nitrogen (N2 Pipe) 2. leakage from nitrogen line to enclosed space (during maintenance)	1.Wear and tear 2.Mechanical failure 3.Human error	Suffocation will prevented by current control measures	1. 1.1.Ventilation in ER and methanol fuel supply room 1.2.Oxygen meter in nitrogen room 2. 2.1.Double block and bleed segregation 2.2.Non-return valve 2.3.PPE 2.4.Procedures
13	N2 Generator: Loss of nitrogen supply	Malfunction of the nitrogen generator	Supply provided by redundant design	1.Redundant design 2.Buffer tank 3.Location of the service tank in cargo area
14	Loss of detection	1.Mechanical failure 2.Wear and tear	No effect, due to redundant design	1.Redundant design 2.Automatic shutdown

15	Ventilations:- 1.Ventilation blocked for outer pipe 2.Malfunction of ventilation fan for outer pipe (Dilution of methanol vapour in outer piping Leakage detection Create under- pressure in the outer pipe)	1. -Large leakage from the inner pipe 2. 2.1.Mechanical failure 2.2.Loss of power	1.No dilution of possible leakage 2.Lack of gas detection 3.No under- pressure	1. 1.1.Flow switches and triggering automatic shutdown 1.2.Integrity of inner piping 1.3.Pressure testing of outer piping according to procedures 1.4.Liquid leakage detection will initiate shutdown, purging and drain of inner pipe manual drainage 2. 2.1.Feedback signal on fan motor triggering automatic shutdown 2.2.Flow switches and triggering automatic shutdown 2.3.Integrity of inner piping 2.4.Pressure testing of outer piping according to procedures
16	Leakage: 1.Leakage from inner piping to outer piping (below deck) (Transfer of methanol to/from main engine) 2.External leakage in the outer pipe (Transfer of ventilation air) 3.Leakage Transfer of methanol to/from main engine Piping on Deck 4.leakage from nitrogen system to fuel system (Segregation between fuel and nitrogen)	1.and 2. Fatigue Vibration Corrosion 3. 3.1.Dropped object 3.2.Impact 4. 4.1.Wear and tear 4.2.Mechanical failure	1. 1.1.Gas and/or liquid leakage detection triggering automatic shutdown and switch to fuel oil mode 2. 2.1.Loss of secondary barrier 2.2.Reduced ventilation rate 2.3.Likelihood of gas detection reduced 3. 3.1.Leakage of methanol on deck 4. 4.1.Engine will stop 4.2.Loss of fuel supply, causing alarm and shutdown as well as automatic switching to fuel oil mode	1. 1.1.Gas detectors 1.2.Liquid detectors 1.3.Outer piping 1.4.Mechanical extraction ventilation with 30 air changes per hour 1.5.Automatic switching to fuel oil mode possible 1.6.Automatic pressure test before start-up 1.7.Possibility of manual draining of the outer pipe, including procedure 2. 2.1.Flow switch 2.2.Liquid leakage detectors 2.3.Switch to fuel oil mode 2.4.possible Manual Moderate effect 3. 3.1.All welded piping 3.2.Stainless steel material 3.3.Visual detection 3.4.Pressure indicators 3.5.Automatic pressure test before start-up 4. 4.1.Double block and bleed valve arrangement 4.2.Double block and bleed valves in nitrogen supply line 4.3.Fail to safe design Alarm and automatic switching to fuel oil mode

17	Transfer of Methanol 1.Trapped liquid in case of shut-down Pipe connecting service tank to methanol fuel supply 2.Trapped liquid in case of shut-down Pipe connecting service tank to methanol fuel supply room	1.Shut down 2.Loss of instrument air supply	1.Exposure to personnel during maintenance safeguarded by current control measures 2.Possibility of overpressure in case of external heating	1. 1.1.Slope in pipe towards the methanol fuel supply room 1.2.Maintenance procedures 1.3.PPE 2. 2.1.Deluge system
18	Over- filling Containment of methanol Service Tank	1.High delivery rate of submerged methanol transfer pump 2.Human error 3.Improper operations 4.Wrong position of the swing bends	Tank overfilling will be prevented by the current control measures (overfilling could only occur in case of breaching multiple safety barriers)	1.First barrier: monitoring of service tank level and filling progress 2.Second barrier: high level alarm, high-high level alarm with automatic closing of valve 3.Third barrier: PV valve with pressure alarm back-up 4.Filling procedures for Manned control station during transfer
19	Intoxication when opening filters for inspection/maintenance	1.Wear and tear 2.Blocking of filter	Exposure to methanol would be safeguarded by existing control measures	1.PPE 2.Procedures for opening the filters Recommendation: 3.Ensure that drainage of filters are possible before opening
20	Loss of power supply to valve control system during fuel transfer to deck tanks	Various	Pressure build-up in isolated liquid lines and potential for line rupture	1.24 V DC battery system (control system should not be affected by black-out). 2.Pressure relief valves in isolated pipe sections
21	Any undesired incidents related to operation of the Methanol fuelled vessel	Lack of experienced and trained personnel on board the vessel for operating Methanol specific equipment	1.Increased probability for undesired incidents related to operation of the Methanol vessel 2.Lack of personnel that are trained to put out Methanol Fire	IGF Code on training of personnel Consider structured training to handle systems
22	Loss of Maneuverability	Loss of power for propulsion and power generation due to failure in gas fuel system	1.Grounding 2.Collision	Automatic changeover to liquid fuel for main engine without disrupting power
23	Sensor failure	Component malfunction	1.Incorrect pressure reading 2.Overfilling	1.At least two independent tank level gauges (95% High Alarm and 98% High High Alarm will automatically close the fuel transfer valve) 2.Redundant gas detection 3.Arrangements for testing pressure transmitters 4.Engine and engine control systems are complied with Regulations

24	Fire and Explosion	low flash point fuel	Risk to crews	safety control barriers, monitoring and control systems (such as overfill alarms, automatic shutdown, monitoring of ventilation and gas detection) to minimize risks to crews
25	self-ignition	cetane number of less than five	Poor Engine combustion	pilot fuel or ignition enhancer is needed
26	Health and environmental impact	Various due to failure and release	Exposure to personnel, Uptake of methanol is possible through ingestion, but also through the skin and by inhalation. Human beings, in contrast to most other species, have a very limited ability to degrade methanol into carbon dioxide. The enzymatic degradation occurring in the liver will instead result in an increasing level of formic acid, causing intoxication.	The health hazards of methanol have been well known for a long time, as is treatment to prevent intoxication after exposure.
27	Combustion chamber material failure	corrosion property of methanol	mechanical failure and engine shut down	quite a corrosive environment and the combustion chamber is designed to cope with this

5. Recommendations

Total 15 recommendations with comprehensive summary in terms of design and operation proposed and made covering a wide range of design and operation topics with the division in high prioritization for follow-up. Several important gaps beyond mandatory regulations, standards, guidelines or of relevant organizations have been identified requiring for action under the recommendations below:

5.1 The following design recommendations should be considered for the safe operation of methanol fuelled ship based on HAZID findings and results:

5.1.1 Materials choices and selections

Regarding ship board installations for fuel storage and transfer, considerations need to be given to material choices due to higher corrosion potential of methanol as compared to conventional fuels, methanol has an energy density that is approximately half that of conventional fuels. This requires larger storage volumes or more frequent bunkering, and could be a barrier for some ship applications. Methanol is highly corrosive, a factor that needs to be considered in design and maintenance of methanol fuelled vessels. But as far as the combustion chamber is concerned, no changes to corrosive levels considering quite a corrosive environment and the combustion chamber is designed to cope with this **[22][23]**.

5.1.2 Methanol cetane number

With a cetane number of less than five **[22]**, methanol has little potential for self-ignition, so a pilot fuel or ignition enhancer is needed, and with a vapour pressure of less than one atmosphere at 60°C, it also requires considerable injection pressure of 550 - 600 bar. The solution is an adapted booster fuel injection valve and slide injectors, which have separately been used on engines **[5]**.

5.1.3 Over- filling containment of methanol service tank

The design of valve to be considered to account for hammering in case of emergency closing, evaluate closing time of valve, evaluate capacity limitations of the transfer pump (into two different modes) and also consider orifice on the filling line to limit the filling rate to the service tank.

5.1.4 Safety relief valves fail to open

Considering pressure transmitter with high pressure alarm and automatic shutdown, level switch if liquid is detected drain pumps will start automatically. The other safety valve will act as backup safety valve, pressure regulating valve will function as pressure relief, consider separate safety relief line with no "obstacles" (e.g. non- return valves, etc.), also to be considered for drain return piping from engine room.

5.1.5 Avoiding blackout when automatic emergency shutdown is activated.

A fuel leakage with required automatic emergency shutdown functions should not take out the whole propulsion and power generation system, thus causing blackout. For system configurations with inherently safe machinery spaces, there are two situations where automatic shutdown of fuel supply to engine room is required according to the international requirements for gas supply system safety functions. also, automatic emergency shutdown should only be given if there is gas detection in two detectors. Gas detection in one detector should give alarm. Consider a separate UPS for the critical valves which allows for purging of the methanol fuel system Intermediate states with some UPSs offline to be used.

5.1.6 Minor modifications are needed to current infrastructure

As a liquid fuel, only minor modifications are needed to current infrastructure to enable methanol marine fueling in major port facilities. This makes methanol a cost effective alternative marine fuel in terms of storage and fueling infrastructure costs.

Unlike some alternative fuels, methanol can be made available through existing global terminal infrastructure. For example, existing gasoline storage tanks can be cleaned and used to store methanol.

There are three main ways to supply methanol fuel to ships: pipeline, truck and barge. As a liquid fuel, pipeline and trucks can be easily converted for methanol to supply by barge, that minor modifications are required such as nitrogen blanketing, SOLAS compliant pressure relief systems and flame arrestors.

5.1.7 Methanol low flash point fuel

Safety and handling of methanol changing fuels poses new challenges to operators in terms of handling and safety. Methanol is a low flashpoint fuel, meaning that it can vaporize and mix with air to form a flammable mixture at a relatively low temperature, a fact that has to be addressed in the safety assessment. Having a low flashpoint is a characteristic that methanol shares with LNG. However, unlike LNG, methanol is a liquid at ambient temperature and pressure, meaning that it can be stored in ordinary tanks with few modifications. With regards to storage and handling, methanol shares many characteristics with HFO. There is ample experience in handling and transporting methanol as a chemical, both in tank trucks and bulk vessels. In terms of handling, the main difference compared with diesel fuel is that methanol is a low-flashpoint fuel. The technology for handling low-flashpoint chemicals is well developed. Since methanol is a low flash point fuel, it’s necessary to introduce safety control barriers, monitoring and control systems to minimize risks to crews. From a technical perspective, these safety features are very achievable, both for new build and retrofit systems. All methanol components are double walled and monitored for leakages.

From the regulatory point of view, number of regulations and guidelines have been issued to manage and mitigate the risk of fire and enable the safe transport of large volumes of methanol by land and sea. Guidelines and international regulations in the IGC code provide for the safe transport of low-flashpoint liquids such as methanol. The IBC code for ships carrying chemicals in bulk also applies however earlier regulations cover the handling of methanol as a cargo on board ships. The IGF code addresses the use of methanol as a fuel. Specifically regarding low flashpoint fuels, there are the IMO Res MSC.285(86) Interim guidelines on safety for natural gas fueled engine installations in ships, the IGF code. Within the IGF code, a draft code on safety for ships using low-flashpoint fuels is in preparation. A related safety issue is that methanol’s explosion range is quite wide, at 6.7% to 35% proportion of air to methanol, methane’s explosion range is narrower at 5.0% to 15%. More stringent requirements on the safety routines and technology are therefore needed for bunkering and delivery. The rules that can be applied today are risk-based, meaning that there is need for a risk assessment for each installation.

5.1.8 Hazardous zone on ventilation location of methanol double pipe locations of double pipe ventilation air inlet and exhaust to be in safe position. In addition, the locations of vent mast to be especially considered to prevent ignition from funnel and ingress into any air inlet. Ensuring also vent piping are routed in a way that external leakage do not result in hazardous situation.

5.1.9 High pressure components

High pressure components in the gas injection and system are to be designed in accordance to international standards.

5.1.10 Blockage of safety relief valves

Considering manual shutoff valves for integrity control of purging sequence, safety relief valves fail to open, also separate safety relief line with no obstacles.

5.1.11 Escape and evacuations routes

The main potential for risk reduction is the potential for personnel to escape. Key aspects of that include, ensuring that detection of release is communicated to personnel onboard effectively, and in terms of minimizing risks to personnel, and from delayed ignition events in particular, the most effective mitigation is to escape to a place of safety, which is either to accommodation or suitable shelter or to an area outside the flammable cloud envelope. The former is the most reliable, although the latter is likely to be practicable in most cases. Training is fundamental in escape, although measures such as temporary shelters or ensuring that accommodation can be used as required are recommended. Escape and evacuations routes and means are to be always available, at least two widely separated escape routes and two evacuations means.

5.2 The following operational recommendations should be considered for the safe operation of methanol fuelled ship based on HAZID findings and results:

5.2.1 Attention to dropped objects, restrict and prohibit overhead operation near methanol bunker station while bunkering and system.

It should be proposed to restrict/prohibit overhead operation near the bunkering station while bunkering and methanol system in order to avoid objects tipping over the side or unintentionally being dropped on the bunkering hose or above the pump room. There should be constant monitoring of the entire bunkering operation, and use of watchmen. Company procedures should also be established for special concerns regarding internal lifting activity in the pump room and protection of methanol equipment. The colour marking of all methanol piping in the engine room and cargo areas limit methanol fuel piping in the crane operation area.

5.2.2 Using checklist during bunkering **[24]**

Procedures/checklists should be established between ship owner and methanol supplier for safe bunkering operation. The bunker station should have restricted access during bunkering operation, i.e. safety zone to be established. Make sure that the responsibilities during bunkering process are clearly defined for all foreseen methanol bunkering configurations and locations. The bunkering procedures are the preferred instrument to document the responsibilities during methanol bunkering.

5.2.3 Entering hazardous areas such as pump room and fuel valve train room. Personal protective equipment shall be mandatory for entering the pump room. In addition, training of personnel to operate the system should be given.

5.2.4 Inspections and maintenance

One separate operational and maintenance manual for the methanol fuel system is to be developed.

6. Conclusions

This study has concluded the system’s ability to operate safely and reliable during different predefined scenarios and potential events that proof and support to ensure a safe and reliable methanol fuel system. The study and evaluation can also conclude that there is no HSE (health, safety and environment) showstopper for construction/ conversion of conventional oil fuelled to dual fuelled using methanol which HAZID can also be mitigated and eliminated with sufficient design, engineering and operational controls that meet the required standards. The study is performed to ensure comprehensive identification of hazards. The conditions of IMO MSC. /Circ.1455 on alternative design and equivalent have been met which is no showstopper was identified and the alternative and equivalency was found feasible and suitable for its expected application.

References

[1] H. Etemad and J. H. Choi, “The hazard identification (HAZID) of LNG-dual fuelled ship operating between Korean port/Busan and Iranian Port/Bandar Abbas,” Journal of the Korean Society of Marine Engineering, vol.41, no.5, pp. 473-488, 2017.

[2] P. Biedermann, T. Grube, and B. Höhlein, Methanol as an Energy Carrier, Energy Technology, vol. 55, 2006.

[3] MARPOL, International Convention for the Prevention of Pollution from Ships, 2016.

[4] S. Brynolf, E. Fridell, and K. Andersson, “Environmental assessment of marine fuels: Liquefied natural gas, Liquefied biogas, methanol and bio-methanol,” Journal of Cleaner Production, vol. 74, pp. 86-95,2014.

[5] MAN, Retrofit to ME-LGI. Copenhagen: MAN Diesel & Turbo, 2015.

[6] MAN 201, Using Methanol Fuel in the MAN B&W ME-LGI series, Copenhagen: MAN Diesel & Turbo, 2015.

[7] J. Bøgild Hansen, “Methanol production technology: Today´S and future renewable solutions,” Methanol Workshop, Lund University, 2015.

[8] A. Posti and J. Häkkinen, Survey of Transportation of Liquid Bulk Chemicals in the Baltic Sea, Turku, Finland, Publications from the Centre for Maritime Studies University of Turku, 2012.

[9] International Maritime Organization, “Guidelines for Measures to Prevent Fires in Engine Rooms and Cargo Pump Rooms,” MSC.1/Circ.1321, London, June 2012.

[10] International Maritime Organization, “Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments,” MSC.1/Circ.1455, London, June 2013.

[11] K. Andersson and H. Winnes, “Environmental trade-offs in nitrogen oxide removal from ship engine exhausts,” Proceedings of the Institution of Mechanical Engineers Part M, Journal of Engineering for the Maritime Environment, vol. 225, no. 1, pp. 33-42, 2011.

[12] S. Bengtsson, E. Fridell, and K. Andersson, “Environmental assessment of two pathways towards the use of biofuels in shipping,” Energy Policy, vol. 44, pp. 451-463, 2012.

[13] IGF Code, International Code for the Construction of Gas Fuelled Ships, 2017.

[14] The IMO publication, “Interim guidelines on safety for natural gas fuelled engine installations in ships,” IMO Resolution MSC 285 (86), 2009.

[15] International Maritime organisation (IMO)-SOLAS, “The international convention for the safety of life at sea,” 2016.

[16] BSI, Explosive Atmospheres Gas Detectors – Selection Installation, Use and Maintenance of Detectors for Flammable Gases and Oxygen, BS EN 60079-Part 29-2, 2014.

[17] 2014/94/EU of the European Parliament and of the Council, “Directive on deployment of alternative fuels infrastructure,” October 22, 2014.

[18] IEC TC/SC 18, Electrical Installations in Ships: Tankers - Special Features: IEC, IEC 60092-502, 2009.

[19] IEC 60812,Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis, Second edition, 2016.

[20] NTS, Risk and Emergency Preparedness Analysis, Rev 2, NORSOK Standard Z-013, 2001.

[21] ISO, “Risk mangaement – Risk assessment techniques,” IEC/ ISO 31010, ISO/TC 262, September 14, 2014.

[22] Methanol Institute, The Methanol Industry, http://www.methanol.org/Methanol-Basics/The-Methanol-Industry.aspx , Accessed May 10, 2015.

[23] P. Fagerlund, B. Ramne, Production of Methanol Sustainably and Related Engine Technology, PROMSUS Organisational Committee, Workshop Groups Summary, Gothenburg, 2014.

[24] STCW Code, “International convention on standards of training, certification and watch keeping for seafarers,” June 2016.