Winterthur Gas & Diesel

CONCEPT GUIDANCE for X-DF-A

Prod.								
Change History								
B	iav101	dst009	24.11.2023	CNAA004860	... Drawing update		-	-
A	mhu019	dst009	06.04.2023	CNAA003495	... Drawing update		4	3
-	iav101	dst009	16.12.2022	CNAA002981	new Document		-	-
Rev.	Creator	Approver	Approval Date	Change ID	Change Synopsis	Activity Code	E	C

Winterthur Gas & Diesel

CONCEPT GUIDANCE for X-DF-A

PC-Drawing

Dimension

Design Group 9729	Q-Code XXXXX	Standard WDS	
A4	Document ID **DTAA000514**	PC Page/s	1 / 33

Rev	Date	Made	Appr	Description
B	2023-11-24	IAV	DST	Ammonia fuel supply system – sketch updated Design requirements updated
A	2023-04-06	IAV	DST	Ammonia fuel supply system – sketch updated Design requirements updated

Revision	Reference	Description
Revision: B Date: 2023-11	2.2.1	Toxic area zones, definition reviewed
	3	Chapter updated
	3.1	Figure 3-1 updated
	3.1.5	Table 3-4 updated
	3.1.7	Section updated
	3.2	Table 3-8 updated
	3.4	Hot air supply system added
	4.1	Figure 4-1 added

Table of Contents

List of Figures

List of Tables

0 Purpose of this document

The purpose of the Concept Guidance for the X-DF-A engine is to introduce the ammonia as a fuel for marine application with the related implication on the system design. This document covers a wide range of information such as the characteristics of ammonia as a fuel, the related risks of fire and explosion, as well as toxicity for humans and environment. The engine design criteria are under WinGD's responsibility, while the design requirements for the external supply system are mentioned for reference only and are not binding.

1 Characteristics of Ammonia as a Fuel

1.1 Introduction

Ammonia (NH_3) is a colourless, toxic gas at ambient temperature and pressure. It has a pungent smell and lower density compared to air. To be in liquid state, it needs either to be cooled down at -33°C at atmospheric pressure or pressurised to the corresponding saturation pressure at ambient temperature.

Ammonia has a carbon- and sulphur-free molecular composition. Burning of NH_3 creates minimal CO_2 and SO_X emissions due to pilot fuel requirements. Emissions of air pollutants related to carbon (black carbon or soot, unburnt hydrocarbons (HC), methane slip and carbon monoxide (CO)) are nearly eliminated. Therefore, it is an attractive fuel for marine applications towards lower carbon emissions as required by the International Marine Organization's (IMO) CO_2 and Greenhouse Gas (GHG) targets for 2030 and 2050. In addition, since ammonia is sulphur free, the sulphur content limits established by Regulation 14 of MARPOL Annex VI, are completely met when using ammonia as a fuel.

Generally, ammonia is produced via the Haber-Bosch synthesis process from hydrogen and nitrogen. While the nitrogen comes from air separation, different sources can be used to produce hydrogen. Based on the sources used to produce hydrogen, ammonia can be classified as "grey", "blue" and "green". Large-scale industrial productions of ammonia are based mainly on fossil fuel feedstock for "grey" and "blue" ammonia production which still produces CO_2 as residual product of the synthesis process. However, ammonia has the potential to become completely "green" when it is produced by using hydrogen obtained from using renewal energy sources (e.g. hydrogen is obtained by electrolysis of water, and the electricity used in the process is obtained by only renewable energy sources). A gradual decarbonisation is possible by increasing the amount of "green" ammonia production and use.

The WinGD X-DF-A is a dual-fuel engine which injects ammonia into the engine. For this engine, liquid injection is under development. This engine utilises the diesel combustion principle, ensuring emission optimised combustion.

The WinGD X-DF-A engines meet IMO Tier II NO_x emission levels in both ammonia mode and diesel mode. The engines also meet IMO Tier III NO_x levels in both modes through exhaust gas aftertreatment (e.g., Selective Catalytic Reduction (SCR)).

This document is based on the "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)" and "International Code of Safety for Ship Using Gases or Other Low-flash-point Fuels (IGF Code)" as well as on the available classification society rules at the time of the document release. This document is for application of X-DF-A engines on any vessel type, i.e. it is valid for both Ammonia carriers as well as Ammonia fuelled non-gas carriers.

1.2 Ammonia properties

The following Table 1-1 provides the required ammonia specifications at the engine inlet.

Table 1-1: Required ammonia specifications at the engine inlet

Characteristic	Unit	Limit	Ammonia	Test method reference
Purity (on a dry basis)	(% w/w)	Min.	99.5	-*
Water	(% w/w)	Range	0.2 – 0.5	ISO 7105
Oil	(% w/w)	Max.	0.4	ISO 7106
Oxygen	ppm	Max.	2.5	-*

(*) Suitable method to be applied and reported

The following values are only for guidance. Project-specific values must be considered.

Table 1-2: Comparison of energy properties for ammonia and marine gas oil

Characteristic	Unit	Ammonia	Marine gas oil
Flash point	°C	132	60
Density	kg/m³	680 *	850 (at 15°C)
Lower Heating Value (LHV) at ISO condition	MJ/kg	18.6	42.7
Relative volume per energy content	-	2.8 *	1
Boiling point at 1 bar	°C	-33	150 – 380
Explosive limit in air	%(vol)	14 – 27	1 – 6
Solubility: fuel in freshwater	%	32 **	NA

(*) storage condition -33°C and 1 bar(a)
(**) condition 25°C and 1 bar(a)

2 Safety Considerations

Using ammonia as a fuel adds some additional challenges during the design phase of the vessel, engines and related systems. Fuel containment, distribution and supply systems can be based on existing technologies, but still risk assessment must be performed to confirm that the risks from ammonia fuel affecting persons on board, environment and ship structural strength or integrity are addressed. The risk assessment must be carried out using acceptable and recognized risk analysis techniques, taking into consideration the IGF code and corresponding class rules for Ammonia.

In a liquid state, ammonia is not flammable and cannot ignite. However, it vaporizes rapidly. The main safety concern is its toxicity. For these reasons, during the design phase the following must be considered:

- segregation
- double barriers arrangements
- leakage detection
- automatic isolation of leakages.

2.1 Fire or explosion

Ammonia is a flammable gas with narrow flammability range. Its flammable range in dry air is between 14% (vol) and 27% (vol). It has a flashpoint of 132°C and an auto ignition temperature of 651°C. Therefore, the risk of fire caused by ammonia is lower compared to other fuels due to its higher Lower Explosion Limit (LEL). However, when ammonia is stored in a liquid phase under pressure, the Boiling Liquid-Expanding Vapours Explosions (BLEVEs) are a hazard often associated with ammonia. BLEVE can occur when ammonia is stored in a pressurised tank above its boiling point. The liquid can begin to boil and expand if the tank fails and is exposed to ambient pressure. This can result in tank explosions.

2.1.1 Fire prevention

Ammonia fire and explosion prevention is achieved by ***reducing potential ignition sources to a minimum, controlling the storage conditions of ammonia, using certified safe type electrical equipment*** suitable for hazardous zones.

Reduction of potential ignition sources to a minimum
Ammonia burns with difficulty in open air and generally needs a supporting flame to keep burning. Even if risk of ammonia fire is lower compared to other fuels, it can still occur in case particular conditions are met. In addition to pure ammonia fires, the fire risks of ammonia are higher when ammonia is mixed with other fuels and lubricating oils because of increased flammable properties of ammonia. Such fuel mixtures can have a much broader explosive range. Ammonia fires and explosions can be prevented by reduction of potential ignition source to a minimum where ammonia can be present.

Control of ammonia storage conditions
Ammonia can react with halogens, interhalogens and oxidizers and can cause violent reactions or explosions. Therefore, ammonia should be stored in temperature-controlled tank(s), well-ventilated location, and separate from oxidizing gases and acids. Dilution can be utilized in order not to reach ammonia flammability range.

Certified safe type electrical equipment
Electrical equipment cannot be installed in hazardous areas, unless it is essential for operational purposes. To facilitate the selection and design of appropriate electrical equipment and installations, hazardous containment areas are classified into zones 0, 1 and 2 based on the associated risk of explosion. All hazardous areas must always be inaccessible to passengers and unauthorised crew.

According to the IGF code (Part A-1, 12.5), the hazardous area zones are classified as following:

Hazardous area zone 0 includes, but is not limited to, the following areas:
- interiors of ammonia tanks
- pipework for pressure relief or other venting systems for fuel tanks
- pipes and equipment containing ammonia.

Hazardous area zone 1 includes the following areas:
- tank connection space
- fuel preparation rooms
- fuel storage hold space and inter-barrier spaces
- cofferdams
- enclosed or semi-enclosed spaces where ammonia leakages can occur.

Hazardous area zone 2 includes, but is not limited to, the following areas:
- areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1
- space containing bolted hatch to tank connection space.

2.1.2 Fire detection

Standard fire detection devices can be applied for ammonia fuelled installations.

2.1.3 Fire control

The United States National Centre for Biotechnology Information (NCBI) recommends dry chemicals or CO_2 for fire extinguishment in case of small fires, and water spray, fog or foam fire extinguishment systems in case of large ammonia fires. It is important to carefully handle the contaminated waters to prevent environmental effects.

2.1.4 Ammonia detection

The four most common types of fixed sensors used to detect ammonia vapour are reported below.

<u>Infrared sensors</u>
Infrared sensors measure gas as a function of the absorbance of infrared light. Ammonia has a usable absorbance peak at a wavelength of about 1.53 μm. Absorbance at this wavelength is proportional to the concentration of ammonia present in the sensing chamber of the sensor. The benefit of infrared technology for ammonia detection is long-term sensor stability, resulting in a limited requirement for calibration. Infrared detectors have a wide dynamic range and are not degraded or consumed by exposure to high concentrations of ammonia. The limitations are the physical size of the detector, need to protect the detector against potential effects of fluctuating temperature and humidity, and higher cost compared to other detector types.

<u>Chemosorption sensors</u>
Chemosorption sensors consist of a metal oxide semiconductor on a sintered alumina ceramic support contained within a flame arrestor. In clean air the electrical conductivity is low. Oxidation of the measured gas on the sensing element increases its conductivity. An electrical circuit is used to convert the change in conductivity to an output signal which corresponds to the gas concentration. The benefits of chemosorption sensors are their long operational life and low cost. However, since the sensors are not specifically designed to ammonia, false alarms can be triggered by interfering contaminants.

<u>Electrochemical (EC) sensors</u>
The gas detection technique is very straightforward in concept. Gas that enters the sensor undergoes an electrochemical reaction that causes a change in the electrical output of the sensor. The difference in the electrical output is proportional to the amount of gas present. EC sensors are designed to minimise the effects of interfering contaminants, making the readings as specific as possible for the gas being measured. The positive benefits for this type of sensor are the specificity to ammonia, low cross sensitivity to other interfering contaminants, the low ppm range resolution as well as the cold temperature performance down to −40° C. The limit is that the lifetime of this type of sensors is based on the "ppm" exposure. Once the "ppm hour" exposure life of the sensor is exceeded, it is no longer capable of detecting gas and needs to be replaced. Therefore, this type of sensor is recommended to be used where the ambient background concentration of ammonia is sufficiently low to allow a reasonable operational life of the device.

<u>Charge carrier injection (CI) sensors</u>
CI sensors depend on the adsorption of ammonia by "charge carrier" molecules in a solid-state substrate. By absorbing ammonia, the charge carriers are "injected" into the sensor element, causing a change in resistance that is proportional to the concentration of ammonia present. The substrate materials are selected to maximise the sensor sensitivity to ammonia while minimising the effects of interfering contaminants. The benefits of CI sensors are wide detection range, stability and long lifetime. CI sensors are not affected by humidity and severe temperature.

2.2 Impact on health

Ammonia is toxic to humans. The odour threshold for ammonia is very low, from 5 ppm concentration it can be detected by most people, and this does not constitute a health risk.

Based on Acute Exposure Guideline Levels (AEGL) for airborne chemicals defined by the US Environmental Protection Agency (EPA), the limits to ammonia exposure can be identified, as shown in the Table 2-1:

Table 2-1: EPA Acute Exposure Guideline Levels (Source: EPA, 2016)

Guideline	10 minutes	30 minutes	1 hour	4 hours	8 hours
AEGL-1	30 ppm	30 ppm	30 ppm	30 ppm	30 ppm
AEGL-2	220 ppm	220 ppm	160 ppm	110 ppm	110 ppm
AEGL-3	2,700 ppm	1,600 ppm	1,100 ppm	550 ppm	390 ppm

AEGL 1: Notable discomfort, irritation or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape
AEGL 3: Life-threatening health effects or death

Toxic exposure can occur by inhalation (breathing in vapour), dermal or eye contact with ammonia vapour or liquid.

Table 2-2: Exposure guidance (Source: Karabeyoglu A, Brian E., 2012)

Effect	Ammonia concentration in air (by volume)
Readily detectable odour	20 – 50 ppm
No impairment of health for prolonged exposure	50 – 100 ppm
Severe irritation of eyes, ears, nose and throat. No lasting effect on short exposure	400 – 700 ppm
Dangerous, less than ½ hours exposure can be fatal	2000 – 3000 ppm
Serious oedema, strangulation, asphyxia, rapidly fatal	5000 –10000 ppm

Because of its toxicity, the direct release of ammonia to open air must be limited to the lowest practicable level. Direct venting of ammonia to the atmosphere is not permitted in normal condition. Venting of ammonia for control of pressure in the storage tanks is not permitted. It is only allowed in case of failure conditions.

NOTE	For this guideline, Ammonia Permissible exposure limit (PEL) means a concentration 30 ppm ammonia vapours in air, corresponding to the Acute Exposure Guideline Level 1 (AEGL-1) given by US-EPA (see Table 2-1).

2.2.1 Toxic area zones

The conducted analysis demonstrates that the main safety concern in relation to ammonia is associated with its toxicity and gas-dispersion properties. Toxicity adds complexity to the ship design, and toxic areas must be defined.

In addition to hazardous areas classification, toxic areas must be classified to identify areas or spaces in which a toxic atmosphere is present or can be expected to be present. Therefore, appropriate safeguards must be implemented and access to such areas must be restricted.

Toxic areas must be classified into different zones based upon the frequency of the occurrence and duration of a toxic atmosphere, as follows:

- Zone A: an area in which toxic atmosphere is present continuously or for long periods or frequently

- Zone B: an area in which toxic atmosphere is not likely to occur during normal operation but, if it does occur, will persist for a short period only.

2.2.2 Ammonia detection against toxicity

The same ammonia detector types, as mentioned in section 2.1.4, can be applied for toxicity detection but calibrated according to the ammonia concentration within the PEL range.

For further information about the ammonia leakage detectors against toxicity, please see WinGD 2-Stroke Dual-Fuel Ammonia Safety Concept.

2.2.3 Inhalation

Ammonia can be very toxic, and inhalation can cause severe symptoms according to the exposure time and concentrations, as defined in Table 2-1 In case of inhalation of ammonia vapours, the individual must be moved to an area with fresh air. Supplemental oxygen with assisted ventilation can be also required. Symptoms can develop hours after exposure and are made worse by physical effort. Severe short-term exposure can cause long-term damage.

2.2.4 Ingestion

Not a relevant route of exposure because at ambient temperature and pressure ammonia is in gaseous state.

2.2.5 Skin contact

In case of contact with skin, it is recommended to immediately use an emergency shower and flush the exposed area with ample amounts of lukewarm water for at least 15 minutes. Note that ammonia can freeze the exposed clothing and the skin below it and this can result in extensive skin damage. Contaminated clothing and shoes must be removed and washed before reuse. Medical attention is required.

2.2.6 Eye contact

In case of contact with eyes, the gas irritates or burns the eyes. Permanent damage including blindness can result. It is recommended to immediately flush the eyes with ample amounts of lukewarm water for at least 20 minutes. Medical attention is required.

2.3 Environmental impact

Ammonia is classified as toxic to aquatic life with long lasting effects. The permissible discharge limit is defined as the maximum concentration of ammonia in the effluents. This limit depends on the international or local regulation limits. Normally, effluents containing liquid or dissolved ammonia are not to be discharged overboard.

2.4 Material compatibility

Ammonia is corrosive to a wide variety of metals, such as copper, zinc or copper-based alloys. Steel, stainless steel and some non-ferrous metals, such as aluminium- or nickel-based alloys, are compatible with ammonia. However, carbon steels are known to be prone to stress corrosion cracking. The susceptibility of carbon steels stress corrosion cracking increases with higher strength steels, particularly in situations with high residual or applied stresses. The risk of stress corrosion cracking can be mitigated by using minor amounts water in ammonia of approximately 0.2%.

Polymers used, e.g. in sealings, exhibit a varying degree of compatibility with ammonia.

In general, materials selection must also be compliant with the IGC and IGF codes as well as the available classification society requirements.

For further information on material selection for the ammonia supply system, see Table 3-5.

2.5 Spill prevention and handling

For ammonia fuelled vessels, an exhaustive risk assessment must be performed to consider all the hazards associated with physical layout, operation, process and maintenance, with regard to any foreseeable failure. The analysis must ensure that risks are ALARP (As Low AS Reasonably Practicable). Risks which cannot be eliminated must be mitigated.

The risk assessment must consider the possible liquid and gaseous ammonia fuel leakages and spills and their related consequences during the ship operations (e.g. during bunkering). It is important to consider the following aspects:

- accumulation of ammonia vapours in spaces containing a potential source of ammonia release and their spreading over the ship's spaces through non-gastight openings
- spreading of ammonia vapours from the vent mast outlet on open decks and their possible recirculation to accommodation through openings and ventilation inlets
- formation of ammonia vapour cloud
- heat release in case of ammonia dissolution in water
- draining of the hold space in case of type A tank failure.

The risk assessment must cover at least the following aspects:

- design and arrangement of the bunkering station
- design and arrangement of the contaminated water holding tank
- materials of machinery, equipment and components
- protection of single walled piping outside of machinery spaces
- toxic area zones
- spaces, systems and equipment requiring gas detection
- gas detector locations
- emergency ventilation rates
- dispersion of emergency toxic releases to atmosphere
- control, alarm, and safety instruments for other essential equipment
- additional control, alarm and safety requirements, apart from the mentioned
- Engine Safety Concept.

The systems must be designed to detect leakages of gases and liquids from the fuel system and automatically isolate any leakages to limit the amount of ammonia release. For spillages handling, drip trays must be provided where leakages are expected (e.g. bunkering connection, flanges).

Each drip tray must be:

- made of suitable material to hold spills
- fitted with a drain valve to enable drain
- of sufficient size and capacity to handle reasonably foreseeable spills and to collect water from any water spry located above it.

Mechanical spray shielding must be arranged around potential leakage points from the ammonia system.

In addition to all design and operation preventive measures, suitable Personal Protective Equipment (PPE) must be available for all people working with ammonia to eliminate the residual risks.

The PPE must include, but not be limited to:

- large aprons
- special gloves with long sleeves
- suitable footwear
- coveralls of chemical-resistant material
- tight-fitting goggles or face shields.

The protective clothing and equipment must cover all skin so that no part of the body is unprotected. Respiratory and eye protection for evacuation purposes must be available for everyone onboard.

To entry and work in a gas-filled space, self-contained positive pressure air-breathing apparatus incorporating full face mask must be available.

3 Ammonia fuel system arrangement

3.1 System arrangement

The ammonia fuel system arrangement comprises the following:

- ammonia bunkering station and storage tank(s)
- ammonia Fuel Supply System (FSS)
- Fuel Valve Unit (FVU)
- ammonia piping system
- venting system
- inert gas supply system
- hot air supply system
- ammonia injectors cooling system, low-salinity water supply

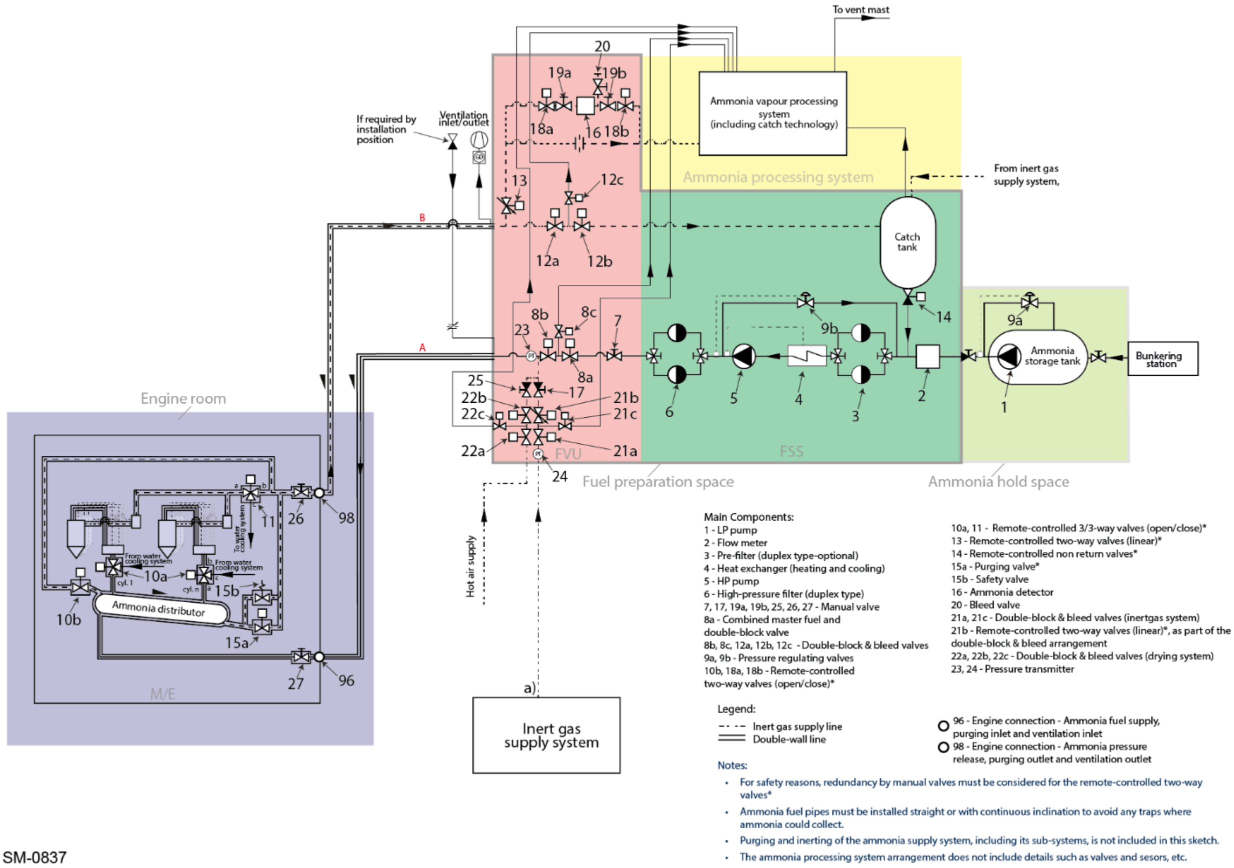

Figure 3-1: Proposal for the ammonia fuel system arrangement of an ammonia storage and supply system arrangement

3.1.1 Bunkering station

Ammonia is transferred on board the vessel through a bunkering station. The recommended location for this station is on the open deck because there is natural ventilation. Ammonia bunkering station must be of enclosed or semi-enclosed type and must be subject to special consideration within the risk assessment. It must be designed in such a way to minimise the vapour accumulation and to avoid the gas release to the atmosphere during bunkering operations. This station must be designed with two means of escape as widely separated as possible. One of them must open outwards and give direct access to the open deck. Where direct access to the open deck is not practicable, an airlock must be provided. Access doors or hatches to bunkering station must be gastight towards other enclosed spaces in the ship and adjacent open areas. The bunkering station must be provided with a ventilation of mechanical extraction type. In addition, it must be located at a certain distance from air intakes, accommodation openings and machinery spaces. The bunkering lines cannot be led through accommodations. In case of passage in enclosed spaces, a second barrier for the bunkering line must be considered (e.g. double-wall pipe or ducts). To prevent ammonia contamination, filters must be considered on the bunkering lines. All the bunker hoses on board must be suitable for ammonia. The bunkering manifold must be designed to withstand the external loads during bunkering. The connections at the bunkering station must be of dry-disconnect type. The couplings must be of standard type. A manually operated stop valve and a remotely operated shutdown valve must be arranged in series and as close as possible to the connection point. Otherwise, a combined manually operated and remote shutdown valve can be used. Remote control must be possible from the bunkering control station.

Table 3-1: Proposal of design parameters for the ammonia bunkering station

Parameter	Bunkering station
Shutdown valve closing time	Max. 5 secs. *

(*) This represents the recommended closing time from trigger of the alarm till full closure of the valve. Longer time based on pressure surge consideration can be acceptable. The closing time must also be sufficient to prevent overfilling of the storage tank when automatic shutdown is initiated by the tank high level alarm.

Ammonia leakages detection system must be provided in the bunkering station. A water mist system (water screen) must be provided on the outside of all the access doors to bunkering station. This must be manually operable from the outside of the compartment and automatically in the event of gas detection or emergency shutdown. Remote control of the pumps supplying water to the water mist system must be possible from a remote and safe location. Bunkering station must also be monitored by direct line of sight or Closed-Circuit Television (CCTV).

Bunkering lines must be arranged to be self-draining to the storage tank(s). Different arrangements can be selected in case the bunkering station is lower than the storage tank(s). The bunkering lines must be designed for inerting and gas freeing. In case two bunkering connections (e.g. one for each side of a ship) with a common bunkering line are available on board, a suitable segregation arrangement must be provided.

For safety purposes, drip trays must be provided below the bunkering connections to collect and direct any spillage to a dedicated drain tank.

3.1.2 Ammonia storage tank(s)

From the bunkering station ammonia is transferred to the ammonia storage tank(s).

Given that the Lower Heating Value (LHV) of ammonia is lower compared to MGO, larger quantities of ammonia are required compared to MGO for the same energy content. Ammonia requires about 2.8 times more storage tank volume than MGO.

Table 3-2: Design parameters for ammonia storage and service tanks

Description	Ammonia storage tank semi-cryogenic system	Ammonia storage tank pressurised system
Pressure [bar(a)]	1	20
Max. design temperature [°C]	-33	45

From storage tank and catch tank, liquid ammonia is delivered via the low-pressure supply side and the High-Pressure (HP) pump to the engine.

The following requirements must be considered for the ammonia storage tanks:

- Tanks must be protected against mechanical damages which can occur during ship's operation.
- Tanks must be protected against external damages which can occur in case of collision or grounding.
- Tanks connections must be located above the highest liquid level in the tank. Connection below the liquid level can be accepted for tank(s) of type C.
- Ammonia tank inlet and outlet valves must be provided. It is recommended to place these valves as close as possible to the tanks.
- Possible vacuum in the ammonia tank must be taken into account.
- Tanks must not be vented directly to the atmosphere during normal operation. Venting of fuel vapour for controlling the tank pressure is not allowed, except for emergency situations.
- Filling levels must be monitored.
- Ammonia storage tank(s) relief valve(s) must open only in case of overpressure resulting from fire in the vicinity of the tank.
- The Maximum Allowable Working Pressure (MAWP) of the fuel tank must not exceed 90% of the Maximum Allowable Relief Valve Setting (MARVS).
- Except for fully pressurised type C tank(s), ammonia tanks must be provided with a vapour return line. Alternative design to control pressure in the tank during bunkering can be considered.

Different types of storage tank(s) can be used for ammonia such as:

- independent (types A, B and C)
- integral (membrane type)
- portable (independent tank of type C)

Depending on the selected type, a secondary barrier can be required, as mentioned in the Table 3-3:

Table 3-3: Secondary barriers requirements for storage tank(s)

Description	Secondary barrier requirements
Membrane tank	Complete secondary barrier
Type A	Complete secondary barrier
Type B	Partial secondary barrier
Type C	No secondary barrier

Except for fully pressurised type C tank(s), the pressure and temperature in the storage tank(s) must always be kept within the design range by means of different methods. The following methods are recommended by the classification societies:

- liquified ammonia fuel cooling
- reliquefication of vapour
- thermal oxidation of vapour
- energy consumption by the ship (engine, gas turbines, boilers etc.)
- pressure accumulation
- dissolution of vapours in water.

For redundancy, except for fully pressurised type C tanks, always at least two methods must be selected. Independently of the selected method, the maximum tank pressure must always be maintained below the set pressure of the pressure relief valve for a period of 15–21 days (based on administration/classification society rules), assuming the tank is full.

3.1.2.1 Independent and integral tanks(s)

Independent tanks are self-supporting and not integrated in the ship structures. They can be classified as A, B and C type.

Integral tanks are part of the ship structure and stressed in the same manner and by the same loads as the adjacent hull structure.

The different types of independent and integral tanks are defined below:

Type A: Tanks at (or near) atmospheric pressure and refrigerated to temperature of -33°C (fully refrigerated tank). Design vapour pressure must be less than 0.7 bar(g).

Type B: Tanks designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Where such tanks are primarily constructed of plane surfaces (prismatic tanks), the design vapour pressure must be less than 0.7 bar(g).

Type C: Tanks under pressure at ambient temperature (fully pressurised tank) or tanks under pressure lower than the vapour pressure at ambient temperature (semi-pressurised tank).

Integral Tanks: Integral type tanks, such as a membrane tank, are built into the hull as part of the vessel structure. Integrated tanks are low-pressure tanks, designed for pressure less than 0.7 bar(g).

For type A tanks there are following additional requirements:
- The secondary barrier must be designed to contain possible ammonia leakages for a period of 15 days.
- In case the second barrier is provided by the ship hull, it must be built with suitable material to withstand -33°C.
- The ammonia hold space must be provided with drainage system for liquid ammonia handling in case of spillages or tank rupture.
- The ammonia hold space must be inerted with inert gas provided by inert gas system.

For type C tanks there are following additional requirements:

- The design pressure of a fully pressurised tank type C must not be less than the ammonia vapour pressure at the maximum ambient temperature expected in service. This temperature must be minimum 45 °C (for marine applications).
- Fuel storage hold spaces act as a secondary barrier if the tank is located below open desks and the fuel storage bulkheads are at least 900 mm away from the outer shell of the tank.

Furthermore, depending on the tanks position, additional requirements can follow. For instance, if the tank is located on open deck, the tank must be protected against mechanical damage and surrounded by coamings. Water spray system for emergency cooling must also be provided, as well as drip trays for spillage collection. If the tanks are located below open decks, tank connections, valves and flanges must be in a tank connection space (see section 3.1.3). The ammonia hold space must be separated from the machinery space of category A by a cofferdam of at least 900 mm.

3.1.2.2 Portable tank(s)

Portable tanks are independent tanks which can be easily loaded and unloaded from the vessel and connected and disconnected from the ship systems. Portable tanks must be certified by the classification society and comply with requirements for type C tanks.

Portable tanks must have an equivalent safety as permanent fuel tank. For portable tanks, following additional requirements must be considered:

- Tanks can be located either on the open decks or in ammonia hold space.
- Tanks must be secured to the ship structure.
- The influence of the portable tanks on the ship stability must be considered.
- Connections to the ship fuel piping systems must be made with approved flexible hoses suitable for ammonia.
- Pressure relief system of portable tanks must be connected to the venting system.
- Control and monitoring systems for portable tanks must be integrated in the ship control and monitoring system.
- Access to all tanks connection must be ensured for inspection purpose.

In addition, the portable tanks connected to the ship Fuel Supply System (FSS) must be designed so that they can be isolated at any time without affecting any of the other tanks.

NOTE	Portable tanks must be certified by the classification society and comply with the type C tanks requirements.

3.1.3 Ammonia hold space

The ammonia hold space is the area enclosed by the ship structure in which ammonia storage system is located.

This space acts as a full or partial second barrier and must be inerted with inert gas. Alternatively, in case it acts as a partial second barrier, the space can be filled with air. If this space surrounds type C tanks, it can be inerted with dry air. Access to fuel storage hold space must be arranged as a bolted hatch, unless this access is independent and direct to open decks. The ammonia storage hold space cannot be used for other purposes.

3.1.4 Tank connection space

All tank connections, fittings, flanges and tank valves must be enclosed in a gas tight space, unless the tank connections are on open deck. The space must be able to safely collect leakage from the tank connections.

The tank connection space must be separated from the machinery space of category A. Separation of this space from other high fire risk spaces must be considered. This space must be ventilated to open deck. Suitable material must be selected to withstand lowest temperature which can occur in case of a spillage. The space entrance must be designed according to the classification society rules. Water screen must be provided at the entrance.

NOTE	The above-mentioned requirements are not applicable for gas-carrier ships which follow the IGC code.

3.1.5 Ammonia piping

The ammonia piping must be designed to minimise risks associated to any possible leakage in the system. Therefore, the ammonia piping must be always enclosed in a gastight secondary barrier with exception for the following spaces:

- ammonia hold space (for all tanks type except C type)
- tank connections space
- fuel preparation space
- bunkering stations
- on open decks (for piping containing ammonia for short period)
- in case of full-welded vent piping (if passing through ventilated spaces).

In addition, the following requirements must be considered:

- Fuel piping systems must be designed in such a way that the systems can be emptied, purged and inerted.
- Ammonia pipes must be located at least 800 mm from the ship side.
- Ammonia pipes (especially on open decks and ro-ro spaces) must be protected against mechanical damages.
- Ammonia piping must not be directed through accommodation spaces, service spaces, as well as electrical equipment rooms.
- Fuel piping and vent lines must not be routed through the tanks.
- Any valve on the piping system, required to isolate ammonia supply system in case of leakages, must be remotely operated from safe locations.
- The piping must be designed to deal with possible icing of component due to low temperature in the ammonia storage tank. Low-temperature piping must be insulated from the adjacent structure.
- Fuel piping must be capable of absorbing thermal expansion or contraction caused by extreme temperature. Provision must be considered to protect piping from stress and fatigue.
- All the piping segments which must be isolated while fully filled with liquid ammonia must be equipped with a pressure relief valve. The vent line from these valves must be directed to the ammonia vapour processing system.

Depending on the ammonia state (liquid or gaseous) the following additional requirement must be considered:

- If the piping system is designed for liquid ammonia, design pressure above the vapour pressure of ammonia at 45 °C must be considered (18 bar(a)). It is done to prevent venting of ammonia.
- If the piping system is designed for gaseous ammonia, the fuel line must be sufficiently heated with heat trace.
- The piping system must include the piping for ammonia recovery system.

Table 3-4: Design parameters for the ammonia inner pipe of supply system (at the engine inlet)

Parameter	Ammonia supply system
Supply pressure [bar(g)]	85 +/- 2
Design pressure/setting for pressure relief valve [bar(g)]	110
Ammonia temperature [°C]	40 +/- 5
Pipe temperature [°C]	- 35 to 45
Max. surface roughness [µm]	20

Table 3-5: Material recommendation for ammonia supply system piping

Common name	Steel number	UNS no.	EN designation
304L	1.4306	S30403	X2CrNi19-11
316L	1.4404	S31603	X2CrNiMo17-12-2

The material is selected based on sufficient corrosion resistance, required strength, temperature fracture toughness, stress, as well as fatigue resistance. These recommendations are valid for inner and outer piping. The engine ammonia fuel piping system applies 316L quality.

For the design of single wall piping or the inner pipe of double-wall piping, the minimum wall thickness for steel pipes can be calculated using the following formula:

$$t = \frac{(t_0 + b + c)}{(1 - \frac{a}{100})}$$

Equation 3-1: Wall thickness calculation for steel pipes

where:

- $t[mm]$ represents minimum wall thickness for steel pipes at the deign pressure
- $t_0[mm]$ represents theoretical thickness for steel pipes at the deign pressure
- $b[mm]$ represents bending allowance
- $c[mm]$ represents corrosion allowance. This value is equal to 0 for ammonia piping.
- $a[\%]$ represents negative manufacturing tolerance for thickness. This value is equal to 12.5.

Theoretical thickness t_0 can be calculated using the following formula:

$$t_0 = \frac{(PD)}{(2Ke + P)}$$

Equation 3-2: Theoretical wall thickness calculation for steel pipes

where:

- $\mathrm{P}[MPa]$ represents maximum system design pressure defined in Table 3-4
- $D[mm]$ represents the outside pipe diameter
- $K[\frac{N}{mm^2}]$ represents allowable stress defined as the lower value between $\frac{R_m}{2.7}$ and $\frac{R_e}{1.8}$
- $R_m[\frac{N}{mm^2}]$ represents specified minimum tensile strength at ambient temperature
- $R_e[\frac{N}{mm^2}]$ represents specified minimum yield stress at ambient temperature
- e represents non-dimensional efficiency factor equal to 1.

Bending allowance b can be calculated using the following formula:

$$b = \frac{(Dt_0)}{(2.5r)}$$

Equation 3-3: Bending allowance

where:

- $\mathrm{r}[mm]$ represents the radius of the bend

3.1.6 Ammonia supply pumps

The ammonia storage and supply system include the following pumps:

- low-pressure (LP) ammonia supply pumps
- high-pressure (HP) ammonia supply pumps

LP pumps can be located adjacent to the ammonia storage tank or can be of submerged type. HP pumps must be located downstream the connection of the catch tank return line.

These pumps must be designed to ensure the ammonia is delivered at the engine inlet at 85 bar(g) with a tolerance +/- 2 bar. LP and HP ammonia supply pumps are controlled based on the signals from the Engine Control System (ECS).

All pumps in ammonia storage and supply system must be protected against dry running. Therefore, a flow switch is recommended at each pump outlet. In addition, if the pumps can develop pressure exceeding the system design pressure, the pumps must be provided with a pressure relief valve. This valve must relieve the pressure to the suction side of the pump.

3.1.7 Heat exchanger and filters

To ensure ammonia is supplied to the engine inlet at proper temperature, a heat exchanger is required. This heat exchanger can be located up- or downstream the HP pump. The location upstream the HP pump is recommended due to lower operating pressure. The temperature sensor must be placed downstream the HP pump to measure the resulting temperature including the pump heating effect.

Table 3-6: Design parameters for the heat exchanger

Parameter	Heat exchanger
Temperature range at the engine inlet [°C]	40 +/- 5
Low-temperature shutdown [°C]	25

When the system temperature is below the low-temperature shutdown value, ammonia supply to the engine must be stopped.

A filter of duplex type must be provided at LP side of the ammonia supply system. The filter must be provided with a differential pressure display and alarm signal.

Table 3-7: Design parameters for the ammonia duplex filter

Parameter	Ammonia filter
Design pressure [bar(g)]	110
Absolute sphere passing mesh size [μm]	10
Mesh material	Stainless steel/metal mesh

3.1.8 Fuel valve unit

The Fuel Valve Unit (FVU) is the interface between the engine and the auxiliary systems. The purposes of this unit are to isolate the engine from the ammonia supply system, to connect the inert gas supply system, as well as to divert the flow during purging procedure.

The FVU is normally located in a dedicated area outside the machinery space. This area can be accessed after the ammonia supply system is shut down and after gas freeing of the area.

The main components of the FVU include the following:

- A manually operated stop valve(s) and an automatically operated master fuel valve(s) coupled in series or a combined manually and automatically operated master fuel valve(s) installed on the main ammonia supply line to each consumer. These valves must be placed outside the machinery space in which ammonia fuelled machinery is located and as close as possible to the ammonia fuel preparation equipment.
- Two shut-off valves in series with a venting valve in between with a double-block-and-bleed function, installed on the main ammonia supply line to each consumer.
- A manual shutdown valve, installed on the main ammonia supply line to each consumer for maintenance purposes. This must be installed upstream of the double block and bleed valve.
- If the master fuel valve is in an enclosed space, such as a fuel preparation room, this space must be protected against fuel leakage by another automatic shutdown valve arranged for closure in case ammonia is detected within the enclosed space or in case of loss of ventilation in the duct of the double-wall fuel pipe. That additional automatic shutdown valve can be the fuel tank outlet valve.
- The final layout of the FVU can vary depending on ammonia FSS design and engine requirements. The number of valves can be reduced by combining several functions in a single valve depending on different class requirements.

NOTE	All valves in the ammonia supply system must be remotely controlled, if they are not easily accessible.

3.1.9 Fuel preparation space

The fuel preparation space is a dedicated area containing equipment for ammonia preparation purposes. Such equipment can include:

- fuel pumps
- FVU
- compressors
- vaporisers
- heat exchangers and filters.

The design of this space must follow the IGF code requirements together with additional requirements defined by the relevant classification society.

In general, this space must be provided with independent ventilation of underpressure type and must be arranged to safely contain and manage leakage in the foreseeable worst-case scenario. The area cannot be located adjacent to the machinery space of category A or any other high-risk area, therefore, a segregation must be foreseen. Access from open deck is preferable. If this is not possible, access via air lock must be foreseen.

3.2 Inert gas supply system

The purpose of the inert gas supply system is to provide inert gas (e.g. N_2) to the engine and ammonia storage and supply system for inerting and purging procedures.

Table 3-8: Design parameters for the inert gas supply system

Parameter	Inert gas supply system
N_2 purity	Min. 95%
Pressure for liquid purging [bar(g)]	30
Pressure for vapour purging [bar(g)]	5
Operational function test pressure	30
Leakage test after maintenance [bar(g)]	85
Purging temperature	Ambient

3.3 Inerting and purging procedure

The purging procedure can be performed on the engine, the ammonia FSS and the system components to remove ammonia from ammonia fuel system by substituting it with inert gas (e.g. nitrogen). It is carried out through different connections to inert gas supply system. This procedure is used e.g. to verify tightness of the system before ammonia operation (operational function test), when ammonia operations stop, for emergency, for maintenance and whenever required. For safety purposes, purging procedure must also be available for the bunkering station. In this case, the procedure is used to protect the operator before disconnecting the bunker hoses.

The inerting procedure is used to eliminate possibility of any flammable mixture being present in ammonia storage and supply system. This is achieved by utilising an inert gas which must be permanently available on board. Normally, N_2 is used as inert gas and provided by means of a nitrogen generator. If this generator is installed outside of the engine room, an independent mechanical ventilation system of extraction type must be provided capable of providing six air changes per hour. Nitrogen pipes must be led through well-ventilated spaces. If the pipes are directed in enclosed spaces, these pipes must be full-welded. The number of flange connections to valves must be minimised as much as possible. Two shut-off valves in series with a venting valve in between, providing a double-block-and-bleed function, must be installed on nitrogen supply system. This prevents any return of flammable liquid and vapour to inert gas system.

The capacity of the inert gas supply system is the sum of inert gas volume required for engine operation and volume required for ammonia supply system and other upstream systems which are connected to the inert gas supply system.

After maintenance on ammonia fuel system, a tightness test must be performed. It consists of pressurising components (up to maximum operational pressure) to verify that the components have been correctly assembled (see Table 3-8: Design parameters for the inert gas supply system).

3.4 Hot air supply system

Hot air (40 °C–60 °C) is used for final purging process. As soon as the ammonia vapour concentration is below 10% of LEL, the system can be purged with hot air until the ammonia vapour concentration is below the level which defines the completion of the purging procedure.

3.5 Ammonia vapour processing system

The ammonia vapour processing system is designed to collect and treat ammonia vapours from the engine as well as from the ammonia fuel storage and supply system. The ammonia vapour processing system must be designed with a capacity which enables the reduction of ammonia vapour concentration below the PEL (30 ppm) in case the ammonia vapours are released for a longer period. After the treatment, the ammonia vapours are directed to the vent mast.

Different technologies can be selected for the ammonia vapour processing system, as reported below.

<u>Diffusion tank</u>
This type of technology consists of a diffusion tank filled with water. The ammonia vapours coming from the venting system are directed to this tank. The piping system directs the ammonia to the tank bottom at maximum 10 m from the maximum liquid level. The tank capacity must consider the amount of water and ammonia without overflowing at a defined temperature (since solubility of ammonia can vary with temperature).

The following requirements must be considered for the diffusion tank:

- A vent pipe with an installed ammonia sensor must be provided and connected to the vent mast.
- A level indicator on the tank, for low- and high-level alarm, must be provided.
- Discharge connection for contaminated water must be provided.
- Overboard discharge under the water level is also possible in accordance with local regulations.

<u>Scrubber</u>
This type of technology consists of a closed-loop scrubber to reduce ammonia concentration in case of ammonia vapour release.

<u>Combustion unit</u>
The ammonia vapours are burned. Pilot fuel is used to initiate and sustain ammonia combustion. The ammonia combustion units must be designed to immediately operate in case of ammonia release (e.g. from safety valve or venting system). Therefore, a buffer tank must be provided. In addition, a phase separator (knockout drum) must be provided to separate the liquid and gaseous state to prevent ammonia droplets to enter the combustion unit before being evaporated.

<u>Dilution system</u>
This system can be applied for failure mode handling and must be designed to provide sufficient dilution of effluents containing gaseous ammonia by mixing them with fresh air or by increasing the ventilation rate. The dilution rate must be sufficient to reduce the ammonia release below the PEL at any location where passengers or crew members can be present.

In addition to different technologies available for ammonia vapour processing systems, in general, water mist system can also be used to absorb ammonia release. This system must be installed in the areas where ammonia release can occur (e.g. piping and components, bunkering station connection). The system must be activated automatically when ammonia concentration exceeds 30 ppm. Manual activation must be also possible locally or from the engine control room.

3.6 Venting system

During normal operation, including fuel change-over and engine stop, direct venting of ammonia to the atmosphere is not permitted. Therefore, a fixed venting system must be arranged to collect the vapours generated from failure conditions, from tank safety valves, from valves with double-block-and-bleed function, as well as other pressure relief valves available in the ammonia supply system.

For the tank venting system the main components which must be considered are vents, pressure relief valves, stop valves, as well as vacuum relief valves (if the tank can be subject to external pressure above the tank design pressure).

NOTE	Pressure relief valve must be connected to the highest part of the liquified fuel tank.

Any ammonia vapour release to the atmosphere must be done via a vent mast which is designed for venting:

- processed vapours (coming from ammonia vapour processing system)
- vapours generated from failure conditions
- vapours from tank safety valves in case of fire.

The ammonia vapour release to atmosphere must not exceed the PEL at any location where passengers or crew members can be present. The vent mast must be located at B/3 or 6 m height (whichever is higher) above the main deck, walking ways and working areas, and at B or 25 m height (whichever is less) from any air intake or accommodations.

NOTE	Ammonia vapour within enclosed spaces can also be absorbed by water mist system (see section 3.5).

3.7 Ventilation system

A separate ventilation system for hazardous spaces is required to avoid any ammonia vapour accumulation. This system is of mechanical extraction type with independent fans and must be kept separated from non-hazardous space ventilation system.

The following requirements must be considered:

- During normal operation, the ventilation must ensure at least 30 air changes per hour.
- The ventilation system must ensure proper ventilation in the lower and higher points of the hazardous space and must always be active during ammonia operations.
- Ventilation outlets from hazardous spaces must be located at a proper distance from nearest air intake, air outlet, from opening to other enclosed spaces as well as from decks and gangways, according to the classification society requirements.
- Ventilation outlets from hazardous spaces can be grouped together.

Back flow prevention device must be considered for ventilation outlets.

In case ammonia vapour concentration at the ventilation outlet of the enclosed spaces exceeds 30 ppm, different actions are possible:

- stop the ventilation system and activate the water mist system
- direct ventilation outlets to the ammonia vapour processing system
- increase the ventilation rate to achieve ammonia vapour concentration below the LEL at the ventilation outlet.

The annular space of the double-wall piping is also equipped with a mechanical ventilation of under pressure type (see section 4.3). The ventilation system must ensure an extraction capacity of at least 30 air changes per hour. In case ammonia vapour concentration in the annular space exceeds the defined trigger values, different actions must be initiated, according to the classification society requirements.

3.8 Exhaust gas system

Some requirements must be followed for the design of the exhaust gas system as following:

- The system must be designed to prevent any accumulation of unburnt fuel.
- Pressure relief valves must be considered.
- The explosion venting system outlet must be in an area where people can normally be present.
- Separate exhaust system must be considered for any other engine.
- The ammonia concentration in the exhaust gas must not present a significant health hazard.

For further details about the arrangement of the exhaust gas system against explosion and toxicity, please see the WinGD 2-Stroke Ammonia Dual Fuel Safety Concept.

3.9 Fire system provisions

The following design requirements must be considered for ammonia fire protection system:

- The fuel preparation space must be classified as a machinery space of category A.
- The boundaries of the fuel preparation space towards other machinery spaces of category A, control stations and cargo areas must be at least of A-60 type.
- Boundaries of A-60 type must also be considered for accommodations (up to the navigation bridge), service spaces, control spaces, machinery spaces and escape routes which are adjacent to ammonia tanks on open decks.
- The ammonia storage hold space must be separated by a cofferdam of at least 900 mm with insulation of at least A-60 type from the machinery space of category A. For type C tanks, the fuel storage hold space is considered as a cofferdam.
- The bunkering station must also use insulation of A-60 type except for spaces with little fire risk where the standard insulation can be used.
- Fire protection of fuel pipes led through ro-ro spaces must be subject to specific consideration of classification society.
- Ammonia tanks on open decks must be provided with a fixed water mist fire system. This system must be designed with an application rate of 10 $(\ell/min)/m^2$ for horizontal surfaces and 4 $(\ell/min)/m^2$ for vertical surfaces. This system can be part of the main fire system.
- The fixed water mist fire system must be divided at least into two sections which can be operated independently.
- Remote control of pumps and valves must be possible from safe locations.

- The bunkering station must be provided with a fixed installed dry chemical powder extinguishing system with a capacity of 3.5 kg/s for a minimum of 45 seconds discharge. In addition, a dry chemical powder extinguisher of about 5 kg (or equivalent) must be located near the entrance of the bunkering station.
- Fuel preparation space and tank connection spaces arranged with motors for submerged pumps must be protected by a fixed fire-fighting system.
- Approved automatic fail-safe fire dampers must be fitted in the ventilation trunk for tank connection space and fuel preparation room.

Fixed fire detection and fire alarm system must be provided for all compartments containing ammonia FSS.

3.10 Ammonia bilge system

Following requirements must be considered for the bilge system:

- Bilge system serving hazardous spaces must be segregated from other bilge systems and must be designed to discharge to designed shore reception facilities.
- Bilge wells must be designed in such a way to contain any foreseeable leakage.
- When a second barrier is required for storage tank(s), suitable arrangement to bilge system must be provided.
- Bilge system sections must be designed to fulfil the required drainage capacity in spaces where water mist system is installed.
- Bilge water holding tanks and drain tanks, which can contain dissolved ammonia, must be located outside the machinery spaces. These tanks must be vented to the ammonia vapour processing system or vent mast and must be provided with a vapour detector in the vent pipe.
- Bilge water holding tanks and drain tanks, which can contain dissolved ammonia, must be protected by cofferdams.
- Effluents, containing dissolved ammonia below the permissible limit, can be discharged overboard below the water line, in accordance with local regulations.

3.11 Control, monitoring and safety system

The safety functions of the ammonia storage and supply system must be arranged in a dedicated control, monitoring and safety system that is independent from the fuel control system. Control and monitoring instruments must be provided to prevent unacceptable loss of power, in case of a single failure of the ammonia storage and supply system.

This system must be arranged to automatically isolate the ammonia storage and supply system, upon failure and/or fault conditions and it must be designed to restore the propulsion as soon as possible upon a fuel safety action. Manual intervention for operators must be provided.

For X-DF-A engines, each fuel type must be fitted with its own independent control, monitoring and safety system. The control, monitoring and safety system of other consumers must be kept independent.

3.11.1 Bunkering and ammonia tanks

For overflow control, each ammonia tank must be fitted with a level gauging device. In addition, visual and audible high-level liquid alarm must be provided. This alarm must be released when the tank is filled up to about 95% of the tank volume. In case of a high liquid level alarm, a shut-off valve is automatically activated to prevent excessive liquid pressure in the bunkering line, as well as to prevent the tank from becoming full.

Each fuel tank must be monitored for pressure and fitted with local indicating devices. The indicators must clearly mark the highest and lowest pressure permitted in the tank. High-pressure alarm and, if vacuum protection is required, low-pressure alarm must be provided before the safety valve set value is reached. Alarms must be available on the bridge, in the control room and locally.

A local reading pressure gauge must be fitted between the stop valve and the shore connection at each bunkering line. Pressure gauges must also be fitted to fuel pump discharge lines and to the bunkering and vapour return lines. Each fuel pump discharge must be monitored for pressure.

In case submerged fuel pump motors are installed in the tanks, liquid low-level must be monitored. In addition, each fuel tank must be provided with fuel temperature indicators in at least three locations, at the bottom and middle of the tank, as well as the top of the tank below the highest allowable liquid level. Fuel storage hold spaces and inter-barrier spaces, without open connection to the atmosphere, must be provided with pressure indication.

The bunkering station must be controlled from a safe remote location, where it is possible to control its level and to operate the remote-control valves. From this location, overfill alarms, tank pressure and temperature and automatic shutdown must also be visible. If the ventilation of the double-wall bunkering lines stops, an audible and visual alarm must be activated at the bunkering control location. If ammonia leakage is detected in the double-wall bunkering lines, an audible and visual alarm and emergency shutdown of the bunkering valve must automatically be activated.

3.11.2 Ammonia detection provisions

Ammonia detector sensors must be permanently installed in several locations according to the classification society requirements. The number of detectors and the limits of ammonia vapour concentration must be compliant with the classification society requirements and to the satisfaction of the administration.

Possible locations for ammonia detectors are the following:

- tank(s) connection space
- annular spaces around ammonia piping
- ammonia preparation rooms
- hazardous areas containing potential sources of ammonia release
- machinery spaces containing ammonia equipment/piping and consumers
- air locks
- bunkering station
- vent pipes (e.g. from ammonia drain tank or from bilge water holding tanks)
- vent mast outlet
- ventilation outlets.

When ammonia tank(s) other than type C tanks are used, hold spaces and/or inter-barrier spaces must be provided with a permanently installed system of ammonia detection capable of measuring ammonia concentrations from 0% to 100% by volume.

The ammonia detectors must be installed at least to the ceiling and at the bottom of the concerned space. Additional ammonia detectors can be required depending on the results of ammonia dispersion studies performed by the shipyard.

3.11.3 Fire detection provisions

Fire detection in machinery spaces must provide audible and visual alarms on the navigation bridge, the central control station (e.g. engine control room), as well as locally.

3.11.4 Ventilation provisions

Any loss of the required ventilating capacity must provide audible and visual alarms on the navigation bridge, the central control station (e.g. engine control room)..

3.11.5 Bilge wells

Bilge wells must be provided with sensors to detect its levels, as well as with ammonia detector, according to the classification society requirements. Alarm must be given at high-level in bilge well.

3.11.6 Alarms and safeguard settings

Different alarms and monitoring parameters for ammonia leakage detection are provided by the classification societies.

4 Engine Design Criteria

4.1 Operating modes

The engine is designed for continuous service on ammonia and diesel. Depending on the selected option, different operating modes are available within specific engine power ranges.

The following list includes the operating modes available for the ammonia engine:

- ammonia mode
- diesel mode.

Changeover between the operating modes:

- transfer (automatically active for changeover to, or between, modes with ammonia operation)
- ammonia trip (immediate action, always available while a mode with ammonia operation is selected).

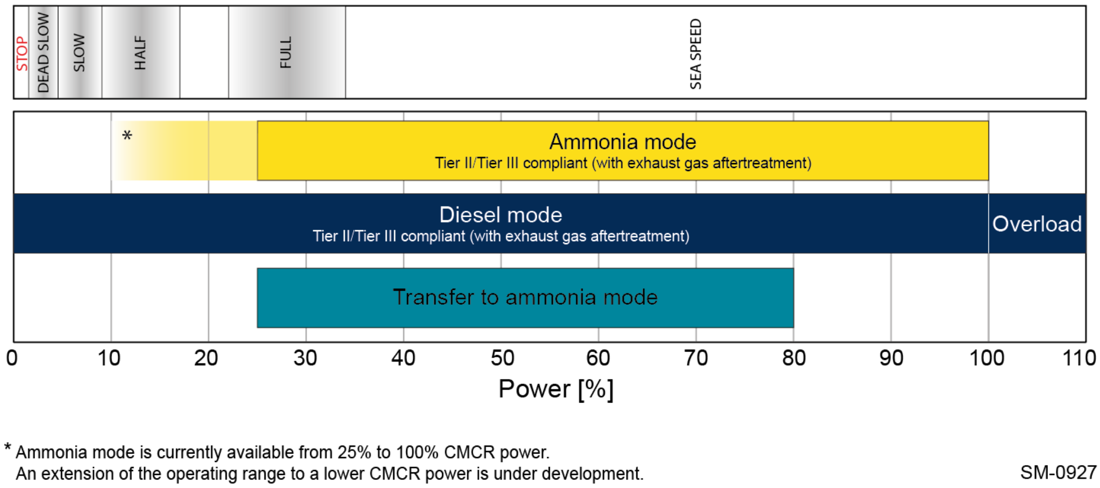

Figure 4-1 Operating modes for the X-DF-A-1.0 engines

4.2 Injection concept

4.2.1 Main fuel injection

Considering the ignition proprieties of ammonia, a high-pressure injection system is applied. This enables optimum combustion process.

The system comprises:

- ammonia supply pipes
- ammonia injectors.

4.2.1.1 Ammonia supply pipes

Ammonia is supplied to the engine inlet at 85 bar(g). If a fuel rail is provided in a fuel box, no double-wall pipes are required because the fuel box fulfils the second barrier function.

4.2.1.2 Ammonia injection system

Design under development.

4.2.1.3 Ammonia injectors

Spring-loaded injectors dedicated to ammonia are located on the cylinder cover.

4.2.2 Pilot fuel injection

Pilot fuel injection is provided by main diesel injectors.

4.3 Double barrier concept for Ammonia

4.3.1 Annular space concept

The ammonia storage and supply system must be arranged in a way that any ammonia release and consequences thereof are minimised. Therefore, a double barrier concept is applied for piping system. In this concept, the piping system is protected by a gas- and liquid-tight outer pipe or duct.

A failure of one barrier must not lead to a leak from the piping system into the surrounding area. This prevents danger to the persons on board, to the environment and to the ship.

The annular space between the inner and outer pipe must have mechanical ventilation of extraction type with a minimum capacity of 30 air changes per hour, and be ventilated to the open air, after passing a gas detector. The double-wall enclosure must be connected to a suitable drainage tank allowing the collection and detection of any possible leakage.

Inerting of the annular space can be accepted as an alternative to ventilation. Suitable alarms must be provided to indicate a loss of inert gas pressure between the pipes.

4.3.2 Sealing concept

Design under development.

5 Emission Considerations

All X-DF-A engines are IMO Tier III compliant with an exhaust gas aftertreatment system. Selective Catalytic Reduction (SCR) system is an exhaust gas aftertreatment system which can be selected to reduce NOx emissions for compliance with Tier III NOx regulations in diesel mode and ammonia mode.