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GUIDELINES ON **ONBOARD CARBON CAPTURE AND STORAGE**

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Guidelines

Onboard Carbon Capture and Storage

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Introduction

In response to the continued development of international and industry measures aimed at reducing greenhouse gas emissions from shipping, onboard carbon capture and storage (OCCS) is emerging as one of the technologies that may be applied to reduce carbon dioxide (CO₂) emissions to atmosphere from shipboard fuel oil combustion units. These Guidelines have been developed by the Indian Register of Shipping (IRS) to support the consistent application of classification requirements for the design, installation and verification of OCCS arrangements fitted on board ships. These Guidelines are intended to assist shipowners, ship designers, technology providers and shipyards in the design, construction and operation of ships fitted with OCCS.

These Guidelines provide requirements for OCCS systems, with particular focus on post-combustion CO₂ capture using chemical absorption and the associated systems for exhaust gas pre-treatment, solvent handling and regeneration, CO₂ conditioning and liquefaction (where fitted), CO₂ storage, and CO₂ transfer/offloading arrangements. The basic philosophy is to provide guidance on the provisions for the arrangement, installation, control and monitoring of OCCS-related machinery, equipment and systems in order to minimise risk to the ship, its crew and the environment, having due regard to the properties and hazards of CO₂ and any chemicals/solvents used.

It is recognised that OCCS installations should be based on sound engineering principles, and on the best understanding available from operational experience, field data, technology development and relevant research. Accordingly, these Guidelines identify areas requiring special consideration for shipboard application, including safe arrangement and segregation, safe access and maintainability, system integration with essential services, ventilation and gas detection, emergency shutdown, and the management of low-temperature CO₂ and chemical hazards.

While certain operational practices, training, drills and emergency preparedness are primarily matters for the Owner/Operator, reference is made to such aspects where necessary to support safe design and to ensure that the required onboard documentation and procedures are in place for uptake of such technologies.

Section 1

General

1.1 Scope and Application

1.1.1 The purpose of these Guidelines is to provide requirements for the design, arrangement, installation, integration, control, monitoring, and testing of Onboard Carbon Capture and Storage (OCCS) systems installed on ships for the purpose of reducing carbon dioxide (CO₂) emissions to atmosphere. These Guidelines are applicable to both newbuilds and retrofits and intended for use throughout the design, detailed engineering, installation, commissioning and operation phases.

1.1.2 This document addresses OCCS systems primarily based on post-combustion CO₂ capture using chemical absorption (amine-based solvents), including associated systems for exhaust gas pre-treatment, solvent circulation and regeneration, CO₂ conditioning (compression, cooling and drying), liquefaction and storage, and CO₂ transfer/ offloading arrangements.

1.1.3 The requirements in this document are intended to ensure that OCCS installations:

- maintain an acceptable level of safety for personnel, the ship, and the environment
- do not adversely affect the safety or availability of propulsion, power generation, steering, and other essential services and
- provide arrangements suitable for safe access, operation, inspection, maintenance, and emergency response.

1.2 General Requirements

1.2.1 These Guidelines are to be applied in conjunction with the applicable requirements of IRS Rules and relevant statutory instruments. Where statutory approval or equivalence is required (e.g., alternative design arrangements), such approval is to be obtained from the Flag Administration.

1.2.2 The OCCS installation is to be arranged such that it does not introduce hazards to the ship, persons on board, or the environment, and does not adversely affect the safe operation of propulsion, power generation and other essential services.

1.2.3 Where Statutory requirements on any aspect are more stringent than these Guidelines, those requirements are to be complied with, unless an approved equivalence is granted by the Flag Administration.

1.2.4 Where the OCCS arrangement involves novel features or deviations from prescriptive statutory provisions, an alternative design / equivalence assessment is to be carried out and submitted for approval in accordance with Flag Administration requirements, supported by risk assessment to the satisfaction of IRS. The IRS Guidelines for Alternative and Risk Based Design/ IACS documents can be referred on a case-to-case basis.

1.2.5 Applicable IRS Rules

(a) Machinery systems, piping systems, electrical installations, automation and safety systems are to comply with the relevant requirements in Part 4 of the *Rules and Regulations for the Construction and Classification of Steel Ships* (hereinafter referred to as the Main Rules), as applicable to the equipment type, design pressure/ temperature and installation environment.

(b) CO₂ storage, CO₂ transfer/ handling arrangements, tank location and segregation, pressure relief, ventilation, gas detection, and related safety provisions are to comply with Part 5 Chapter 4 of the IRS Main Rules, as applicable, taking account of the specific design basis for CO₂ condition (pressurised/cryogenic/refrigerated liquid). The arrangement and location of storage tanks for solvents/chemicals are to comply with Part 5 Chapter 3 of IRS Main Rules, as applicable.

1.2.6 IMO Instruments

(a) Relevant provisions of SOLAS, including those related to fire safety, ventilation, electrical safety, safe access/ escape, and control/ monitoring, are to be complied with as applicable to the ship type and arrangement.

(b) Where CO₂ is stored as refrigerated liquid or under pressure in dedicated tanks, the safety intent and technical provisions of the IGC Code are to be applied, as applicable, for arrangements including tank protection, pressure/temperature control, pressure relief, hazardous area considerations, and CO₂ handling spaces.

(c) Where chemical solvents/absorbents or related substances are carried/stored onboard as part of the OCCS process, relevant provisions of the IBC Code and/or other applicable chemical carriage/handling requirements are to be complied with based on the chemical classification, MSDS, and stowage/ handling category.

(d) Where packaged dangerous goods are carried for OCCS operation (e.g., chemicals in drums/Intermediate Bulk Containers, dry ice, cylinders), relevant provisions of the IMDG Code are to be complied with for identification, packaging, marking/labeling, stowage and handling.

1.2.7 Control, monitoring and safety-related functions (including ESD logic) are to be designed with due consideration of fail-safe behaviour, single-fault tolerance where required, and verification/ testing arrangements, commensurate with the risk assessment outcomes.

1.2.8 Flag/Port/Local Requirements

1.2.8.1 Where CO₂ venting, offloading, temporary storage, or port interface arrangements are involved, additional requirements imposed by Flag Administration, Port Administration, and terminal/shore facility rules are to be identified by the Owner/Operator and complied with. Any such requirements affecting the OCCS design are to be submitted to IRS for review as part of the documentation set.

1.2.9 Environmental and Discharge Considerations

1.2.9.1 Where the OCCS process involves wash water, residues, spent solvent, sludge, contaminants or any discharge/overboard interface, applicable statutory environmental regulations are to be identified by the owner and complied with. Discharge arrangements (if any) are to be addressed in the ship-specific risk assessment and operating procedures.

1.3 Notations

1.4.1 An additional class notation **OCCS** will be assigned when systems for onboard carbon capture and storage are installed, commissioned and satisfactorily tested in accordance with the requirements specified in these Guidelines.

1.4 Definitions

.1 Absorber: A dedicated unit in the OCCS system where cooled exhaust gas is brought into contact with a solvent. The absorber promotes gas–liquid interaction so that CO₂ is chemically absorbed into the solvent.

.2 Amine: An organic compound derived from ammonia, commonly used as a chemical absorbent in OCCS systems. Amine-based solvents (e.g., monoethanolamine) react with CO₂ in the absorber and release it in the desorber during regeneration.

.3 Bypass Arrangement: An exhaust routing system that allows OCCS to be isolated without affecting the safe operation of engines or boilers, preventing backflow and excessive backpressure.

.4 Closed Loop: A system configuration where wash water or solvent circulates continuously within the OCCS process without routine discharge overboard. This arrangement minimizes environmental impact and ensures controlled handling of chemicals and residues.

.5 CO₂ Machinery Space: A dedicated enclosed space housing OCCS equipment for CO₂ compression, cooling, drying, and liquefaction. It is designed with gas-tight boundaries, mechanical ventilation, and gas detection to prevent accumulation of CO₂ and maintain safe access for personnel.

.6 CO₂ Storage Tank: A dedicated tank for storing liquefied CO₂ onboard, equipped with instrumentation for pressure, temperature, and level, and designed to operate safely near the CO₂ triple point.

.7 Desorber: Also called a stripper or regeneration unit, this is the part of the OCCS system where the CO₂-rich solvent is heated to release concentrated CO₂ and restore the solvent to a lean state for reuse. It generally incorporates a reboiler or heat source, associated piping, and controls for temperature and pressure.

.8 Emergency Shutdown (ESD): An automated safety function that isolates or stops parts of the OCCS system upon detection of abnormal or hazardous conditions.

.9 Fuel Oil: Any fuel delivered to and intended for combustion purposes for propulsion or operation on board a vessel, including gas, distillate, residual, alcohol, or bio derived fuels from petroleum refining or derived by methods other than petroleum refining.

.10 Lean Solution: The regenerated solvent after CO₂ has been removed in the desorber, ready to be recirculated to the absorber.

.11 Pre-Scrubbing/ Quenching: An upstream treatment stage that cools and cleans exhaust gas before it enters the absorber. This process reduces temperature and removes particulates or contaminants, improving the efficiency and reliability of CO₂ capture.

.12 Reboiler: A heat-exchange device used in the desorber to supply thermal energy for solvent regeneration and CO₂ release.

.13 Residue Tank: A containment tank for collecting spent solvent residues, filters, and contaminants for controlled disposal ashore.

.14 Triple point of CO₂: The triple point of CO₂ is the unique thermodynamic condition where its solid, liquid, and gaseous phases coexist in equilibrium. For pure CO₂, this occurs at approximately -56.6 °C and 0.518 MPa (absolute pressure). At this point, small changes in temperature or pressure can cause phase transitions, so OCCS systems are to maintain operating margins to avoid phase changes during storage and transfer.

.15 Cryogenic CO₂ system: Temperature of less than -55 °C

1.5 Abbreviations

.1 OCCS: Onboard Carbon Capture and Storage.

.2 EGC: Exhaust Gas Cleaning.

.3 FOCUs: Fuel Oil Combustion Units

.4 GHG: Green House Gas

1.6 Documentation

1.6.1 The following documents/details/plans are required to be submitted to IRS:

a) For information/ review:

- General Arrangement of the OCCS system indicating the location and layout on board
- OCCS System Specific HAZID HAZOP study with risk Assessment and mitigating measures
- Ship Specific Risk Assessment report
- Chemical storage tank location and design basis
- Ship Specific Personnel Protection arrangement
- Details of OCCS system (also see 2.2.1)
 - o EGCPre-scrubbing/quenching and absorber systems
 - o CO₂ separation arrangements including desorbers or stripping systems and associated auxiliary equipment
 - o Compression, refrigeration, and liquefaction systems
- CO₂ or carbon compound disposal and/or storage arrangements
- For existing vessels, documentation related to weights and c.o.g calculations due to OCCS retrofit is to be submitted
- OEM Manual for the operation, maintenance and trouble shooting including component certificates and FMEA

b) For approval:

- Pumping Piping arrangement for the system integration
- Electrical load analysis
- Electrical system SLD including alarms, controls & monitoring
- Ventilation arrangements
- Plans for Gas detection

c) Any other additional documents that IRS may require in order to evaluate OCCS.

Section 2

Design Basis and System Overview

2.1 OCCS system boundaries and functional description

2.1.1 The OCCS installation is to be considered as an integrated plant comprising, as applicable:

- a) exhaust gas take-off and routing arrangements, including isolation and bypass
- b) exhaust gas pre-treatment (e.g., quenching/pre-scrubbing, particulate/contaminant reduction) as required for the selected capture technology
- c) CO₂ capture unit (absorber and associated internals) and solvent circulation loop
- d) solvent regeneration unit (desorber/stripper, reboiler/heat source, associated heat exchangers and pumps)
- e) CO₂ conditioning (e.g., compression, cooling and drying/dehydration), and where fitted, liquefaction/refrigeration
- f) CO₂ storage arrangement (tank(s), instrumentation, pressure/temperature control, relief and venting systems)
- g) CO₂ transfer/offloading arrangements (connections, hoses/arms interface, isolation, drainage, sampling and purge arrangements, as applicable)
- h) chemical/solvent storage, handling and residue management (storage tanks, day tanks, drains, residue/sludge tanks and shore disposal arrangements)
- i) control, monitoring, alarms, safety systems and emergency shutdown (ESD) arrangements and
- j) supporting systems (power, cooling, heating/steam, ventilation, inert gas/dry air where required, and drains).

2.1.2 The OCCS system boundaries are to be clearly identified on the OCCS process flow diagram and piping and instrumentation diagram, including all interfaces with ship systems (e.g., exhaust, seawater cooling, steam/hot water, electrical power distribution, bilge/drain systems, ventilation, automation systems).

2.1.3 The system is to be arranged such that failure, shutdown, isolation or bypass of the OCCS plant does not impair the safe operation of propulsion machinery, boilers, generators, or essential auxiliaries.

2.2 Design basis and operating envelope

2.2.1 The following design basis data are to be defined by the manufacturer/ designer and submitted to IRS as part of the OCCS documentation (refer Section 1.6):

- a) ship particulars relevant to OCCS integration (ship type, machinery arrangement, available spaces, hazardous area boundaries if applicable)
- b) exhaust source(s) served by OCCS (main engines, auxiliary engines, boilers, incinerator where applicable), including maximum/ minimum exhaust flow rates, temperatures, pressures, CO₂ concentration range, and expected contaminant content (SO_x/NO_x/PM/water content, as applicable)
- c) intended OCCS operating modes and duty cycle (continuous, part-load, port/sea restrictions if any)
- d) target capture performance basis (e.g., design capture rate/efficiency, design throughput, performance at part load)
- e) CO₂ product condition and specification basis for storage/offloading (e.g., compressed gas / refrigerated liquid / cryogenic liquid allowable impurities and water content as assumed by the Designer and compatible with the storage/offloading concept)

f) solvent/ chemical selection and properties (including MSDS, corrosion compatibility, degradation products as applicable, and any toxicity/flammability considerations)

g) utilities demand basis (electrical load, heat/ steam demand, cooling demand, ventilation demand, inert gas/ dry air demand if applicable)

h) environmental design conditions (ambient air temperature range, seawater temperature range, humidity, salinity, ship operating area assumptions) and

i) design ship motions and vibration environment applicable to the equipment and instrumentation.

2.2.2 Design pressures and temperatures for all OCCS equipment and piping are to be established based on the most onerous combination of:

a) process operating conditions

b) start-up/ shutdown transients

c) abnormal and emergency conditions reasonably foreseeable (including loss of cooling, loss of ventilation, compressor trip, blocked discharge, inadvertent isolation, and loss of power, as applicable) and

d) environmental conditions and heat ingress for low-temperature CO₂ systems.

2.2.3 Where CO₂ is stored or handled at low temperature or near conditions that may lead to solid formation (dry ice) or hydrate formation, the operating margins and safeguards are to be defined in the design basis and addressed in the risk assessment (refer Section 3) and CO₂ control provisions (refer Section 8).

2.2.4 Where the OCCS arrangement includes CO₂ conditioning, liquefaction, storage and/or transfer/offloading, the CO₂ product quality (including intended purity and allowable contaminants/impurities, as applicable) is to be defined as part of the design basis and reflected in the process design, materials selection, instrumentation, and operational procedures. The additional and special CO₂ requirements of the Main Rules Part 5 Chapter 4 Section 17.21/17.22 are to be applied, as applicable:

- 17.21 Carbon dioxide: high purity
- 17.22 Carbon dioxide: reclaimed quality

In case of reclaimed quality CO₂, the Designer is to identify the expected impurity profile and demonstrate that the selected design parameters (including pressure/ temperature control, dehydration, corrosion management, and safety systems) remain suitable for the declared CO₂ quality.

2.3 Interfaces with ship services and systems

2.3.1 Interfaces with ship services are to be identified, and the OCCS system is to be arranged such that:

a) essential ship services remain available in accordance with the Rules and statutory regulations

b) the OCCS does not introduce unacceptable risks to existing machinery, electrical systems, ventilation systems, or control stations and

c) the effects of OCCS operation on the ship's energy balance and machinery loading are considered (e.g., steam extraction, heat recovery, electrical load variation).

2.3.2 The following typical ship services/ interfaces are to be addressed as applicable:

a) **Power Supply:** normal and emergency supply philosophy for systems necessary to maintain the plant in a safe condition

b) **Heat Source:** steam/hot water/electric heating for solvent regeneration and heat tracing, including safeguards against overheating

c) **Cooling:** seawater/freshwater cooling for quenchers, condensers, compressors and refrigeration units, including failure response

d) **Drains and Residues:** dedicated arrangements for chemical drains, wash water, residues and sludge, preventing uncontrolled discharge and preventing migration to bilges where this may create hazards

e) **Ventilation:** dedicated ventilation for enclosed OCCS spaces as required, with monitoring and alarm interfaces

f) **Automation:** alarm, monitoring, control and ESD interfaces with ship Integrated Automation System/Alarm and Monitoring System where provided

g) **Compressed air/Inert gas/Dry air:** where required for purging, inerting, or environmental control around tanks and

h) **Structural integration:** foundations, supports, load paths, access and removal routes for major equipment.

2.3.3 Where any ship system is shared with OCCS (e.g., cooling water, steam, electrical distribution), the interface arrangement is to prevent backflow, contamination, or unintended interaction that may compromise the ship's primary functions.

2.4 Bypass philosophy and engine/boiler backpressure limits

2.4.1 A bypass arrangement is to be provided such that the exhaust gas can be routed around the OCCS plant without affecting the safe operation of engines/boilers and without causing unacceptable exhaust backpressure.

2.4.2 The bypass arrangement is to be arranged so that, upon OCCS trip or ESD activation, exhaust flow is maintained in a safe manner. The response philosophy is to be defined (automatic/ manual) and demonstrated by the manufacturer/ designer.

2.4.3 The maximum permissible exhaust back pressure for each connected combustion unit is to be declared by the engine/ boiler manufacturer, and the OCCS design is to demonstrate compliance for:

a) OCCS in operation (capture mode)

b) transition conditions (start-up, shutdown, changeover to/from bypass) and

c) degraded modes (e.g., partial blockage, fan/pump trip, control valve failure) as identified in the risk assessment.

2.4.4 The bypass and isolation arrangements are to be designed to prevent:

- a) backflow of exhaust gas into OCCS equipment not in service
- b) uncontrolled release of CO₂ or chemicals due to improper sequencing and
- c) unsafe temperatures or overpressure in the OCCS plant during transition or shutdown.

2.4.5 Where bypass arrangements are fitted (e.g., exhaust bypass or process bypass), isolation and bypass valves should be arranged with appropriate interlocks and fail-safe logic to prevent unsafe valve line-ups and unintended backflow, consistent with the FMEA.

2.5 Arrangement, access, maintainability and retrofit impacts (if applicable)

2.5.1 OCCS equipment and storage arrangements are to be located and arranged to provide:

- a) safe access for operation, inspection, sampling and maintenance
- b) safe escape routes from enclosed spaces and machinery spaces serving OCCS
- c) arrangements for removal/ handling of heavy components (pumps, heat exchangers, compressors) without compromising ship structure or safety and
- d) segregation from accommodation, control stations and other spaces as required by applicable IRS Rule requirements and the risk assessment.

2.5.2 The arrangement is to consider the hazards associated with CO₂ accumulation in low-lying areas and confined spaces, and is to incorporate suitable ventilation, detection, access control and rescue arrangements (refer Section 11 and Section 15).

2.5.3 For retrofit OCCS installations, the following are to be assessed and submitted where applicable:

- a) weight estimate and weight growth margin for OCCS components, including stored CO₂ and chemicals
- b) centre of gravity impacts (KG/LCG/TCG) and any required stability reassessment
- c) structural reinforcement requirements for foundations and supports
- d) impact on ship systems routing (exhaust, ventilation, firefighting boundaries, escape routes)
- e) confirmation that statutory and operational requirements (including access, visibility, and safe working practices) remain satisfied following retrofit and
- f) revised electrical load analysis including systems associated with OCCS.

2.5.4 Where the OCCS arrangement introduces new enclosed spaces, new hazardous areas, or modifies existing fire boundaries and escape routes, such changes are to be clearly identified in the plans and addressed in the risk assessment and safety arrangements.

Section 3

Risk Assessment and Safety Philosophy

3.1 General

3.1.1 A risk assessment is to be conducted to ensure that risks arising from the installation and use of CO₂ capture systems affecting persons on board, the environment, structural strength or ship integrity are addressed. Relevant outcomes of risk assessment are to be considered for additional measures. Consideration is to be given to the hazards associated with physical layout, operation and maintenance, following any reasonably foreseeable failure.

3.2 Analysis and mitigation of risk

3.2.1 The risks are to be analysed using acceptable and recognised risk analysis techniques, and loss of function, component damage, fire, explosion, toxicity, CO₂ leakages, and asphyxiation are, at a minimum, to be considered.

3.2.2 In the case of retrofitting CO₂ capture systems, consideration is to be given to the compatibility with existing equipment through the retrofit, and analysis is to ensure that risks are eliminated wherever possible. Risks which cannot be eliminated are to be mitigated as necessary, and the details of such risks, and how they are mitigated, are to be documented to the satisfaction of IRS.

3.2.3 The risk assessment should also address risk aspects including the assessment of events triggered by accidental CO₂ release at cryogenic conditions, overflow in the absorption (exhaust gas cleaning) column, Boiling Liquid Expanding Vapor Explosion (BLEVE), and relevant safeguards (bypass, tripping of pumps, demister, etc.).

3.2.4 A risk assessment is to be conducted and the relevant outcome considered for additional measures.

3.2.5 The risk assessment is to address, at least the following:

- Absorption and desorption processes of OCCS
- Supply, storage, handling and unloading system (if installed) of absorbent
- Compression, liquefaction, storage and unloading system of carbon storage system (if installed)
- Location and impacts of OCCS equipment and CO₂ storage tanks
- Supply, storage, and handling of refrigerant for CO₂ liquefaction system
- Possible impact of operation or failure of the carbon capturing system on essential services
- Interfaces of the OCCS plant with the vessel
- Control and safety system of the OCCS system

3.2.6 The hazards to be considered are to at least include the following:

- Leakage/ loss of containment of absorbent media
- Leakage/ loss of containment of CO₂ (during storage, compression and offloading)
- Leakage/ loss of containment of refrigerant for carbon dioxide liquefaction system
- Failure and malfunction of components of carbon capture and storage system
- Accidental incidents onboard which may affect the OCCS system e.g. dropped objects, fire, explosion, etc. (Collision, grounding, Cyclonic effects etc.)

3.2.7 When assessing the expected risks at least the following are to be considered:

- Toxicity and flammability of absorbent media
- Toxicity of CO₂
- Toxicity and flammability properties of refrigerant

3.2.8 All ventilation outlets from the CO₂ handling space are to be at safe locations with regards to:

- the hazards of possible CO₂ in the ventilation air
- intake of ventilation air into other ventilation systems on the vessel
- recycling between the ventilation outlets and intakes for the refrigerating machinery room.

Section 4

CO₂ Capture Plant Requirements (Chemical Absorption: Amine-Based)

4.1 Process description and system arrangement

4.1.1 Chemical absorption-based CO₂ capture is better suited for gas streams having a low concentration and partial pressure of CO₂ due to the high chemical affinity of CO₂ to amine-/carbonate-based chemical solvents as well as faster rate kinetics. While the chemical solvents can achieve high absorption capacity at low partial pressures of CO₂, a non-reactive or physical solvent performs well at higher partial pressures of CO₂.

4.1.2 Since the chemical reaction between CO₂ and chemical solvents is exothermic, the exhaust gas is pre-cooled to react at lower temperatures. The exhaust gas flows from the bottom of the absorber upwards against a counter-current stream of the lean solution. The CO₂ in the exhaust gas is absorbed and the treated exhaust gas leaves from the top of the absorber. The CO₂ loaded (rich) solution flows from the bottom of the absorber to the stripper. Upon entry into the stripper, the solution is heated by the reboiler, which regenerates the solvent by breaking the chemical bonds between CO₂ and the solvent and releasing CO₂. The application of higher temperatures provided by a reboiler results in generation of the solvent by breaking the chemical bonds between CO₂ and the chemical solvent.

4.2 Solvent identification and applicable UN/ IMDG references

4.2.1 In general, ethanolamine solvent is used in such systems. Reference is made to the UN 2491, (ETHANOLAMINE) According to Chapter 3.2 of the IMDG Code Dangerous Goods list, Ethanolamine is included in Packing group III and 'Category A' for stowage/ handling.

4.2.2 When solvents other than ethanolamine are used, refer to the corresponding UN, and carriage requirements, etc., as appropriate

4.3 Exhaust gas pre-treatment (pre-scrubbing/quenching), absorber and desorber

4.3.1 The location of pre-scrubbing/ quenching, absorber and desorber units is to be justified through the risk assessment in Section 3. The assessment is to evaluate possible exhaust and process media leaks, including wash water or solvents, and their effects on operations, line of sight, and emergency access to LSA and escape routes.

4.3.2 The pumps, heat exchangers, pressure vessels, electrical systems and piping systems are to comply with the relevant requirements of Part 4 and Part 5 of the Main Rules, as applicable.

4.3.3 Where a pre-scrubbing or quenching unit is also designed for the removal of SO_x emissions, the requirements in Main Rules Part 4, Chapter 4, Section 4.15 are to be complied with.

4.4 Special considerations for proprietary solvents

4.4.1 Where proprietary solvents are proposed, the OCCS installation will be evaluated on a case-by-case basis. The designer is to demonstrate that all safety, material compatibility, storage/handling, and environmental considerations are adequately addressed.

4.4.2 The solvent is to be clearly identified by trade name and chemical composition range, and supported by a current Material Safety Data Sheet or Safety Data Sheet (MSDS/SDS). The applicable UN number, IMDG classification, packing group (if applicable), and stowage/ segregation requirements are to be identified. Where a solvent has properties that may trigger requirements under the IBC Code (e.g., toxicity, corrosivity, flammability, reactivity), those requirements are to be assessed and applied as applicable.

4.4.3 The following solvent-specific hazards are to be addressed, as applicable, and reflected in the risk assessment and design:

- a) toxicity (inhalation/skin contact), permissible exposure limits, and required PPE
- b) flammability/combustibility, flash point, and ignition risk (including electrostatic risks)
- c) corrosivity and materials compatibility for tanks, piping, seals, gaskets and coatings
- d) reaction hazards with other shipboard chemicals or cargoes
- e) degradation products and their hazards (including any potential gaseous emissions such as ammonia/volatile components)
- f) spill behaviour, neutralization requirements and disposal/ shoreside handling.

4.4.4 Storage tank arrangement, ventilation, detection, spill containment, drainage, and residue handling are to be reassessed against the solvent MSDS and any applicable statutory requirements. Additional arrangements may be required, including dedicated ventilation, gas/ vapour detection, segregated storage, special coatings/ linings, heating/ cooling, eyewash/ showers, and enhanced firefighting measures, based on the solvent properties.

4.4.5 For non-ethanolamine solvents, the following are to be submitted in addition to the baseline documentation:

- a) solvent qualification data from the OEM (including compatibility, operating limits, degradation tendencies)
- b) updated hazard identification/risk assessment reflecting the solvent-specific hazards
- c) operating procedures addressing storage, transfer, sampling, spill response, first aid and disposal.

Section 5

Chemical/ Solvent Storage and Handling

5.1 General requirements

5.1.1 The arrangement and location of storage tanks for solvents/chemicals used in the OCCS process (including amines and any auxiliary treatment chemicals) is to be assessed on a case-by-case basis, taking into account the chemical properties, quantities carried, operating conditions, and the ship-specific risk assessment (refer Section 3).

5.1.2 The hazards of the declared solvent/chemical (including toxicity, corrosivity, flammability/combustibility, reactivity and degradation products) are to be determined from the applicable MSDS and relevant statutory/code classification (e.g., IBC Code/IMDG Code, as applicable). Safety arrangements for storage, handling and transfer are to be based on this hazard identification. *(Note: Solvent properties are not to be assumed; they are to be declared by the Designer/OEM.)*

5.2 Storage tank arrangement and segregation

5.2.1 Chemical -Amine based tanks are subject to special consideration where they are located in the same space as essential services, e.g. main combustion machinery and equipment. Tanks for chemical substances are not to be situated where spillage or leakage therefrom can constitute a hazard by dripping or spraying onto combustibles or hot surfaces. The storage tank is to be protected from excessively high or low temperatures applicable to the particular amine based chemical along with the fitting of heating and/or cooling systems.

5.2.2 Each storage tank for amine based chemical is to be provided with appropriate alarms and monitoring arrangements.

5.2.3 Storage tanks are to be made with a material compatible with the particular amine based chemical and are to be arranged so that they can be safely emptied of the solution and ventilated by means of portable or permanent systems.

5.2.4 Where amine-based chemicals are stored in integral tanks, such tanks shall be segregated from:

- a) accommodation spaces;
- b) service spaces and control stations;
- c) food stores; and
- d) fresh water tanks and fuel oil tanks;

and from cargo spaces containing cargoes that may react hazardous manner with the stored chemical. Segregation may be by cofferdams, void spaces, pump rooms, empty tanks or other equivalent spaces, as applicable. Where cofferdams are impracticable, alternative arrangements may be accepted based on risk assessment and to the satisfaction of IRS.

5.2.5 Integral tanks used for chemical storage are to be designed and constructed in accordance with applicable structural requirements for deep tanks and primary supporting structures, including consideration of corrosion protection, coatings/linings, inspection access and leak detection where applicable.

5.3 Containment, drainage, spill control and residues/sludge handling

5.3.1 Chemical/solvent storage and handling areas are to be provided with secondary containment (e.g., coamings) sized and arranged to limit the spread of leakage and to prevent migration to bilges or other machinery spaces where it may create hazards. Suitable leak detection and alarm arrangements are to be provided.

5.3.2 Any drainage is to be led to a dedicated collection arrangement (e.g. dedicated drain tank) suitable for shore disposal, as applicable. Overboard discharge of solvent/chemical residues is not to be permitted unless explicitly allowed by statutory requirements and supported by risk assessment.

5.4 Venting and ventilation requirements

5.4.1 For ethanolamine storage/handling, the applicable requirements of the Part 5, Chapter 3 are to be complied with, as relevant to the installation arrangement, including:

- Section 15.17 Increased ventilation requirements;
- Section 15.12 Toxic products requirements; and
- Section 15.19 Overflow control requirements.

5.4.2 Where chemical/solvent storage or transfer is located in an enclosed space, mechanical ventilation is to be provided as necessary to maintain a safe atmosphere and to prevent accumulation of hazardous vapours/mists, taking into account the MSDS and risk assessment outcomes.

5.5 Materials compatibility and corrosion considerations

5.5.1 Pipes, valves, fittings, gaskets and seals in contact with the chemical/solvent are to be constructed of materials compatible with the declared chemical/solvent, including consideration of temperature range, concentration, degradation products and corrosion behaviour. Where required, linings/coatings and corrosion allowance are to be provided.

5.6 Special cases (e.g., NaOH / Ca(OH)₂)

5.6.1 Where aqueous solutions of sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)₂) are used and are corrosive or otherwise hazardous to personnel, the applicable requirements for chemical treatment fluids in IRS Main Rules Part 4 Chapter.4 Sec.4.15 (EGCS chemical treatment fluid) are to be complied with, as relevant to the OCCS arrangement.

5.6.2 As a minimum, the following provisions of Part 4 Chapter 4 Sec.4.15 are to be applied as applicable:

- 4.15.1.2 Storage tank arrangement;
- 4.15.1.4 Residue tanks;
- 4.15.1.2.10 to 4.15.1.2.12 Materials for storage tanks, piping and drip trays;
- 4.15.1.2.8 Storage tank leakage prevention;
- 4.15.1.2.5 and 4.15.1.2.6 Ventilation;
- 4.15.1.2.1 Strength;
- 4.15.2.1 Exhaust bypass requirement; and
- 4.15.2.3 Safety shutdown system.

Section 6

CO₂ Conditioning and Liquefaction Systems

6.1 CO₂ compression system

6.1.1 The processing capacity of the CO₂ compression (and associated liquefaction) systems is to meet the CO₂ compression/liquefaction requirements under the maximum working load of the OCCS.

6.1.2 Necessary gas–liquid separators (e.g., for separating absorbents, water, oil, etc.) are to be provided in the compression/liquefaction system.

6.1.3 In general, a surge tank is to be provided in front of the compressors. Where a two-stage process of compression and heat-exchanging liquefaction is used, a surge tank is generally also to be provided between the compressors and the liquefaction unit.

6.1.4 The surge tank is to be provided with temperature and pressure monitoring and alarm.

6.2 Refrigeration/ liquefaction system

6.2.1 The OCCS compression/cooling/drying/liquefaction plant is to be designed taking into account the composition of the CO₂ gas stream and envisaged impurities, including the effect those impurities may have on the CO₂ “triple point” temperature.

6.2.2 The capacity of the cooling or reliquefaction systems required for temperature/ pressure control of stored CO₂ is to be based on the intended CO₂ storage condition.

6.3 CO₂ machinery space arrangement

6.3.1 CO₂ machinery spaces are not to be treated as cargo pump rooms for the purpose of:

- a) fire protection in accordance with IRS Main Rules Part 6 Chapter 3 Table 3.3 and 3.4, and
- b) prevention of potential explosion in accordance with IRS Part 6 Chapter 2 Section 1.5.10

6.3.2 Bulkheads and decks forming the boundary between CO₂ machinery spaces and accommodation spaces, service spaces, control stations, and machinery spaces of category A are to be arranged such that the ingress of gas into these spaces is prevented, including in the event of a single failure of the boundary (deck or bulkhead).

6.3.3 CO₂ machinery spaces are to be arranged to ensure safe and unobstructed access for personnel wearing protective clothing and self-contained breathing apparatus. The arrangement is also to permit the recovery and removal of an injured or unconscious person. As a minimum, two widely separated means of escape are to be provided. A single escape route may be accepted where the maximum travel distance to the exit door is 5 m or less.

6.3.4 All valves necessary for CO₂ handling are to be readily accessible to personnel wearing protective clothing.

6.3.5 Warning signs are to be posted at entrances to CO₂ machinery spaces and other enclosed spaces where CO₂ may accumulate, warning of the risk of asphyxiation.

Section 7

CO₂ Storage Arrangement and Tank Requirements

7.1 Tank type and applicable design/testing requirements

7.1.1 CO₂ storage tanks intended for carriage of liquefied CO₂ as part of OCCS is to be designed as independent tanks Type C, unless otherwise accepted by IRS based on the declared CO₂ condition and the design basis (refer Section 2).

7.1.2 The applicable requirements for Type C independent tanks in IRS Main Rules Part 5 Chapter 4 (Cargo Containment) are to be complied with, as relevant to the tank design, supports, loads and service conditions, including:

- 4.3 Functional requirements
- 4.8 Supporting arrangements
- 4.9 Associated structure and equipment
- 4.10 Thermal insulation
- 4.11 General
- 4.12 Permanent loads
- 4.13 Functional loads
- 4.14 Environmental loads
- 4.15 Accidental loads
- 4.16 General
- 4.17 Structural analyses
- 4.18 Design conditions
- 4.19 Materials
- 4.20 Construction processes
- 4.23 Type C independent tanks

7.1.3 Tank testing is to be carried out in accordance with the applicable requirements of IRS Main Rules Part 5 Chapter 4, including Sec.4.23.6 (where applicable to the tank type and service conditions), and any additional testing requirements identified by the risk assessment and approved design basis.

7.2 Tank location, segregation and damage protection requirements

7.2.1 The location of CO₂ storage tanks is to comply with the applicable tank location and damage protection requirements of IRS Main Rules Part 5 Chapter 4, and where applied by analogy, the location criteria for ship type 3G may be used as the baseline, subject to IRS acceptance and the ship-specific risk assessment.

7.2.2 Where the ship type 3G location philosophy is applied, CO₂ storage tanks are to be located not less than B/15 or 2.0 m (whichever is less) inboard from the moulded line of the bottom shell at centreline, and in any case not less than $d = 0.8$ m from the moulded line of the outer shell, in accordance with Part 5 Chapter 4 Sec.2.1.5 and the associated figures (e.g., Fig.2.1.5 and Fig.2.4.1(a)), as applicable.

7.2.3 CO₂ storage tanks are not to be located forward of the collision bulkhead in accordance with Part 5 Chapter 4 Section 2.4.4

7.2.4 Segregation of CO₂ tank hold spaces from adjacent spaces (including spaces below or outboard of hold spaces) shall be achieved by one of the following arrangements, as applicable and acceptable to IRS:

- a) cofferdams;
- b) oil fuel tanks; or
- c) a single gastight bulkhead of all-welded construction forming an “A-0” class division.

7.2.5 CO₂ storage tanks may be located forward or aft of machinery spaces of category A, provided segregation, ventilation, detection, access/escape, and emergency response arrangements are demonstrated to be acceptable by the risk assessment and comply with applicable IRS Rules.

7.2.6 For CO₂ storage tanks below deck, suitable drainage arrangements for the hold spaces that are not connected with the machinery space are to be provided. Means of detecting any leakage are to be provided.

7.3 Hold space/ insulation inspection requirements (where applicable)

7.3.1 For cryogenic CO₂ system located in hold spaces, inspection of one side of any insulation in hold spaces is to be possible. If the integrity of the insulation system can be verified by inspection of the outside of the hold space boundary when tanks are at service temperature, inspection of one side of the insulation in the hold space need not be required.

7.4 Environmental control of surrounding spaces (dry air/inert gas, where applicable)

7.4.1 Spaces surrounding CO₂ storage tanks that do not have secondary barriers are to be filled with suitable dry air and be maintained in this condition with dry air provided by suitable air-drying equipment. If the CO₂ is carried at ambient temperature, the requirement for dry air is not applicable.

Section 8

CO₂ Pressure/ Temperature Control and Relief Systems

8.1 CO₂ tank pressure/ temperature control

8.1.1 With the exception of tanks designed to withstand full gauge vapour pressure of the CO₂ under conditions of the upper ambient design temperatures, tank pressure and temperature are to be maintained at all times within their design range by one, or a combination of, the following methods:

- reliquefaction of vapours
- pressure accumulation and
- liquid cooling.

8.1.2 Venting of the CO₂ to maintain tank pressure and temperature is not acceptable except in emergency situations.

8.1.3 CO₂ tank pressure/temperature control are to comply with the requirements of Main Rules Part 5, Chapter 4, Section 7 as applicable, with consideration of risk assessment.

8.1.4 The following requirements in IRS Main Rules Part 5 Chapter 4 Section 7 are to be applied as relevant

- 7.1 Methods of control (except for thermal oxidation of vapours)
- 7.2 Design of systems
- 7.3 Reliquefaction of cargo vapours
- 7.5 Pressure accumulation systems
- 7.6 Liquid cargo cooling
- 7.8 Availability

8.2 Triple point / dry ice / hydrate avoidance and safeguards

8.2.1 The CO₂ conditioning, storage and transfer system should be designed and operated with adequate margin from the CO₂ triple point to prevent formation of solid CO₂ (dry ice) and/or hydrates/ice, which may block PRVs, vents and discharge lines. Thermophysical properties and reference values for pure CO₂ are given in Appendix 1.

8.3 Pressure relief systems and vent outlet arrangement

8.3.1 The following requirements in Main Rules Part 5 Chapter 4 Section 8 are to be applied, as relevant:

- 8.2 Pressure relief systems (except for 8.2.2 PRV for interbarrier spaces, 8.2.10.3, 8.2.10.4, 8.2.11 and 8.2.12 position of vent outlet, 8.2.13 PRV for cargoes that react in a dangerous manner, 8.2.15 protection screens)
- 8.4 Sizing of pressure relieving system

8.4 Vacuum protection systems

8.4.1 The requirements in Main Rules Part 5 Chapter 4 Section 8.3 are to be applied, as relevant.

8.5 Filling limits and overfill protection

8.5.1 The following requirements of IRS Main Rules Part 5 Chapter 4 Section 15 are to be applied as relevant:

- 15.1 Definitions
- 15.2 General requirements
- 15.3 Default filling limit
- 15.4 Determination of increased filling limit
- 15.5 Maximum loading limit

Section 9

CO₂ Transfer, Offloading and Disposal Interfaces

9.1 Transfer arrangements and system integration

9.1.1 Suitable transfer/offloading arrangements (including manifolds, piping, control and monitoring) are to be provided, and their layout/ location is to be addressed in the risk assessment (e.g., consequence of CO₂ release, impact on normal operations, line-of-sight, and emergency access/ escape routes).

9.1.2 Unloading manifolds, pipework and associated control and monitoring systems are to be provided for unloading of liquefied CO₂, with arrangements considered in the risk assessment.

9.1.3 Unloading control is to be from a safe location as a minimum, CO₂ storage tank pressure/ temperature and unloading pump pressures are to be monitored from this location, and it is to be possible to activate the ESD system from the same location (visual/ CCTV monitoring may be used to support this).

9.1.4 Unloading manifolds are to be fitted with shut-off valves capable of full closure and local manual operation (remote operation may also be provided). Local pressure indication is to be provided at the manifold between the manifold shut-off valve(s) and the ship/ shore connection (presentation flange/hose connection).

9.1.5 Transfer connections not in use are to be isolated (e.g., by suitable blank flanges).

9.2 Sampling, drainage and disposal arrangements

9.2.1 Where liquid CO₂ sampling connections are provided, they are to be clearly marked, designed to minimize vapour release, and arranged as a closed-loop so that CO₂ liquid/ vapours are not vented to atmosphere during sampling.

9.2.2 Drainage arrangements not directly connected to other spaces are to be provided in spaces where CO₂ compression/ liquefaction equipment and/or CO₂ storage tanks are located. Drip trays are to be provided at likely liquid CO₂ leakage points, with monitoring and alarms.

9.2.3 Process residues generated by the carbon capture/ stripping process are to be collected in a designated residue tank (separate from the engine-room sludge tank) and arranged for discharge to appropriate shore reception facilities such residues are not to be discharged to sea or incinerated onboard.

9.3 Emergency release and isolation arrangements

9.3.1 All liquid and vapour line connections associated with transfer/ unloading (including gas-freeing and unloading connections) are to be fitted with shut-off valves located as close to the CO₂ storage tank as practicable. Valves are to provide full closure and be capable of local manual operation (remote operation may also be provided).

9.3.2 Transfer/ unloading connections are to be provided with remotely-controlled ESD functionality to stop liquid/ vapour transfer to/ from the ship. ESD valves are to be fail-closed, capable of manual closure, and provided with positive valve position indication.

9.3.3 ESD valves are to close fully and smoothly within 30 seconds, and the ESD/ transfer arrangement is to be designed to avoid surge pressures in the transfer pipework. Valve closing-time information is to be available onboard and verifiable/repeatable.

9.3.4 The ESD system is to be operable manually from the remote-control position(s) and at the local control station.

9.3.5 Where non-permanent connections (e.g., flexible hoses) are used, arrangements are to be provided to limit the quantity of liquid and gas spilled in case of inadvertent disconnection or rupture.

Section 10

Piping Systems

10.1 General requirements and piping classification

10.1.1 Materials, design, construction, inspection and testing of OCCS piping systems (including CO₂, solvent/chemical and associated utility piping) should comply with the applicable requirements of IRS Main Rules Part 2 Chapter 6 Section 1 and Section 2, together with the relevant piping requirements of IRS Main Rules Part 4 Chapter 2, as applicable to the design pressure, design temperature, pipe class and service medium.

10.1.2 OCCS piping should be assigned the appropriate piping class (Class I, II or III) in accordance with the Main Rules, taking into account the properties of the conveyed medium (e.g., toxicity/corrosivity, operating pressure/temperature, and where applicable, flammability of the solvent/chemical). Open-ended drains, vents and similar low-risk services may be accepted as Class III where justified by the design and risk assessment and permitted by the Rules.

10.1.3 CO₂ and solvent/ chemical piping systems should be designed to prevent uncontrolled release, inadvertent interconnections with other systems, and adverse impact on essential ship services. Where the OCCS system interfaces with ship systems, suitable isolation, non-return provisions and interlocks should be provided as applicable.

10.2 Piping arrangement and routing restrictions

10.2.1 The piping and venting systems are to be independent of other ship service piping and/or systems. They are not to be located in accommodation, service spaces, or control stations. The vent pipes of the storage tank are to terminate in a safe location on the weather deck, and the tank venting system is to be arranged to prevent entrance of water into the storage tank.

10.3 Materials, fabrication, welding/NDT and testing

10.3.1 For CO₂ piping systems and transfer arrangements, the applicable requirements of Main Rules Part 5 Chapter 4 Section 5 should be complied with, including as applicable:

- 5.1 General
- 5.2 System requirements
- 5.4 Design pressure
- 5.5 Co₂ system valve requirements
- 5.6 Co₂ transfer arrangements (except for 5.6.1 redundancy of Co₂ pumps)
- 5.7 Installation requirements (except for 5.7.3 Water curtain, 5.7.4 Bonding)
- 5.8 Piping fabrication and joining details
- 5.9 Welding, post-weld heat treatment and non-destructive testing
- 5.11 Piping system component requirements
- 5.12 Materials
- 5.13 Testing requirements

10.3.2 Where applicable, the construction and material requirements of IRS Main Rules Part 5 Chapter 4 Section 6 should be complied with, including:

- 6.2 Scope and general requirements
- 6.3 General test requirements and specifications
- 6.4 Requirements for metallic materials
- 6.5 Welding of metallic materials and non-destructive testing
- 6.6 Other requirements for construction in metallic materials (except for 6.6.3 Secondary barriers, 6.6.4 Semi-membrane tanks, 6.6.5 Membrane tanks)

10.4 Valves, isolation and remote operation requirements

10.4.1 Valves used in OCCS piping systems should comply with the applicable requirements of Main Rules Part 4 Chapter 3, and where relevant, with the CO₂ system valve provisions of Main Rules Part 5 Chapter 4.

10.4.2 Valves are to be installed in accessible positions and are to be free from, or protected against, obstructions, moving equipment, and hot surfaces to enable inspection and servicing.

10.4.3 For remotely controlled valves, the fail-safe position on loss of power/control (fail-closed, fail-open or last position) should be defined by the manufacturer/ designer and justified by the system FMEA. Manual local operation/ override should be provided where required by the risk assessment and the Rules.

10.4.4 Remotely controlled valves are to be clearly identified and fitted with position indicators locally and at the OCCS remote control station, where applicable.

Section 11

Ventilation, Detection of CO₂ and Enclosed Space Safety

11.1 Ventilation requirements by space type

11.1.1 Enclosed spaces containing OCCS/CO₂ handling equipment (e.g., CO₂ machinery spaces, CO₂ tank rooms/hold spaces and other spaces where CO₂ may be released or accumulate) should be provided with mechanical ventilation arranged to prevent the accumulation of CO₂ and to support safe access, operation and emergency response.

11.1.2 For CO₂ machinery spaces, exhaust mechanical ventilation is to be provided with a capacity of not less than 30 air changes per hour, in accordance with Part 5 Chapter 4 Section 12.1.3 of the Main Rules, as applicable.

11.1.3 For spaces required to be entered during normal CO₂ handling operations, the requirements of Main Rules Part 5 Chapter 4 Section 12.1 should be complied with (*except for 12.1.6, where not applicable to the OCCS arrangement*).

11.2 CO₂ detection and oxygen deficiency monitoring requirements

11.2.1 Fixed CO₂ gas detection should be provided in enclosed spaces where CO₂ may be present, including as a minimum:

- a) LCO₂ tank room / CO₂ tank hold space (as applicable) and
- b) CO₂ machinery space (compression/conditioning/liquefaction spaces, as applicable).

11.2.2 Fixed oxygen (O₂) deficiency monitoring should be provided in spaces covered by 11.2.1. As a minimum, two (2) O₂ sensors should be installed in each such space at locations selected to provide representative monitoring of the space, taking into account ventilation flow patterns and the tendency of CO₂ to accumulate in low-lying areas.

11.2.3 Gas detection and O₂ monitoring alarms should be annunciated at an appropriate continuously manned location and/or the OCCS control station, and should be integrated with the alarm and shutdown philosophy in Section 12, as applicable.

Section 12

Alarms, Monitoring and Control

12.1 Control philosophy

12.1.1 Automation systems are to be designed, installed and tested in accordance with IEC 60092-504:2016. Processes for the development and maintenance of integrated systems are to be in accordance with ISO/ IEC 15288:2008 and ISO 17894:2005. These processes are to include appropriate risk identification and management.

12.1.2 System integration is to be carried out as required by Main Rules Part 5 Chapter 4 Section 13.9.

12.2 Instrumentation and minimum monitoring requirements

12.2.1 Instrumentation, monitoring and alarm arrangements for CO₂ storage, conditioning, transfer and associated systems should comply with the applicable requirements of Main Rules Part 5 Chapter 4 Section 13, as relevant to the design basis and arrangement. As a minimum, the following should be provided, as relevant and applicable:

- a) Pressure and temperature indication for liquid and vapour CO₂ piping systems at relevant locations (e.g., upstream/downstream of major equipment, tank connections and transfer lines)
- b) Tank level indication for CO₂ storage tanks in accordance with Part 5 Chapter 4 Section 13.2.3, applying the relevant column of Table of Section 19 as applicable to the tank arrangement and service
- c) Overflow control / overfill protection, including independent high and high-high level alarms and shutdown actions, as applicable, in accordance with the alarm/shutdown philosophy in Table 12.1
- d) Pressure monitoring with direct gauge reading where fitted, with minimum and maximum allowable limits clearly marked, and associated alarms and shutdown actions as per Table 12.1 and
- e) Temperature monitoring for tanks and critical equipment, including high/high-high and low/low-low alarms where applicable, and associated shutdown actions as per Table 12.1.

12.2.2 Where automatic shutdown actions are provided, the shutdown functions should be designed to bring the OCCS system to a safe condition (e.g., isolate CO₂ transfer, stop compressors/pumps, initiate bypass of exhaust gas around capture plant as applicable), without impairing the safe operation of propulsion and essential ship services.

Table 12.1: Alarms, Monitoring and Control Arrangements			
Monitoring Parameters	Alarm Indication	Alarm Activation	Automatic Shutdown Activation
CO₂ storage tank			
Tank level at 95%	X	High	
Tank level at 98%	X	High-High	X
Tank pressure	X	Low	
	X	High	X
Tank temperature	X	High	
	X	Low	
	X	High-High	X
	X	Low-Low	X
Chemical treatment fluid tank			
Tank level at 95%	X	High	
Tank level at 98%	X	High-High	X
Tank level at 10%	X	Low-Low	X
Tank temperature	X	High	
	X	Low	
	X	High-High	X
	X	Low-Low	X
Absorber-desorber system			
Desorber temperature	X	High	
	X	Low	
	X	High-High	X
Absorber temperature	X	High	
	X	Low	
Refrigerant for liquefaction system-			
Tank level at 95%	X	High	
Tank level at 98%	X	High-High	X
Tank level at 10%	X	Low-Low	X
Leak detection	X	Absorbent leak	X
	X	Liquefied CO ₂ Leak	X
	X	Refrigerant leak	X
Ventilation loss	X	CO ₂ Tank hold space	X
	X	CO ₂ handling space	X
	X	Desorber/absorber space	X
Pipeline Monitoring	X	CO ₂ liquid pressure Low	
Gas Detection System	X	>5000 ppm CO ₂	
	X	>40000 ppm CO ₂	X
Compressor Operation Status	X	Failure/ Malfunction	X
Pump Operation Status	X	Failure/ Malfunction	X
By-pass arrangements	X	Activation	X

12.3 Additional requirements for alkaline chemical treatment fluids (where applicable)

12.3.1 Where aqueous solutions of sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)₂) having corrosive properties, or other chemical treatment fluids representing a hazard to personnel, are used in the OCCS installation, the additional alarm and monitoring requirements applicable to chemical treatment fluids (EGCS) should be applied as appropriate, including requirements in IRS Part 4 Chapter 4 Section 4.15.2.3 (Table) — Alarms and Monitors.

Section 13

Electrical

13.1 General

13.1.1 Electrical installations associated with the OCCS system (including power supply, distribution, control, monitoring, alarms and safety/ESD functions) should comply with the applicable requirements of Main Rules Part 4 Chapter 8 and Part 5 Chapter 4 Section 10, as relevant to the equipment type and installation arrangement.

13.1.2 The ship's electrical generation and distribution system, and associated control systems, should be arranged such that a single fault does not result in loss of the capability to maintain:

- a) CO₂ storage tank pressure within the required operating/design limits, as applicable (refer Main Rules Part 5 Chapter 4 Section 7, including 7.8.1) and
- b) hull structure temperature within required limits where low-temperature CO₂ containment is fitted, as applicable (refer Main Rules Part 5 Chapter 4 Section 4, including 4.19.1.6).

13.1.3 A failure modes and effects analysis (FMEA) should be carried out for electrical power supply and control arrangements necessary to maintain the OCCS plant in a safe condition, and the results should be documented and submitted to IRS to a standard acceptable to IRS.

Section 14

Fire Protection

14.1 General

14.1.1 Fire safety arrangements for the OCCS installation (including capture plant equipment, solvent/chemical storage and handling areas, CO₂ conditioning/ liquefaction spaces and associated auxiliaries) should be established based on the ship-specific risk assessment (refer Section 3) and the hazards identified for the declared solvent/chemicals and associated process media.

14.1.2 The fire risk assessment should take into account the relevant information contained in the applicable SDS/ MSDS, including, as applicable:

- a) chemical identity and composition, including relevant impurities and degradation products
- b) physical and chemical properties affecting fire risk (e.g., flash point, auto-ignition temperature, flammable limits, reactivity, vapour density and volatility)
- c) stability and reactivity, including incompatibilities and hazardous decomposition products
- d) firefighting measures and suitable extinguishing media, including any prohibitions or special precautions and
- e) safe handling, storage and spill/leak response measures relevant to escalation prevention.

14.1.3 Based on the above, the design should provide appropriate fire prevention, detection and firefighting measures for OCCS areas, including, as applicable:

- a) segregation/arrangement to minimise ignition sources and prevent spray/drip onto hot surfaces
- b) suitable fire detection and alarm coverage
- c) fixed and/or portable firefighting equipment appropriate to the hazards and
- d) procedures and signage for emergency response and isolation of the OCCS plant.

14.1.4 Fire protection arrangements should be consistent with applicable statutory requirements (SOLAS) and relevant IRS Rules, and any additional measures identified by the risk assessment should be submitted to IRS for review.

Section 15

Personnel Protection Equipment

15.1 General

15.1.1 Personnel protection, first-aid and safety equipment for OCCS spaces and operations are to be provided in accordance with the applicable requirements of Main Rules Part 5 Chapter 4 Section 14, as relevant to the arrangement and identified hazards, including:

- 14.1 Protective equipment
- 14.2 First-aid equipment and
- 14.3 Safety equipment (*except 14.3.2.4 explosion-proof lamp, unless required by the hazardous area classification or risk assessment*).

15.1.2 Where OCCS equipment is installed in enclosed spaces in which CO₂ may accumulate (e.g., CO₂ machinery spaces, CO₂ tank rooms, CO₂ handling spaces), self-contained breathing apparatus (SCBA) of the positive-pressure type is to be provided for emergency response and entry/rescue, in accordance with the risk assessment and the vessel's emergency procedures.

15.1.3 Based on the solvent/ chemical hazards identified from the applicable SDS/MSDS and the IBC Code requirements (as applicable), additional crew protection measures are to be provided where required by the risk assessment, including but not limited to:

- appropriate PPE for chemical exposure (*e.g., chemical-resistant gloves, splash protection, respiratory protection where indicated*) and
- eyewash and safety shower arrangements located to permit rapid access from areas where chemicals may be handled, transferred, sampled or where leaks/spills may occur.

Section 16

Operational Requirements

16.1 General

16.1.1 The following requirements of IRS Main Rules Part 5 Chapter 4 Section 18 are to be applied as applicable

- 18.2 OCCS operations manuals (except for Section 18.2.2.4 nitrogen and inert gas systems, .5 fire-fighting procedures)
- 18.3 OCCS information (except for Section 18.3.1.5 fire-fighting procedures)
- 18.5 Carriage of CO₂ at low temperature
- 18.6 CO₂ transfer operations
- 18.7 Personnel training
- 18.8 Entry into enclosed spaces (except for Section 18.8.3 entry into hazardous area)
- 18.9 CO₂ sampling
- 18.10 CO₂ emergency shutdown (ESD) system (except for Section 18.10.3.2 ESD activation on fire))

16.2 IMDG carriage, stowage and handling requirements (where applicable)

Where substances handled, stored, or transported as part of the OCCS fall within the scope of the IMDG Code, the relevant IMDG requirements for classification, stowage and handling are to be complied with, as applicable, including (but not limited to) the following entries:

16.2.1 UN 1013 CARBON DIOXIDE, Class 2.2 (in term of Stowage and handling defined as 'Category A') if applicable.

16.2.2 UN 1845 CARBON DIOXIDE, SOLID (DRY ICE), Class 2.2 if applicable

16.2.3 UN 2187 CARBON DIOXIDE, REFRIGERATED LIQUID, Class 2.2 (in term of Stowage and handling defined as 'Category D') if applicable.

16.3 Solvents and chemical treatment fluids (where applicable)

16.3.1 UN 2491, (ETHANOLAMINE) : In accordance with the IMDG Code (Dangerous Goods List, Chapter 3.2), Ethanolamine is assigned to Packing Group III and (*where applicable*) Stowage/handling category A.

16.3.2 **Chemical treatment fluid** : Aqueous solution of sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)₂) having corrosive properties and/or other fluids assessed as presenting hazard to personnel, are considered as Chemical treatment fluid. Such fluids are to be treated in accordance with the intent of IRS Main Rules Part 4 Chapter 4 Section 4.15.1.2.6 (EGCS chemical treatment fluids), as applicable. In particular::

- The mechanical ventilation system is to be capable of being controlled from outside the compartment.
- A warning notice is to be provided outside the compartment, adjacent to each point of entry, indicating that the ventilation systems to be operated for at least 15 minutes before entry into such compartments.

Section 17

Rule Requirements and Reference Standards

17.1 General

17.1.1 The Table 17.1.1 below specifies the references to rule requirements and standards applicable to individual components, units, or integrated systems.

Table 17.1.1 : Rule requirements and reference standards			
Units/ Systems	Rule requirement	Reference standard	Subcomponents
Machinery Units:			
EG cooling units	Part 4, Chapter 5	ISO 5149 Series (Refrigerating Systems and Heat Pumps) ISO 16345:2014 (Water-cooling towers)	Heat Exchanger, ISO Standards provide the arrangement of the system design.
Pre-scrubbing/ quenching units	Part 4, Chapter 2, 3, 5		Pipes & Tanks
Absorber unit	Part 4, Chapter 5	ISO 27927:2025 - Carbon dioxide capture	Tank & Chemical Sprinkling system
Desorber unit			
Cooling unit	Part 4, Chapter 5		Heat Exchanger
Heat exchanger	Part 4, Chapter 5	ISO 16812 for shell-and-tube exchangers, ISO 15547-1 for plate-and-frame, ISO 13706 for air-cooled units	
Compressor	Part 4, Chapter 4	ISO 10439 for centrifugal, ISO 10440 for helical-lobe, ISO 13707/13631 for reciprocating compressors	Standards used for the component design & construction
Liquefaction system	Part 4, Chapter 2, 5	IGC Code, IMDG Code	Pressure Vessel & Heat Exchanger
Gas liquid separators	Part 4, Chapter 2, 5	IGC Code, IMDG Code	Pressure Vessel
Tanks:			
Chemical storage tank	Part 4, Chapter 5		IBC Code
Co2 storage tanks	Part 4, Chapter 5	ISO 9809, EN 13445 & EN 13458, BIS IS-7285 / IS-2825	IGC Code
Washing tanks	Part 4, Chapter 5		Storage Tank
Sludge storage tanks	Part 3,		Storage Tank
EG residue tanks			Storage Tank
Portable Co2 tanks	Part 4, Chapter 5	ISO 9809, EN 13445 & EN 13458, BIS IS-7285 / IS-2825	Standards

Pumps:			
Solvent supply pumps		ISO 9905: Technical specifications for centrifugal pumps — Class I ISO 15783: Seal-less rotodynamic pumps — Class II ISO 21049: Pumps — Shaft sealing systems for centrifugal and rotary pumps	Standards Depending on the Operating Pressure & temperature of the medium.
Solvent cooling pumps			Same as above
Washing pumps			Same as above
Solvent sludge pumps			Same as above
Other Units/Systems:			
Control systems/Safety systems	Part 4, Chapter 7		
Associated electrical units	Part 4, Chapter 7		
Pressure vessels	Part 4, Chapter 5	(BPVC), Section VIII	Pressure vessel
Pipes, valves, fittings and auxiliaries	Part 4, Chapter 2		Part 2 Chapter 6 Section 1 & 2
Alarms and indicators	Part 4, Chapter 7		
Personal protection equipment	Part 6		Part 6 For Fire Protection & for Specific Chemical IBC code
Ventilation systems	Part 4, Chapter 1		
Emergency shutdown systems	Part 4, Chapter 7		IGC Code

Appendix 1

General Information

1.1 Physical properties of CO₂

In general, the physical properties of CO₂ to be considered for carriage and design of the OCCS are given in Table 1.1 for guidance.

1.1.1 Physical Properties and Phase diagram of CO₂:

Molecular weight	44.009
Specific gravity of gas	1.529
Gas density (0 °C, 0.1 MPa)	1.977 kg/m ³
Liquid density (20 °C, 1.967 MPa)	934 kg/m ³
Boiling point	-78.5 °C
Melting point (triple point 0.518 MPa (5.11 atm))	- 56.67 °C
Critical temperature (7.37 MPa)	+30.98 °C
Critical pressure (+30.98 °C)	7.37 MPa (72.79 atm)
Appearance	Colourless, odourless
(Source: National Library of Medicine, https://pubchem.ncbi.nlm.nih.gov/compound/280)	

1.1.2 Pure CO₂ has a triple point at - 56.6 °C and 5.18 bar, which determines the point where CO₂ may co-exist in gas, liquid and solid state. At the right combination of pressure and temperature CO₂ may turn into solid state commonly known as dry ice.

1.1.3 Supercritical CO₂ is a highly volatile fluid that will rapidly evaporate when depressurized to ambient conditions.

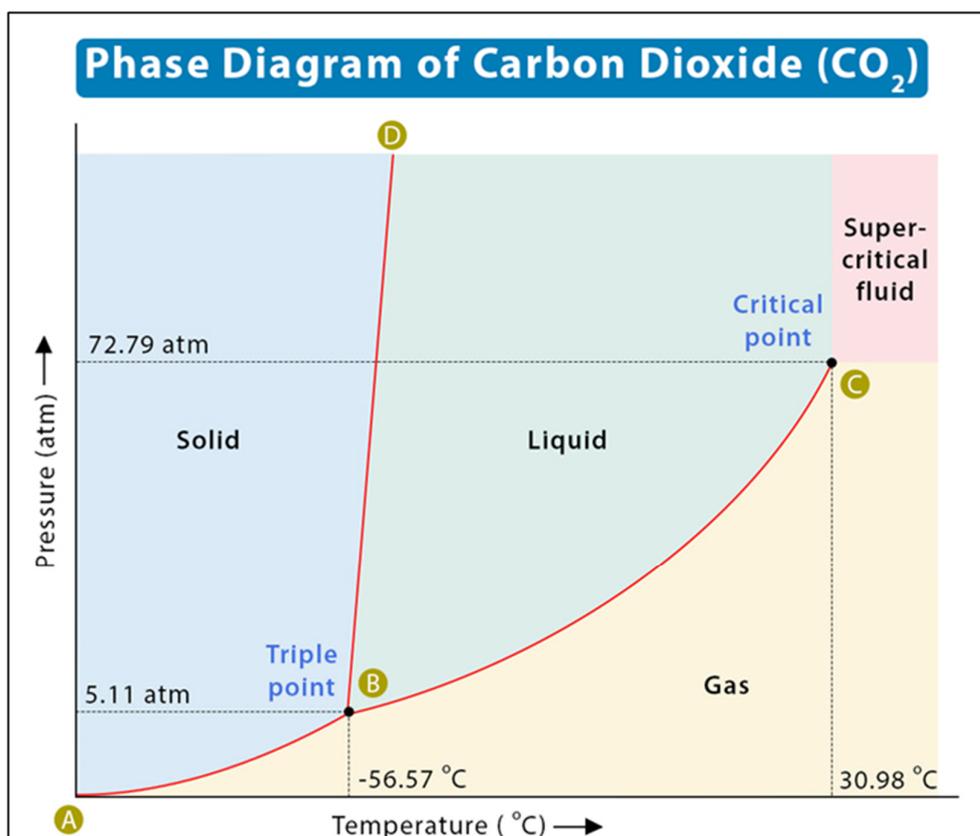


Fig.: Phase diagram of Pure CO₂
(Source: Chemistry Learner [Carbon Dioxide \(CO₂\) Phase Diagram](#))

1.2 Solvent properties:

The solvent properties of CO₂ increase with pressure and temperature with supercritical CO₂ being a highly efficient solvent. This characteristic must be taken into account when selecting materials in contact with CO₂, such as elastomer materials, and when assessing the consequences of a significant pressure reduction (e.g. due to a leak).

There is potential for any substance that is in solution within a high-pressure CO₂ pipeline inventory to be precipitated out at the point of pressure drop due to the decrease in solubility of the CO₂. The precipitation of any hazardous substance held in solution could then result in harmful human exposure or environmental damage at or near the point of release.

1.3 Depressurization Hazards:

High pressure CO₂ when released to atmosphere will undergo a significant cooling due to expansion and potential inclusion of solid CO₂ particles at -79°C. Where the temperature of a CO₂ release plume is below the dew point temperature of the atmosphere into which it is being released, the water vapour in the atmosphere will condense to form a cloud which will be visible to humans, making it difficult to distinguish CO₂ solids from condensed water within the cloud.

If solid CO₂ is formed, a considerable amount of time may be required for the CO₂ to sublime to vapour. The sublimation time will depend on the ambient temperature and the pipeline insulation properties.

The consequence of the very rapid sublimation of solid CO₂ to vapour with the corresponding 750 times increase in volume could lead to over pressurization of the containment envelope.

Appendix 2

Hazard Identification and Mitigation Measures

2.1 Hazards related to Carbon Capture Systems Onboard Ships

Sl. No	Element	Risk/Hazard	Mitigation measures
1	Human	CO ₂ can cause headaches, dizziness, confusion, loss of consciousness and asphyxiation, in case of leakage.	a) Protection devices and measures in case of leakage b) CO ₂ detection and alarm system c) CO ₂ dispersion studies d) Ensure proper welding connection, gaskets and seals e) Impart awareness about CO ₂
		Leakage of CO ₂ can result in its accumulation in low points/low lying areas. Since CO ₂ is heavier than air and at high concentrations it can enter confined spaces such as tanks, sumps or cellars.	a) CO ₂ detection and alarm system b) Installation of OCCS with sufficient ventilation as far as possible c) CO ₂ dispersion studies d) Continuous monitoring of CO ₂ buildup in low lying areas and closed spaces
		Exposure in high concentration can affect the response time of humans. Thus, emergency operations may be affected during CO ₂ leakage.	a) Protection devices and measures in case of leakage
		Dry ice will be formed if liquefied CO ₂ is released to atmosphere from an elevated pressure. This can result in extremely cold temperatures of around -78.5°C. Exposure to dry ice can cause frost injuries/cold burns (Cryogenic burns).	a) Warning signs b) Training in safe handling c) First aid measures d) Awareness sessions for handling emergency situations
		Dry ice can also result in loss of visibility that can make escape from the affected area difficult.	a) Protection devices and measures in case of leakage
		Hazards related to release of CO ₂ such as leakage of CO ₂ and related effects	Ensure use of proper release valves
		Hazards related to presence of impurities in CO ₂ such as CO, H ₂ , H ₂ S etc.	Need to identify case to case basis
		Leakage of carbon capturing chemicals can affect human health depending on the nature of chemical.	Need to identify case to case basis
		Any other hazard related to operation of CC system such as operating conditions (Temperature, pressure), hazards from equipments (compressor, blower), operations (compression,	Need to identify case to case basis

		liquefaction) and hazards from chemicals involved need to be identified (during workshop). This will depend on the method of CC such as pre combustion, post combustion etc.	
2	Ship Structure	Leakage of Co2 and resulting lack of oxygen can affect the functioning of machinery operations such as combustion	Need to identify case to case basis
		Dry ice can also affect the equipment's integrity	Need to identify case to case basis
		Low temperature due to dry ice can lead to materials such as piping materials becoming more brittle (embrittlement)	a) Sufficient design of piping
		Co2 is non-corrosive as long as it is dry. But presence of free water in CO2 results in carbonic acid which is a corrosive fluid which can corrode carbon steel	a) Avoid presence of water/mixing of water with Co2
		Liquid Co2 can be trapped in pipelines which can expand further leading to increase in pressure	a) Pressure monitoring devices and pressure release valves
3	Environment	CO ₂ Emission	a) Ensure leak proof storage
		NH ₃ emissions from degradation of amine-based solvents * * need to verify with technology provider whether the emissions are too significant to be addressed during workshop	-
		Contaminants produced during CC operations	a) Safe disposal measures b) Safe handling measures
4	General	Leakage of carbon capturing chemical can result in fire accidents if they are inflammable	a) Fire detection devices/Alarms b) Design if fire safety measures shall account for fire due to CC system
		Spark can be generated from static electricity from liquified Co2 that can lead to fire if inflammable materials are present nearby	
		CO ₂ Bleve (Boiling Liquid Expanding Vapour Explosion)	-

2.2 Hazards and Risk of CO₂ Handling:

CO₂ is commonly thought of as posing a threat to life through asphyxiation when it displaces the oxygen in air down to dangerously low levels. For CO₂ to reduce the oxygen concentration in air down to a level that is immediately dangerous to life, the CO₂ concentration would need to be in the order of 50% v/v.

Evidence shows, however, that CO₂ does create an immediate threat to life at a concentration of only 15% in air due to the toxicological impact it has on the body when inhaled at this concentration.

To assess the toxicity of substances Health and Safety Executive (HSE), UK has developed what is known as an assessment of Dangerous Toxic Load (DTL) to calculate the exposure conditions in terms of concentration and duration of exposure. In this assessment the specified level of toxicity (SLOT) and the significant likelihood of death (SLOD) are defined.

The table illustrates a significant danger to humans if they inhale CO₂ at concentrations above 7% in air (i.e. > 70 000 ppm) approx. It also highlights the effect of that toxicity increasing rapidly for only small changes in concentration above a certain level (i.e. there is not a large difference between the SLOD and SLOT values).

Table 1: Concentration vs time consequences for CO₂ inhalation

Inhalation exposure time	SLOT: 1-5% Fatalities		SLOD: 50% Fatalities	
	CO ₂ Concentration in air*		CO ₂ Concentration in air*	
	%	ppm	%	ppm
60 min	6.3%	63 000 ppm	8.4%	84 000 ppm
30 min	6.9%	69 000 ppm	9.2%	92 000 ppm
20 min	7.2%	72 000 ppm	9.6%	96 000 ppm
10 min	7.9%	79 000 ppm	10.5%	105 000 ppm
5 min	8.6%	86 000 ppm	11.5%	115 000 ppm
1 min	10.5%	105 000 ppm	14%	140 000 ppm

Note: * Concentration by volume

Source: Assessment of the major hazard potential of carbon dioxide (CO₂), UK HSE

Probit for fatality from exposure to carbon dioxide is given below.

$$Y = \ln C^8 \cdot t - 89.8$$

(Y is the Probit value, C is concentration of carbon dioxide in air in ppm by volume, t is exposure time in minutes). The Probit variable is normally distributed between 2 (zero probability) and 8 (100 % probability of outcome) with a mean value of 5, and a standard deviation of 1.

2.3 Consequences of hydrate formation on pipeline operation:

It is necessary to avoid hydrate formation in carbon dioxide pipelines because there is a strong possibility of solid formation that could choke or even block flow. A piece of hydrate could lodge in a pipeline, restrict the flow and even set up a site for local erosion to start as a consequence.

2.4 Impact of impurities within liquid carbon dioxide:

Carbon dioxide from carbon dioxide capture plants will generally not be pure, and some of the contaminants affect the properties of the liquid. Hydrogen, for instance, a possible contaminant from pre-combustion capture plants, affects the triple point, and does not dissolve in the liquid until the pressure is quite high (>92 bar at 30 °C). Undissolved hydrogen would, for instance, cause a problem in carbon dioxide booster pumps, as two-phase flow would be experienced.

References

1. Part 4 and Part 5 of IRS Rules and Regulations for the Construction and Classification of Steel Ships
2. IBC Code
3. IGC Code
4. IMDG Code
5. SOLAS

End of Guidelines