Novelty Journals

ISSN 2394-7349

International Journal of Novel Research in Engineering and Science
Vol. 13, Issue 1, pp: (54-82), Month: March 2026 - August 2026, Available at: www.noveltyjournals.com

Safety and Technical Considerations in Well-Stimulating Ships and Proposed Key Rule Requirements

PART- II

Proposed Key Rule Requirements for Well-Stimulating Ships

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DOI: https://doi.org/10.5281/zenodo.20668136

Published Date: 12-June-2026

Abstract: **Carrying and handling acids on board well stimulating ships provokes challenges for regulators and operators, due to its links with hazards, risks, and safety concerns.**

This paper seeks to offer a clear overview of safety and technical aspects in well stimulating ships in Part I of the paper and highlights a set of key rule requirements as guidance to stakeholders involved in the applications of these types of ships, in Part II of the paper. The measures implied in proposed rule requirements to eliminate, prevent, contain, mitigate, and control any potential hazards and their consequences of carrying acids in well stimulating ships are explored in Part II of the Paper.

The core contents indicate the extent to which a ship's design, installation and operation are prepared for well stimulating ships in new ship construction, retrofits, and ship in service.

Keywords: **Well Stimulating Ships- Well Stimulation-Matrix Acidizing-Fracturing-Safety of Ships-Risk Assessment/Analysis of Ships-Safety Design-Safety Barriers(layers)-Classification Society Rules-Offshore Support Vessels- Chemical Tanker- Dangerous Goods.**

1. INTRODUCTION

Well stimulation methods, historical background, details about the main two basics categories of well acid treatments: Matrix Acidizing and Fracture Acidizing are introduced.

Well stimulation ships' features include main particulars of typical Hydrochloric acid tanks, typical arrangement, construction details, equipment and systems are given and explained.

The world's marine well stimulation ship fleet analysis is addressed.

The main properties and hazards of acid treating fluids commonly used in well stimulating ships are compiled by the author and presented in simplified Tables.

The utmost goal and outcome of this technical paper was stressed as to participate in highlighting a consolidated and comprehensive provisional rule requirements intended for the Construction and Classification of Offshore Well Stimulation Ships.

The starting points and the foundations of this study are the perceived hazards and risks of handling acids and to amend the old LR provisional rules for well stimulation ships with additional modifications, consolidations, and enhancements. In this study, various existing classification society rules, standards, codes, regulations, and references which are relevant to well stimulation ships were consulted, explored, and utilized. The experience of the author from involvement in well stimulation ship retrofit projects and previous employment with other classification societies is utilized as well. The proposed applicable rule requirements are given.

In well stimulating ships, the carriage and use of acids introduce challenges for regulators and operators. In fact, due to the different chemical/physical characteristics of acids, their link with safety, hazards, and risks arising from using acids are explored and discussed.

The paper indicates and analyzes the key safety and technical considerations interrelated and triggered by the potential hazards and risk-related items associated with carrying and handling acids on board well stimulating vessels. It explored in detail the measures implied in applicable rule requirements to eliminate, prevent, contain, mitigate, and control the relevant potential hazards and their consequences.

Emphasizing the proactive approach, and considering tackling the potential hazards, and risks associated with acid properties and the necessary counter measures as well as the controls required in the design, installation, and operational safety barriers (layers) were identified, explored, and analyzed by the author.

This paper provides a clear overview, simple and essential set of guidance to stakeholders involved in the applications of well stimulating ships. It will be helpful for regulators, ship owners, designers, shipyards, ship operators and researchers, plan approval engineers and field surveyors and indicate the extent to which a ship's design, installation and operation are prepared for well stimulating ships in new ship construction, retrofits, and ship in service.

2. WELL STIMULATION

Is a well intervention performed on an oil or gas well to increase or restore and improve the flow and production of hydrocarbons from the drainage area into the well bore.

Stimulation process is the opening of new channels in the rock for oil and gas to flow through easily and by well stimulating, the hydrocarbon bearing foundation is improved near the well bore.

Sometimes, a well initially exhibits low permeability, and stimulation is employed to commence production from the reservoir. Other times, stimulation is used to further encourage permeability and flow from an already existing well that has become under-productive.

Any applicable and recommended rule set for well stimulating ships should consider and contain many "Safety Barriers" for Design, Installation and Operational aspects for most potential hazards and risks involved when using acids on ships. The rule set shall follow a combination of prescriptive and goal/risk-based approach.

The good engineering practice that the safety of the system should be built into the design and not fully dependent on operational methods or procedures.

Significant attention needs to be paid to safety as part of the design process.

Safety shall be ensured through proper ship design, ship construction and ship operation including crew awareness and training and these important factors must be replicated in the use of HCl.

The utmost goal and outcome of this technical paper was stressed as to participate in highlighting a consolidated and comprehensive provisional rule requirements intended for the Construction and Classification of Offshore Well Stimulation Ships.

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The experience of the author from involving in well stimulation ship retrofit projects and previous employment with other classification societies is utilized as well. [14] [15] [16] [17] [18] [19][20]

The proposed Rules within this technical paper will not cover other well interventions and remain specific to well stimulation only.

It goes without saying that the development of guidelines, rules set, or regulations is always a step or few steps based on continuous learning of other people's efforts. It is not the result of a spur of the moment decision or short-term work or an outcome or decision of only one person, one committee or even the effort of one sole organization. The process is relatively long, tedious, and a continuous process. The development of regulations cannot also go without debate. The swift and final safety aspects and related regulations are a broad issue and can be fulfilled after substantial field experience and accumulation of site and operational feedback.

A ship provided with well stimulation plant and designed, built, and equipped for stimulation of wells in accordance with these requirements will be eligible for; **Class Notation: Offshore Support Vessel / Well Stimulation Ship.** Table (1) summarizes **the most essential sources of rules and statutory regulations** applicable to WSS. [14] [15] [16] [17] [18] [19][20]

Table (1) Applied Rules and Regulations for WSS

Table (1) Applied Rules and Regulations for WSS	
The requirements of LR's published Rules and Regulations for hull, machinery and the well stimulation plant are to be complied with as applicable,	
Application	**Rules/Regulation Instrument**
Ship Structures (General)	LR Rules and Regulations for the Classification of Ships, Pt 3 **Ship Structures (General)** and Pt 4 Ship Structures (Ship Types), Hull structure.
	Hull Structural Requirements of Lloyd's Register's Rules and Regulations for the Classification of Ships.
	Hull Structural Requirements of OSV Chemical Code - Code for the Transport and Handling of Hazardous and Noxious Liquid Substances in Bulk on Offshore Support Vessel.
Acid Cargo Piping System	The **Piping Systems Requirements** of Part 4, Chapter 4, Part 5, Chapter 12 to 15 of the LR Rules and Regulations for the Classification of Ships.
	IMO Resolution A.1122(30) – Code for the Transport and Handling of Hazardous and Noxious Liquid Substances in Bulk on Offshore Support Vessels (OSV Chemical Code).
Topside/Deck Equipment	Majority of equipment installed on topside as packages are designed and constructed in accordance with the international recognized offshore engineering standards.
Piping systems from wells	Arrangements involving return of fluids from the well are not covered by the rules.
Ventilation Arrangement Plan & Air Lock (for Acid Compartment and Pump Room)	OSV Chemical Code with respect to Chapter 10 under provisions of the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.
	The Regulations of **SOLAS 1974** (as amended) with respect to Chapter II-2.
Liquid Chemicals & Liquefied Gases	LR Part 7, Pt 7, Ch 2 Ships with Installed Process Plant for **Chemicals, Liquified Gases** and Related Products Ships with installed process plant.
	Rules for Ships for **Liquid Chemicals.**
	Rules for Ships for **Liquefied Gases.**

Procedures & Arrangements (P & A) Manual	▪ Compliance with Appendix 4 of MARPOL Annex II (Standard Format for the Procedures and Arrangements Manual. ▪ LR Rules for Machinery and Systems, Machinery Installations, Electrical Installations, Liquefied Gas Carriers, Chemical Tankers, Dynamic Positioning Systems, Ventilation) as well as the Rules for Mobile Offshore Units.
	Additional requirements are defined in the LR Rules for Liquefied Gas Carriers for: ▪ Materials for liquid nitrogen. ▪ Design of liquid nitrogen tanks.
	Additional requirements are defined in the LR Rules for Chemical Tankers for: ▪ Requirements additional to these Rules may be imposed by the National Authority with whom the ship is registered and/or by the Administration within whose territorial jurisdiction the ship is intended to operate. ▪ The requirements of these Provisional Rules are based on the assumptions that hazardous liquids or substances will be carried and used in the process, e.g., flammable liquids having a flash point not exceeding 60°C and corrosive acids. Where it is intended that only non-hazardous liquids or substances will be carried and used then the requirements will be modified, where necessary, to take account of the lesser hazards.
Main and Auxiliary Machinery	LR Pt 5 Main and Auxiliary Machinery - Machinery, pumping and piping.
Electrical, Control systems, Refrigeration, and Fire Safety	▪ LR Pt 6 Control, Electrical, Refrigeration and Fire - Control systems, electrical installations, fire protection, detection, and extinction. ▪ IEC 60092 ▪ API RP 505- API RP 505, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1, and Division 2, 1997.
Fire Safety	▪ Regulations of SOLAS 1974 (as amended) with respect to Chapter II-2 / 10.9.1.1; Chapter II-2, Reg.15.2.4, Chapter II-2/10.10, Chapter III. ▪ MSC. Assembly Resolution 952(23). ▪ FSS Code, Chapter 5. ▪ OSV Chemical Code with respect to Chapter 9. ▪ Watertight bulkhead and identify its arrangement complying with IACS UI 156. ▪ Cables shall be fire resistant comply with IEC60331 or equivalent.
Intact and Damage Stability/PPE	The requirements for tank systems and equipment, piping and pumping systems, control, and monitoring systems applicable to well stimulation vessels, including: ▪ Personnel protective equipment. ▪ Intact and damage stability of the vessel.
Dynamic positioning	LR Part 7, Pt 7, Ch 4 Dynamic Positioning Systems - **Dynamic positioning**
Lifting Appliances	Code for Lifting Appliances in a Marine Environment.
General and Specific	Existing Classification Society Rules relevant to WSS: ABS, GL, DNV & CCS.

The most important and imminent safety and technical considerations interrelated and triggered by the potential hazards and risk-related items associated with carrying and handling acids on board are addressed in below sections with detailed discussions.

In the following sections of the paper, measures of tackling, eliminating, mitigating, and controlling the main acid hazards are addressed.

For easy reference, traceability, and recognizing the recommended applicable rule requirements in the text of the remaining part of this technical paper, the text is started by bullet (•) followed by an italic bold text.

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3. WELL STIMULATION SHIPS (WSS)

3.1 Well Stimulation Ship Arrangements

The following rule requirements are applicable and recommended:

•The integrity of the weather deck is to be maintained. Where items of equipment such as cable leads penetrate the weather deck, adequate arrangements are to be provided to prevent the ingress of water to spaces below the freeboard deck. Otherwise, such items are to be fully enclosed in deck houses, or equivalent, complying with the Rules.

Structural strength in way of such arrangements is to be equivalent to Rule requirements for this purpose.

•All accommodation and other compartments that are not directly essential to the operation of the well stimulation plant are to be arranged well clear of the plant, storage, and operational areas.

•The control consoles are to be so sited that the stimulation activities can be kept under constant observation throughout the operation.

•Tanks for acids and liquefied gases or other hazardous substances are to be located inboard of an appropriate damage penetration zone, but in no case less than 760 mm inboard of the moulded line of shell plating.

•Cofferdams may require to be arranged at the boundaries of tanks containing hazardous substances.

•If cofferdams are endangered by gas, they are to be provided with vent pipes led to the open deck and with sounding pipes if they are not accessible.

•Adequate means are to be provided for the protection of ship steelwork in the event of spillage of liquefied gases and/or acid leakage.

•Access to machinery or accommodation spaces is to be from a safe area.

The Safety Barriers here are based on inherent safe design and equipment.

3.2 Hull structure

the following rule requirements are applicable and recommended:

•The hull structural strength shall be as required for the main class considering necessary strengthening of supporting structures for the well stimulation equipment during transit and operation.

•All load effects caused by heavy well stimulation deck equipment shall be considered in the structural design for both transit and operational condition.

The following rules are recommended:

• The longitudinal strength analysis might be carried out as necessary and if applicable.

•Decks and other structures supporting machinery, tanks, and plants, etc. are be considered based on an agreed uniformly distributed loading in association with local loads at plant support points.

•Where the nature and disposition of heavy equipment items are such that forces on the ship and support structure due to ship motions are significant, calculations of the loading and the structural response are to be submitted for review and approval.

•Welding is to comply with the requirements of LR Rules.

The Safety Barriers here are based on inherent safe design and equipment.

3.3 Support Structures

The following rule requirements are applicable and recommended:

• ***The drawings of foundations for such equipment have to be considered as integrated into the structure of the vessel taking into account the acting loads likely to occur during the stimulation process as well as due to the operation of the vessel.***

•***Appraisal to be carried out for hull support structures, based on the loading conditions.***

•***In way of transition joints of dissimilar thickness, chamfering is to be provided.***

•***In way of deck equipment foundations terminating at unsupported plate of panels, additional flat bars of suitable size shall be provided.***

•***Equipment is secured with the foundation by means of double continues fillet welds. Welding and alignment are to be to the attending Surveyors' satisfaction.***

The Safety Barriers here are based on inherent safe design and equipment.

3.4. Locations and Arrangement of Acid Storage Tanks, Piping and Pumping Systems in Well Stimulating Ships
On board protective location of acid storage tanks from grounding and collision hazards, including segregation and separation requirements of acid tanks pumping and piping system are explored in the following sections.

3.4.1 Tanks Location: Onboard Protective Location of acid Storage Tank from Grounding and Collision Hazard

The properties of acids mandate the storage arrangements on board WSS carrying acids.

The location and arrangement of the acid storage tanks, and piping systems tanks shall be optimized to minimize and to guard against such risks of possible acid spillages and consequence risks of an accident such as collision or grounding. Therefore, the location should be optimized to ensure effective safety barriers and to guard against such risks. The worst-case collision scenario would occur if a vessel might hit from the side by a larger ship at full speed. Although the tank is well protected, such an event may have the potential to damage the acid tank. The frequency of such events is, however, considered as being low, and it is probably not cost-effective to design such events.

Safety is also enhanced by the protective location of the acid storage tanks, especially if located above the deck and with free access to open air or below deck at one of the confined spaces.

One of the important issues and consequent Class Rules is the constraints for **the location of the acid tanks.** Generally, the acid storage location can be selected on board the vessel as either vertical or horizontal, on open deck or below deck. When **positioning** of acid storage tanks and pipes on the main deck, the requirements set by the Classification Societies become slightly less demanding.

Acid storage tanks are to be located as near as possible to the center line and as far as possible from ship's side and ship's bottom. The distance should never be less than **760** mm. Hence, the following rule requirements are applicable and recommended: [14] [15] [16] [17] [18] [19][20]

•***Tanks for acid(s) used in well stimulating vessels [Hydrochloric acid (HCl), or / and Hydrofluoric acid (HF), HCOOH, Acetic Acid (CH: COOH) and Formic Acid (HCOOH)] and liquefied gases (nitrogen or CO2) or other hazardous substances are to be located inboard of an appropriate damage penetration zone. In no case to be less than 760 mm inboard of the moulded line of shell plating (measured perpendicularly inboard from the vessel's side to the centerline at the level of the summer load line and at least 760 mm from the bottom), as a protective measure.***

The main origin and driver for these requirements is to protect the tanks in case of grounding or collision. These restrictions are actually not so different from SOLAS requirements of those applying to the conventional diesel tanks in new cruise vessels and follow the same design concepts for double hull tankers.

In fact, and traditionally, the origin of such requirement has been copied initially from early SOLAS regulations on damage stability which is inspired by damage statistics between 1948 and 1966. [13]

Moreover, the acid storage is required to be divided into more tanks of approximately equal size, located in separate compartments to ensure optimum safety and pollution prevention.

The following rule requirements are applicable and recommended:

•The acid tank(s) shall be located in such a way that the probability for the tank(s) to be damaged following a collision or grounding is reduced to a minimum taking into account the safe operation of the ship and other hazards that may be relevant to the ship.

•Acid systems, piping and other acid sources of release shall be so located and arranged that released acid is lead to a safe and contained locations.

•The access or other openings to spaces containing acid sources of release shall be so arranged that flammable, asphyxiating or toxicity cannot escape to spaces that are not designed for the presence of such acid.

•Acid piping shall be protected against mechanical damage.

Figure (1) gives a visual illustration of the minimum safe distance between optimum safety and pollution prevention tank and ship's shell for below and above deck locations.

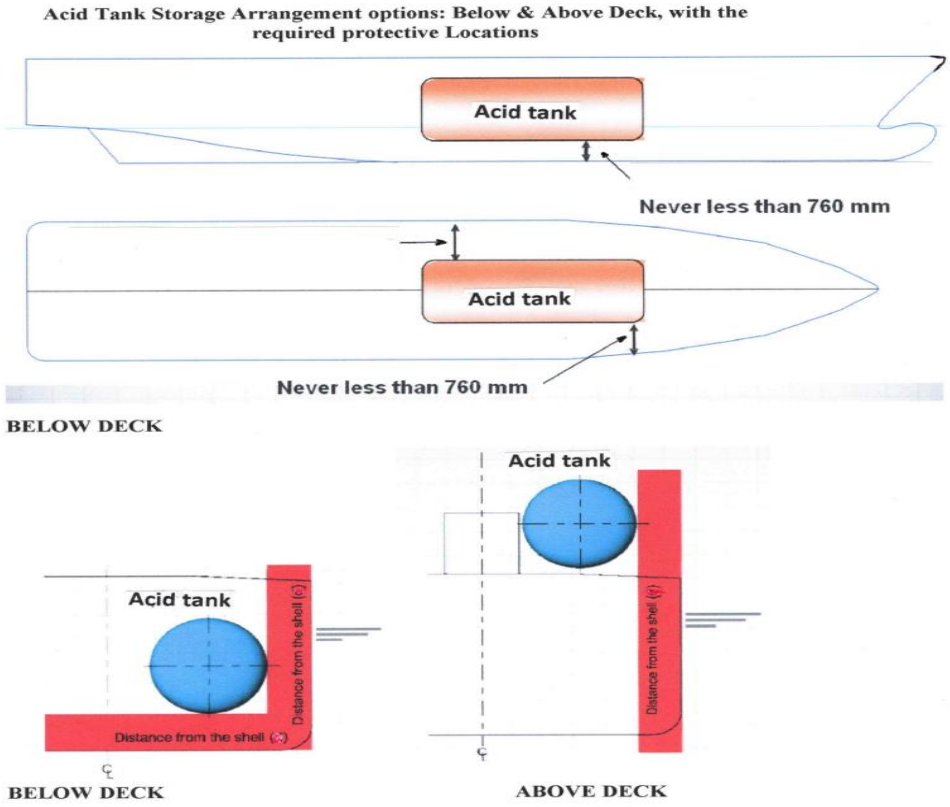

Figure (1) Acid Tank Storage Arrangement options: Below deck & Above deck in open air, with the required protective Locations for optimum safety and pollution prevention

The above discussed Design Safety Barriers of the requirements are relying on inherent safe design, by positioning distant protective limitations.

The following rules are also applicable and recommended:

•The ship's shell plating shall not form any boundaries of tanks containing mineral acids. •Independent portable tanks which are permanently or temporarily installed on the cargo deck of offshore service vessels may be used as storage for the substances necessary for well stimulation. •Certification details of above deck acid tanks shall be provided.

•The area where the tanks are carried is to be surrounded by a suitably tight (temporary) coaming which hinders any spillage and/or substances from leaking tanks to penetrate other areas of the vessel.

•Between the tanks and adjacent walls of the vessel suitable space is to be arranged for checking of the tank walls and passage of the crew.

•Each independent portable tank is to be marked for easy identification.

The Safety Barriers here are based on inherent safe design and equipment.

3.4.2 Segregation Requirements of Acid Tanks pumping and piping System

The following rule requirements are applicable and recommended:

•Acid Tanks, piping and pumping arrangements for the well stimulation processing plants are to be segregated from machinery spaces, propeller shaft tunnels (if provided), dry cargo spaces, accommodation, and service spaces, as well as from drinking water and stores for human consumption by means of cofferdam, void space, cargo pump room, empty tank, oil fuel tank or similar arrangement.

•Acid Tanks should not be carried in either the fore or aft peak tanks.

•Piping Systems for the well stimulation processing plant are not to pass through any accommodation, service, or machinery space other than cargo pumproom or pump-rooms.

•The area designated for well stimulation processing plants is to be arranged as far away as practical from accommodation, service spaces, machinery spaces or control stations.

•Cargoes that react in hazardous manners with other cargoes are to be segregated from them by means of cofferdam, void space, cargo pump room, empty tank, or fuel oil tank. Tanks for other purposes, except of those for fresh water and lubricating oils, may be accepted as cofferdams for these tanks. The spacing between all cargo tank boundaries and adjacent ship's structure is to be minimum 600 mm.

•Independent tanks stowed on deck or installed in otherwise empty holds are considered satisfactory in terms of segregation requirements.

The Safety Barriers here are based on inherent safe design and equipment, and segregation concepts.

3.4.3 Separation Requirements of Acid Tanks, Piping and Pumping System

The following rule requirements are applicable and recommended:

•Tanks and piping systems for the well stimulation processing plant shall be separated from the vessel's machinery and ship- piping systems.

•Tank, piping, and pumping arrangements for the well stimulating system are not to be led from or located in machinery spaces or within accommodation areas.

The Safety Barriers here are based on inherent safe design and separation concepts.

3.5 Spaces for Acid Storage and Handling System

The following rule requirements are applicable and recommended:

•Enclosed spaces containing storage tanks, piping, pumps, and blenders, and other handling systems for uninhibited acid shall have entrances directly from open deck or through air locks from other spaces.

•The air lock shall have independent mechanical ventilation.

•Minimum clear opening for horizontal access shall not be less than 600 mm x 600 mm and for vertical openings not less than 600 mm x 800 mm. The air lockers have independent mechanical ventilation.

The Safety Barriers here are based on inherent safe design and equipment.

3.6 Ventilation of Spaces containing installations for Acid Storage and other spaces containing equipment for well stimulation While locating acid tanks on the open-air deck will facilitate ventilation, ventilation will remain very important for acid tanks just below the main deck and in the vicinity of the machinery room.

In principle, all compartments that contain acid pipework or acid equipment should be adequately ventilated for removal of acid gases for safe personnel access.

In case of acid spillage/leakage, Alkaline materials are to be used as neutralizing chemicals. Since carbon dioxide gas is generated when soda ash is used, ventilation of the working space becomes a crucial safety necessity. [3]

The following proposed rule requirements are applicable and recommended:

•Spaces containing installations for liquids containing inhibited acid shall have an independent mechanical ventilation system with a minimum capacity of 20 air changes per hour, while those containing uninhibited acid a minimum of 30 air changes per hour.

•The ventilation system capacity should be based upon the total volume of the Acid Compartments and Acid pump room and calculation shall be indicated in the plan.

•Ventilation systems extraction from above and below the floor plates of the space should be possible.

•Full required ventilation capacity for each space should be available after failure of any single fan or spare parts should be provided comprising a motor, starter spares and complete rotating element, including bearings of each type.

•New ventilation ducts shall maintain the same fire integrity as the air-lock boundary.

•The ventilation system shall be independent of the ventilation system for accommodation.

•The discharge suctions shall be located both, at floor and ceiling levels of the space concerned

•A warning notice requiring the use of such ventilation prior to entering should be placed outside the acid compartment and Acid pump room.

•Protection screens of not more than 13 mm square mesh should be fitted to outside openings of ventilation ducts.

•Explosion proof electrical equipment is to be used for ventilating spaces containing Acetic Acid.

•Ventilation of spaces for storage and handling dry and liquid additives will be considered case by case based on flammability, toxicity and reactivity properties of the additives used.

3.6.1 Ventilation of Spaces for Liquid Nitrogen

The following rules are applicable and recommended:

•Spaces containing installations for liquid nitrogen shall have mechanical ventilation with a capacity of minimum 20 air changes per hour independent from the ventilation system for the accommodation.

The Safety Barriers in the above subsections are based on inherent safe design and equipment, redundancy, instructions, and procedures.

3.7 Acid Spill/Leakage Prevention and Control As discussed, and tackled in detail earlier, leakage and release of acids and its fumes can lead to personnel injuries, structural failure for exposed steel and equipment.

The biggest risk perceived with acids is that leaks may subsequently damage the vessel. During the Risk analysis process, potential leakage sources shall be identified, and appropriate actions shall be taken. In any case, where acid spill/leakages can occur, two important things must be incorporated into the design to combat the consequences. First, no damage that can harm the integrity of the ship can be allowed to happen. Second, there must be a way to detect and identify the leakage in order to stop it and limit its consequences.

Elimination of this risk can be addressed through isolation measures, the use of inherently safe equipment and the use of sensor and control technologies that automatically shut down equipment if a leak occurs.

The following rule requirements are applicable and recommended:

•The acid handling equipment should be arranged such that an accidental acid leak cannot find its way into any void spaces.

•Adequate means are to be provided for the protection of ship steel structures and ancillaries in the event of spillage or leakage of acid and/or cryogenic effect of liquefied gases such as nitrogen or CO2 (if used).

3.7.1 Acid Spills/Leakage Prevention (Containment)

Containment of a spill or leak is of primary importance. All hydrochloric acid spills should be contained and immediately recovered or flushed with water for the specific purpose of neutralization.

The storage tank should have a containment means and the entire hydrochloric acid unloading area should be designed to properly contain any spills.

Risks of leakage from acid storage and piping systems are encountered by providing it with containment and overpressure relief arrangements as well as ensuring that materials of acid piping, valves, pumps, and ancillaries are properly chosen with the proper suitable materials.

Should anything go wrong, the acid gas detection system should identify the presence of a leak well before it reaches the LFL. In the event of acid detection, the safety system will then isolate all acid supplies. The detection for enclosed compartments and machinery spaces shall be working continuously without interruption.

The Safety Barriers: containment, selecting correct materials and alarming.

3.7.2 Acid Spills/Leakage Control (Dilution, Neutralization and Other Protection Measures)

3.7.2.1 Dilution of Acids

Since HCl acid can be diluted by water and gas is easily dissolved in water, water should always be easily accessible whenever hydrochloric acid is stored or used.

Hydrochloric acid can be neutralized with alkaline material but the reaction between concentrated hydrochloric acid and an alkali gives off heat and can be quite violent. Therefore, the acid should first be diluted by using a water spray and then neutralized.

Enough water will also reduce the fumes of hydrochloric acid.

Safety showers and eye washing fountains should be located in the immediate work area and clearly marked. Every precaution should be taken to ensure that a suitable system is in place and operational before handling hydrochloric acid. These units should be tested on a regular basis.

The Safety Barrier here is dilution.

3.7.2.2 Neutralization

Alkaline materials to be used as neutralizing chemicals are as follows: Quicklime: CaO, Lime: Ca (OH)2, Anhydrous Soda Ash: Na2CO3, Liquid Caustic Soda: 50% NaOH, Flake Caustic Soda: NaOH & limestone (CaCO3). [3] [9]

Since carbon dioxide gas is generated when soda ash is used, ventilate the site well so that the gas cannot remain. [3] Caution should be taken to ensure that the diluted and neutralized acid remains contained. Cleanup and waste disposal must conform and follow current hazardous waste regulations.

The Safety Barrier here is neutralization.

3.7.2.3 Protection of Decks, Floors and Hatches from acid leakage/spill

For protection of decks, floors and hatches from any potential acid leakage/spill, the following rule requirements are applicable and recommended:

•The acid containment system shall be so designed that a leak from the tank or its connections does not endanger the ship, persons on board or the environment. Potential dangers to be avoided.

•Decks or Floors underneath acid storage tanks, pumps and piping for uninhibited acid shall have a lining of corrosion and acid-resistant material extending up to a minimum height of 500 mm on the bounding bulkheads or coamings.

•Hatches or other similar openings in such floors or decks where acid storage tanks, pumps, and piping for acid, are routed shall have watertight coamings having a minimum height of 500 mm and the coamings are to be protected by a lining or an acid-resistant coating.

•Height requirement for coamings may be waived where the Administration decides that this height is not practicable.

•A permanent spill barrier coaming of 150 mm in height shall be provided on deck to keep deck spills away from accommodation, service areas and going to the sea.

•Flanged connections need to be reduced to the minimum possible extent to prevent leaks.

•Flanges or other detachable pipe connections shall be covered by spray shields on acid system installations.

•Flanges of the loading and discharge manifold connections shall be provided with shields, which may be portable, to guard against the danger of the cargo being sprayed; and in addition, drip trays shall also be provided to guard against leakage on to the deck.

•Drip trays of corrosion and acid-resistant material shall be provided underneath acid loading manifold.

•Corrosion and acid resistance protected drip trays or coaming shall be provided in way of Hazardous acid Tanks/Equipment installed on freeboard deck.

•Drip trays shall be fitted where acid leakage/spill may occur which can cause damage to the ship structure, equipment, and crew or where limitation of the area which is affected from a spill is necessary.

•Drip trays shall be made of suitable material.

•Each tray shall be fitted with a drain valve to enable rainwater to be drained over the ship's side or to a safe collection location.

•Each tray shall have sufficient capacity to ensure that the maximum amount of acid spill according to the risk assessment can be handled.

The Safety Barriers here: inherited design, materials, coaming, spill barriers, reducing, shielding and containment.

3.7.2.3.1 Liquid Nitrogen Drip Protection

The following proposed rule requirements are applicable and recommended:

•The issue of cold cracking and brittle fracture of the ship structure, in the event of the cryogenic effect as a result of liquid nitrogen spill, is to be addressed and mitigation measures provided.

•Drip trays resistant to cryogenic temperatures shall be provided at manifolds and at other flanged connections in the system transferring liquefied gases.

The above detailed Design and Installation Safety Barriers utilizing the containment concept.

3.7.2.4 Drainage

For safe drainage and to prevent potential cross-contamination, the following rule requirements are applicable and recommended:

•Spaces housing acid storage tanks, pumping, and piping and pump rooms for acids or additives shall have separate and independent drainage arrangements not connected to the drainage system for other areas.

•Separation of bilge systems are critical to prevent potential cross-contamination of other systems/spaces if there is a leak of acid. This extends to bilges for acid tank hold spaces for underdeck tank locations.

•The cargo pump-room bilge pumping and drainage arrangements for acids shall be of corrosion-resistant materials.

•Drainage system and arrangements for pump rooms, void spaces, any slop tank, double bottom tanks and similar spaces are to be situated entirely within the well stimulation processing area except for void spaces, double bottom tanks and ballast tanks, where such spaces are separated from tanks containing well stimulation substances or residues of such substances by a double bulkhead.

The Safety Barriers here are based on inherent safe design and equipment, separation, and isolation, materials, neutralization, and dilution.

3.8 Material Selection Considerations in WSS carrying acids

Materials and structure which could be affected by a leakage must be chosen with properties to be able to withstand the acid.

Material types which may be considered for service with HCI include nitrile, neoprene, polyvinyl chloride (PVC), butyl rubber, and other suitable materials.

3.8.1 Storage Tanks

The following proposed rule requirements are applicable and recommended:

•The acid storage tank should be made of welded steel or an equivalent material, and they should be lined/coated with strong, acid-resistant materials in accordance with recognized Standards and relevant LR Rules.

•A storage tank should have a means of containment, or bilge coated with an acid-resistance coating/lining to confine any spilled product.

3.8.1.1 Fiberglass-Reinforced Plastic (FRP) coating/lining For Acid Storage Tanks

A fiberglass-reinforced plastic (FRP) lining is constructed in layers of fiberglass, and each layer is mixed with resin. The selection of the resin is extremely important, and the tank manufacturer should specify how each layer will be constructed and specify the correct type of resin for the specific application.

The FRP lining / coating in the tanks to meet the intent of the 'solid state' criteria, is a hot discussion. [21] [22]

IACS Unified Interpretation (UI) UI CC6 was issued to ensure a common basis when considering and accepting linings for the protection of steel tank and pipe materials required by IBC Code item 15.11.2, when carrying acids. [21]

This UI makes it clear that "Spray on" type corrosion protection systems can't be approved for this purpose, while the process of applying solid materials, for example rotational moulding, is acceptable. The technical basis and rationale are that a corrosion protection system applied in liquid state to surfaces cannot be assured to have greater flexibility ("elasticity"), in the cured state, than the supporting boundary plating it is protecting, as required by 15.11.2 of the IBC Code, whereas a lining attached to the tank and pipe surfaces in a solid state (including, for example, rotational moulding) can afford the required flexibility ("elasticity")." [21]

Since IACS Resolutions are usually adopted in Classification Society Rules in full, the Classification Societies should comply with or go beyond such minimum requirements of the IACS Resolutions.

This means the 'elasticity' issue still needs to be addressed. UI CC6 is effectively asking that the lining is capable of remaining bonded as movement of the tank walls occurs.

The issue of possible entrapped air and the variation in thickness, makes hand layup FRP technique to be controversial. It was behind the IACS rejection to be described as solid state.

In view of these arguments, many questions are still open to be answered:

- If the applied FRP coating layer is a mix of resin and CSM/WR which **after curing** becomes a solid state?
- Can an FRP lining be considered to behave more like a solid lining? or does it behave like a coating, which deteriorates over time?
- Can we accept FRP as a solid lining suitable against HCl (corrosion-resistant)? and if so, how will we monitor the condition of the lining?

We still have no solid scientific and experimental data on long term performance of Vinyl Esters in contact with HCl acid.

However, there is evidence that vinyl ester, with glass reinforcement, has been used for a long time in acid containing tanks, where cases experienced with well stimulation classed by other classification societies.

It was referenced the following statement in LR Rules for the carriage of liquid chemicals in bulk: **LR 15.11(b):** *"A corrosion protection lining, when applied to the tank or piping surfaces, is to be applied in* ***solid state****. Application in*

liquid state is not permitted because it may be difficult to ensure adequate control of the thickness of the lining at edges and corners, and to ensure the necessary control of the curing process. A lining approved for use with acids is an acid-resistant material that is applied to the tank or piping system in a ***solid state with a defined elasticity property****, which is to be greater than the elasticity of the structural steel".* [22]

It is advantageously known that composite (reinforced thermoset) liners are commonplace for water-carrying tanks etc., but elastomers/thermoplastics are generally more common for harsh chemicals.

The resin after curing gives high mechanical strength and excellent strength in many chemical environments since it is verified for each specific chemical.

Vinyl esters offer the best combination of chemical resistance to water absorption & acids and strength when compared to polyester or epoxy.

In the other side. All polymers will absorb fluids; the level and speed vary significantly depending on the resin type and the fluid. In this instance, the important thing is that the resin is shown not to leach (i.e., none of the polymer chains are broken- down during long term exposure to HCl) and does not allow oxygen through to the steel to promote corrosion. A thorough inspection (using pinhole detector and thickness gauge) may go some way to mitigating the impact of 'wet' materials use.

Since there are too many variables generating the thickness and composition of the FRP coating with a liquid coating. Therefore, during coating application, it should be ensured it is applied under the right circumstances, coating have no air bubbles entrapped inside, is it evenly distributed.

A composite material's properties are developed during application, the same way a metal's structure is developed during casting etc. Therefore, a clean environment, good training and careful monitoring/inspection are key in any composite application.

As a pre-requisite, the following should be reviewed and approved.

a-Paint spec for acid tanks' coating application.

b-Application/repair procedure from the company who applied the coating manufacturer's confirmation that the appointed company is recognized by them for the type of coating application or a reference letter proving that an appointed company has experience in that type of coating/lining.

c-The company carrying out the work should have been audited, and grant workshop approval is a pre-requisite before starting FRP lining work. As a minimum, training records, experience, and procedures shall be examined to ensure they are following the process correctly.

The surveyor should witness the process of fitting the FRP lining. Quality control documents should be maintained as a minimum: Visual inspection reports, and holiday detection reports.

Stiffeners, frames, stairs, or ladders to be avoided and eliminated FRP during layup operation.

It is also important that any testing used to verify the ability of the liner to withstand the environment should be carried out on samples made by the same personnel and with a strictly defined material set.

As a common industry practice, among the known FRP tests for many purposes such as Ash Test (or so called burn off test) to verify the proportion of glass to resin and Brcol Hardness. Coupons to be prepared for similar FRP lining and carrying out the mechanical testing for the sake of verifying the stiffness (which is a function of Elasticity).

A higher glass content will yield a stiffer panel generally. Barcol is a hardness test – it verifies if the laminate has been properly cured.

There are several tests for coupon stiffness, and it is recommended to carry out some before and after conditioning in HCl, to show any degradation. These tests can also show how stiffness is affected by fiber content, presence of voids, changes in fiber or resin and cure schedule. Once tested, all these need to be fixed in place (void content will be a function of workmanship and access and therefore can only be assessed qualitatively in the tank).

Concentrations of HCl above 35% will cause damage, So, it must be confirmed that HCl concentration never exceeds 35%.

It has been proven and already put in practice the use of "DERAKANE 411-45 coating, suitable for 32 % HCL @ 50 Deg C". It was confirmed by many ship operators that Derakane 411-45, which was in service for 6 years, reveals no issues related to the tanks' structure/FRP lining and confirmed that there was no damage during operation. [3]

The Safety Barriers here are based on inherent safe design, selecting correct equipment/materials, skill training, and awareness.

3.8.1.2 Carriage of Liquid Nitrogen Systems

The following rules are applicable and recommended:

•***Where it is intended to carry liquid nitrogen in bulk, the arrangement is to comply with the applicable Requirements of LR Rules. Relevant LR Rules shall be consulted for materials, piping, pressure/temperature control, nitrogen venting arrangement, personnel protection.***

•***The design and testing of the tanks for liquid nitrogen shall be in accordance with as required for independent cylindrical tanks type C.***

•***Liquid nitrogen is generally kept at atmospheric pressure within temperature range of –210°C to –196°C. Where the working temperature of liquid nitrogen is below –165°C the selection of structural materials is to be undertaken in consultation with relevant LR Rules.***

•***Where the working temperature is below –110°C, a complete stress analysis is to be submitted for approval accounting for the weight of pipes, acceleration loads due to ship motions, internal pressure, thermal contraction, and loads induced by hogging and sagging of the ship, for each branch of the piping system.***

•***IMDG Code requirements for portable tank shall be complied with.***

The Safety Barriers here are based on inherent safe design and equipment.

3.8.2 Equipment, fitting, and ancillaries

Mainly requirements for piping, hoses, pumps, valves, gaskets, and pressure gauges, are addressed in the following subsections.

3.8.2.1 Acid Cargo Piping and Pumping System for Well Stimulation Ships

Appropriate materials should be used for any acid and pipe work designated to carry liquid acid.

In non-marine applications, pipes are typically well supported carbon steel and commonly lined with lining materials such as polypropylene (PP), polyvinylidene fluoride (PVDF) and polytetrafluoroethylene (PTFE). [9] Lined steel is often used in piping systems for hydrochloric acid because of its structural rigidity. Lined steel systems also do not require gaskets at flanged connections since the liner itself acts as the gasket mating material.

In marine use, it is highly recommended to avoid applying FRP lining/coating to piping and its fittings. CPVC or FRP is recommended instead.

FRP (Fiberglass Reinforced Plastic) piping systems used in hydrochloric acid service are constructed of chemically resistant resins **(polyesters and epoxy-based vinyl esters are often used)** that are structurally reinforced with glass fibers during the molding process.

Consideration should be given to coating FRP piping with an ultraviolet (UV) light resistant barrier to extend the life of the piping.

Thermoplastic piping systems used in hydrochloric acid service consist of materials such as **polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polyvinylidene fluoride (PVDF) and perfluoroalkoxy (PFA)**. [9]

The following le requirements are applicable and recommended:

•Generally, piping conveying well stimulation substances shall be joined by welding except as allowed by LR Rules.
•The acid cargo piping system should be subject to a hydrostatic test to at least 1.5 times the design pressure. On completion of work, hydraulic testing or equivalent is to be carried out.

•Storage tanks, pumping, valves, gaskets, and piping for uninhibited acids shall be of corrosion and acid-resistant material or shall have internal lining of corrosion resistant material.

•Proposals for lining applied in the acid steel storage tanks with acid and corrosion-resistant materials (e.g., rubber, Derakane Coating and other appropriate materials) shall be submitted for review and consideration, together with full particulars of the proposed lining material, application procedures, post-application treatment and record of service.

•For acid tanks, coating/linings applied for acid resistant shall be of approved type.

• The elasticity of the lining shall not be less than that of the supporting boundary plating.

•Unless constructed wholly of corrosion-resistant materials or fitted with an approved lining, the plating thickness shall take into account the corrosivity of the cargo.

•The corrosion lining applied is to be applied in solid state. The quality and condition of corrosion protection lining is to be verified to the attending surveyor satisfaction after testing with acid or equivalent medium. Attention is drawn to the high standards of material quality and workmanship required to ensure fault-free application.

•The materials for Class I & II piping systems and other classified components are to be produced at work approved by LR and to be tested in accordance with Rules for the Manufacture, Testing and Certification of Materials.

•The use of the flanged connection in the acid piping system should be limited as far as possible. Flanges should comply with recognized standards as to their type, manufacture, and test.

•Flanges or other detachable piping connections of the loading and discharge manifolds are to be provided with spray shields, which may be portable, to guard against the danger of the medium being sprayed. Chapter 4.4.3 & 4.4.4 of the OSV Chemical Code refers.

•Drip-trays are to be provided to guard against leakage.

•Provision is to be made for suitable apparatus to detect leakage of acids into adjacent spaces.

•The remote actuating isolating valves fitted to the individual filling and discharge line of the 'HCl Acid Tanks' are to be located near to the tank penetration.

•Failure of actuator power is not to permit a valve to move to an unsafe position. The remote-control actuating valves are to be provided with position indication at the remote-control station for the service to show the actual valve position or alternatively that the valve is fully open or closed.

•Provision for local manual operation, independent of remote operating mechanisms, is to be available.

•The material of the cargo transfer pumps shall be of suitable quality compatible to the HCl acid.

•Pump room, piping, pumping, and drainage arrangements are to be independent of other piping systems and of approved corrosion and acid-resistant materials.

•The deck under acid storage tank, pumps, piping for acid should have a lining or coating of corrosion-resistant material extending up to a minimum height of 500mm on the bounding bulkheads or coamings.

•The use of flexible hoses with end connectors shall be in accordance with a recognized standard.

•Tanks, piping, and pumping arrangements for liquid additives having Liquids with Low Flash Point (flashpoint below 60°C) shall comply with relevant requirements of LR Rules.

•Arrangement of pump room for LFL (low flashpoint liquids) substances adjacent to the LFL tanks and without separating cofferdams may be considered in each case.

•Requirements for tanks, piping, and pumping arrangements for chemicals other than acids are considered in each case with due regard to the properties of the chemicals and applicable LR Rules requirements.

The Safety Barriers here are based on inherent safe design and equipment and selecting correct materials, testing, redundancy, eliminating, isolation, and alarming.

3.8.2.2 Hoses and Bunkering Manifolds

Acid resistant hoses can be used to handle hydrochloric acid for both suction and discharge applications. Hose materials that offer good chemical resistance to hydrochloric acid are natural rubber, neoprene, and butyl rubber are some of them. The following rule requirements are applicable and recommended:

•Hoses subject to tank pressure, or the discharge pressure of pumps or vapour compressors, shall be designed for a bursting pressure not less than four times the maximum pressure the hose can be subjected to during bunkering.

•The acid bunkering manifold shall be designed to withstand the external loads during bunkering. The connections at the acid bunkering station shall be of dry-disconnect type equipped with additional safety dry break-away coupling/ self-sealing quick release. The couplings shall be of a standard type.

The external loads that the manifold is to be designed for should include self-weight (including fully loaded), loads due to relative motion between receiving ship and bunker supplier, and loads due to any lifting equipment used to handle the hose.

•A ship-shore link (SSL) or an equivalent means for automatic and manual ESD communication to the bunkering source shall be fitted. [20]

This Installation Safety Barrier is based on inherent safe design and equipment, the ESD concept, monitoring, and alarming, and correct material selection.

3.8.2.3 Pumps

Are mostly chosen composite and lined-steel pumps suitable for hydrochloric acid service and constructed of one of the following materials: PVDF (polyvinylidene fluoride) ETFE (ethylene tetrafluoroethylene) FRP (fiberglass reinforced plastic) PFA (perfluoroalkoxy) PP (polypropylene). [9]

Self-priming centrifugal type pumps are favorably used when pumping hydrochloric acid.

Magnetically driven centrifugal pumps have an advantage in that no seal is required which eliminates the possibility of leakage through a seal.

A double mechanical seal should be considered if regular sealed pumps are used.

The gland area of the pump should be **shielded** for personnel protection.

Hydrochloric acid transfer or offloading pumps should be equipped with **instrumentation** to prevent continued operation when the pump is dead-headed or running dry.

Diaphragm and other positive displacement pumps do not require priming and may find use in these applications.

However, if the diaphragm ruptures, fumes may be worse because of compressed air used to operate the pump.

3.8.2.4 Valves

Several chemically resistant polymers may be suitable for valve lining depending upon the type of valve employed. For instance: PFA (perfluoroalkoxy), PTFE (polytetrafluoroethylene), PVDF (polyvinylidene fluoride) and PP (polypropylene). Composite body ball valves have bodies, balls, and handles made of a fiberglass reinforced epoxy resin. [9]

3.8.2.5 Gaskets

Examples of suitable materials for gaskets are Teflon envelope, ethylene-propylene rubber, or vinyl materials. [9]

3.8.2.6 Pressure Gauges

Pressure gauges need to be protected by a diaphragm from direct contact with hydrochloric acid. [9]

The Safety Barriers in the above sub-sections are based on inherent safe design, correct material selection and shielding.

3.8.2.7 Electrical equipment

3.8.2.7.1 Power Supply

The following rule requirements are applicable and recommended:

•A reliable power supply shall be provided.

•Electrical power supply shall be from a main power system and from a monitored uninterrupted power supply (UPS) capable of continuously operating for at least 30 minutes upon loss of power from the main source.

•The UPS shall be powered from both the main and the emergency power systems.

•Auxiliary energy is required for functionality of emergency control and shutdown.

•Where hydraulic and/or pneumatic power supply is used for actuation of emergency control and shutdown, duplication arrangements shall be made.

.Where driving power for hydraulic and/or pneumatic pumps is electric, power supply circuits shall be connected to the main and emergency power sources separately.

•Where a dynamic positioning system is to be provided the requirements of Dynamic Positioning Systems of the LR Rules are to be complied with

The Safety Barriers here are based on inherent safe design.

3.8.2.7.2 Special Safety Aspects- Area Classification

Definition of the hazardous zone is to be considered on a case by case. It is normal in well stimulation the evolution of flammable material will be limited and so possible the hazardous zone can be reduced in size.

IEC 60092 specifies the hazardous area classification for the sake of the area classification is to minimize and eliminate the potential ignition sources and to allow the correct selection and installation of electrical equipment that can operate safely in such areas.

The following rule requirements are applicable and recommended:

•Electrical installations should satisfy the requirements of Chapter 10 of the International Bulk Chemical Code.

•All mechanical equipment and facilities that could generate sparks should be situated outside hazardous areas.

•Boundaries penetrations for electric cables, pipes, or shafts between hazardous and nonhazardous areas should be eliminated or minimized as practicable as possible. If such penetration is unavoidable, preventive measures against leaks/spill to the non-hazardous areas should be identified, and a relevant risk study and control measures shall be in place.

•Segregation and separation between high-risk hazardous spaces and low-risk non-hazardous spaces.

•For Electrical equipment or other ignition sources in enclosed spaces containing acid tanks and acid piping and pumping arrangements, only equipment certified as safe for operation in hydrogen/air atmosphere shall be used. •Electrical equipment located in hazardous areas is to be of a certified safe type suitable for the gases and vapours involved.

•Because of the danger of evolution of hydrogen when these substances are being carried, the electrical arrangements shall comply with relevant LR Rules. The certified safe type- equipment shall be suitable for use in hydrogen/air mixtures. Other sources of ignition shall not be permitted in such spaces.

•For all types of vessels hazardous and non-hazardous areas shall be investigated and a complete area classification shall be performed, as far as needed in compliance with relevant LR Rules.

•Classified areas related to the installation of well stimulation equipment are to be in accordance with IEC 60092-502. Equipment and machinery are to be suitable to the intended classified locations.

•A notice should be exhibited at the controls of fixed Fire Extinguishing System stating that the system is only to be used for fire extinguishing and not for inerting purposes, due to the electrostatic ignition hazard.

•The alarms of fixed Fire Extinguishing System should be safe for use in a flammable cargo vapour / air mixture.

•The lighting fittings in machinery spaces shall be to a degree of protection, not less than IP 55.

•The protection degree of luminaires on open decks is of, at least IP55.

•Protection degree of the gas detectors and alarm bells on open decks is of, at least, IP56.

The Safety Barriers here are based on inherent safe design, correct material /Equipment selection., instructing procedures, isolation, separation, monitoring, and alarming.

3.9. Monitoring and Control of acid Containment System

The requirements for monitoring and control of acid containment system which include Level Gauging(indicators) for acid tanks, level alarm systems, overflow control of tank fill, venting, vent outlets, and pressure relief from acid storage tanks, are discussed in the following sub-sections.

3.9.1 Level Gauging(indicators) for acid tanks and Acid Tank Level Alarm Systems

Acid storage tanks should be equipped with **instrumentation** to accurately measure tank inventory and provide notification if the storage tank is approaching an over-filled condition.

The following rule requirements are applicable and recommended:

•Each acid tank shall be fitted with liquid level gauging device(s), arranged to ensure a level reading is always obtainable whenever the acid is operational. The device(s) shall be designed to operate throughout the design pressure range of the acid tank and at temperatures within the acid operating temperature range.

•Where only one liquid level gauge is fitted to acid tank, it should be arranged so that it can be maintained in an operational condition without the need to empty or gas-free the tank.

•Cargo tanks shall be fitted with one of the following types of gauging devices:

1. Open device: which makes use of an opening in the tanks and may expose the gauger to the cargo or its vapour. An example of this is the ullage opening.

2. Restricted device: which penetrates the tank and which, when in use, permits a small quantity of cargo vapour or liquid to be exposed to the atmosphere. When not in use, the device is completely closed. The design should ensure that no dangerous escape of tank contents (liquid or spray) can take place in opening the device. 3. Closed device: which penetrates the tank, but which is part of a closed system and keeps tank contents from being released. Examples are the float-type systems, electronic probe, magnetic probes and protected sight-glass. Alternatively, an indirect device which does not penetrate the tank shell and which is independent of the tank may be used. Examples are weighing of cargo, pipe flow meter.

•Open gauging and restricted gauging shall be allowed only where:

1. open venting is allowed by the Code; or

2. means are provided for relieving tank pressure before the gauge is operated

•Tanks for hydrochloric acids shall be equipped with a closed gauging system.

•A high-level alarm shall be provided.

•***The audio-visual alarm shall be activated by a level sensing device independent of the gauging system.*** The Safety Barriers here are based on inherent safe design and equipment, monitoring, and alarming.

3.9.2 Overflow Control of Tank Fill

For safety reasons, it must also be taken into consideration that acid tanks cannot be filled to 100% full. The maximum fill level is 98%, however during bunkering this is reduced to a maximum loading limit of 95% (and depending on the tank conditions and pressure relief valve settings this maximum may not be possible). Consequently, care should be taken during testing to ensure that if the tank is filled beyond the loading limit for the purposes of testing, then the tank is returned to a satisfactory condition before the ship sails. This will reduce the risk of venting and overflow of the acid due to over pressurizing the tank.

The following rules are applicable and recommended:

•***In the event of a power failure on any system essential for safe loading, an alarm shall be given to the operators concerned.***

•***Loading operations shall be terminated at once in the event of any system essential for safe loading becoming inoperative.***

•***Level alarms shall be capable of being tested prior to loading.***

•***The high-level alarm system shall be independent of the overflow-control system.***

•***Cargo tanks shall be fitted with a visual and audible high-level alarm, and which indicates when the liquid level in the cargo tank approaches the normal full condition.***

•***A tank overflow-control system shall:***

a. come into operation when the normal tank loading procedures fail to stop the tank liquid level exceeding the normal full condition.

b. gives a visual and audible tank-overflow alarm to the ship's operator; and

c. provides an agreed signal for sequential shutdown of onshore pumps or valves or both and of the ship's valves. The signal, as well as the pump and valve shutdown, may be dependent on operator's intervention. The use of shipboard automatic closing valves shall be permitted only when specific approval has been obtained from the Administration and the port State authority concerned.

•***The loading rate (LR) of the tank shall not exceed: LR= 3600 U/t m3/h; where; U = ullage volume (m3) at operating signal level; t = time(s) needed from the initiating signal to fully stopping the cargo flow into the tank, being the sum of times needed for each step in sequential operations such as operator's responses to signals, stopping pumps and closing valves; and shall also take into account the pipeline system design pressure.***

The Safety Barriers here are based on inherent safe design and equipment and monitoring and alarming.

3.9.3 Venting, Vent outlets, and Pressure Relief from Acid Storage Tanks

The common practice in filling acid tanks is only one tank should be filled at a time until level reaches 98%. A maximum filling limit of **98%** and a maximum loading limit (under certain conditions) of **95%**.

An Acid storage system is a closed cycle and there must be no venting or discharge to the atmosphere. It is considered a low-pressure system, where low pressure is defined by any pressure not exceeding 10 bar. [23]

Hydrochloric acid storage tanks are vented so that the design limits of pressure or vacuum ratings of the tank are not exceeded so possible tank failure can be prevented.

A properly designed vent system will maintain the tank at or near atmospheric pressure and within the tank design parameters. [9] It is important also to handle and overcome the smaller changes in pressure that occur during static storage conditions due to changes in ambient temperature and the air surge condition especially at the end of unloading.

Vent designs must be based upon a specific system, starting with the **pressure/vacuum rating** for the tank and incorporating maximum anticipated venting requirements which are dependent upon: liquid flow rates; maximum air flow rates for air unloading; transfer line size, length and configuration, and tank pressure/vacuum rating.

A pressure/vacuum relief device should be in place in addition to the tank vent.

The tank manufacturer should be consulted for a recommendation on proper **vent openings and pressure/vacuum relief systems**.

The following rules are applicable and recommended:

•**Acid** ***tanks shall be fitted with a minimum of 2 pressure relief valves (PRVs) allowing for disconnection of one PRV in case of malfunction or leakage/spill.***

•***Vent outlets from acid tanks shall be led to open deck.***

•***The termination of the acid cargo tank's vent outlet should be arranged at a height of not less than 6m above the weather deck and located at a minimum horizontal distance of 5 m from openings to accommodation and service spaces.***

•***The termination of the 'Blender' vent line is to be situated where no danger will be incurred from issuing mixture vapour when blending is in operation.***

•***Vent outlets from acid tanks are to have pressure/vacuum valves provided with flame screens/arrestors.***

•***The PV valves are located at a height more than 6m from the weather deck.***

•***The master of the vessel should be provided with the maximum permissible loading and unloading rates for the group of tanks consistent with the design of the venting system to always protect the cargo containment systems from harmful overpressure or under pressure.***

•***If acid tank vapour return lines are provided leading to the scrubber tank, the master of the vessel should be provided with the maximum permissible loading and unloading rates for the group of tanks consistent with the design of the venting system to always protect the cargo containment systems from harmful overpressure or under pressure.***

Port facilities do not load this product with vapour return, also strength of the non-metallic piping could be an issue for a vapour return ashore. Basically, in this case the vapour refum is connected to the Caustic Soda scrubber. It was considered equivalent as no toxic vapours would enter the atmosphere.

The arrangement for isolation/disconnection of one valve is to incorporate means that prevents both PRVs from being isolated at the same time so that the tank is always protected from excessive pressure build up. Inclusion of this provision allows for the periodic maintenance and testing of relief valves without the need for draining and venting of the acid tank. These Installation Safety Barriers are based on inherent safe design and equipment, relieving, isolation, and redundancy concepts.

3.9.3.1 Tank Venting and Vent outlets from Nitrogen Tanks

The following rules are applicable and recommended:

•***Outlets from safety valves of nitrogen tanks shall be led to open deck.***

•***Outlet pipes shall be arranged and supported to allow for acceptable thermal expansion or contraction during the release of cold gas.***

•***Penetrations of decks or bulkheads shall be such that the structures are thermally isolated from the cold pipes.***

The Safety Barrier here is based on inherent safe design and equipment.

International Journal of Novel Research in Engineering and Science
Vol. 13, Issue 1, pp: (54-82), Month: March 2026 - August 2026, Available at: www.noveltyjournals.com

3.9.4 Hydrochloric Acid Fume Scrubber System

A fume scrubber (closed loop Wet Packed Bed Scrubber technology) can be fitted. It can be part of the storage system to control, reduce and eliminate the release of irritating and corrosive vapors into the workplace and atmosphere, during both unloading operations and during "static" storage conditions. [3] [9]

The acid vapors are removed from the air by scrubbing them with the counter-current flow of water (neutralized). The air then vents out of the top outlet of the scrubber and the weak acid flows into a permitted disposal system.

•If vapor return lines are provided leading to the scrubber tank, the master of the vessel should be provided with the maximum permissible loading and unloading rates for the group of tanks consistent with the design of the venting system to always protect the cargo containment systems from harmful overpressure or under pressure.

The Safety Barriers here are based on inherent safe design and equipment, monitoring, and alarming.

3.10 Control, Monitoring Equipment and Emergency Shut-down System

The requirements for the following related topics are given in below subsections: remote control of the well stimulation processing plant, acid vapor/ gas detection, oxygen deficiency monitoring, leakage alarm emergency shut-down system for (pumps and valves), emergency shutdown of well control system, emergency de-pressurizing and disconnection of transfer hose, and communications.

3.10.1 Remote Control of the Well Stimulation Processing Plant

The following proposed rule requirements are applicable and recommended:

•A system of automatic and manual controls together with process shutdown and operating procedures shall be provided.

•Due consideration shall be given to the normal manning during well stimulation operations, the accessibility of manual controls and the intermittent operation of the system.

•Remote control of the well stimulation processing plant shall be arranged from a position outside the area where the well stimulation systems are located.

•Where tanks or systems are located below deck or in other enclosed compartments, the arrangements are to be such that well stimulation operations can be controlled from a safe location above the weather deck which is outside the compartment in which the tanks or system are located.

•The remote actuating isolating valves fitted to the individual filling and discharge line of the 'HCl Acid Tanks' are to be located near to the tank penetration.

•The remote-control actuating valves are to be provided with position indication at the remote-control station for the service to show the actual valve position or alternatively that the valve is fully open or closed.

•Following conditions apply for the valves that are provided with remote operation:

a. Provision for local manual operation, independent of remote operating mechanism is to be available.

b. Failure of actuator power is not to permit a valve to move to an unsafe position. Positive indication is to be provided at the remote-control station for the service to show the actual valve position or alternatively that the valve is fully open or closed.

3.10.2 Acid Vapor/ Gas Detection

The following rule requirements are applicable and recommended:

•Enclosed or semi-enclosed spaces containing installations of uninhibited acids shall be provided with Vapor detection and alarm systems for hydrogen or hydrogen chloride gases.

3.10.3 Oxygen Deficiency Monitoring

The following rule requirements are applicable and recommended:

•Spaces containing acid tanks and piping system for liquid nitrogen shall be equipped with an oxygen deficiency monitoring system.

3.10.4 Leakage Alarm

The following rule requirements are applicable and recommended:

•Spaces containing equipment and acid storage tanks for the well stimulation system shall be equipped with detection and alarm system for liquid leakages.

3.10.5 Emergency Shut-down System for Acid Pumps and Valves

3.10.5.1 Emergency Shutdown for Pumps

The following rule requirements are applicable and recommended:

•A quick emergency stop of all pumps in the well stimulation system shall be arranged from one or more positions located outside the area housing the WSS.

3.10.5.2 Emergency Shutdown for Valves

The following rule requirements are applicable and recommended:

•A quick emergency stop of all valves shall be provided in liquid nitrogen outlet lines from each acid or nitrogen tank.

•The shut off valves shall be remotely controlled from one or more positions outside the area housing the WSS.

3.10.5.3 Emergency shutdown of Well Control System

The following rule requirements are applicable and recommended:

•Where applicable, at least one emergency shutdown panel capable of operating all essential safety control functions shall be provided at safe and readily accessible location.

•Safety functions may include process shutdown (PSD), emergency shutdown (ESD), emergency quick disconnect (EQD).

•The ESD system should be designed to allow testing without interrupting other systems onboard.

•Systems, actuated devices, and controls shall be designed to fail-safe (i.e., shutdown valves will "fail to- closed" position).

3.10.5.4 Emergency de-pressurizing and disconnection of Transfer Hose

The following rule requirements are applicable and recommended:

•Emergency de-pressurizing and disconnection of the transfer hose shall be arranged from the central control station and from the bridge.

The Safety Barriers in the above subsections are based on inherent safe design and equipment, skill training, awareness, instructing procedures, monitoring, and alarming.

3.10.5.5 Communications

Effective communications are crucial in any response scheme and accident prevention and control. This aspect is heavily considered in safety management systems.

The following rule requirement is applicable and recommended:

•Hardwired means for voice communications shall be provided between the center control station for well stimulation operation and the vessel's position keeping control stations.

The Safety Barriers here are based on skill training, awareness, instructing procedures, and alarming.

3.11 Personnel Safety and Fire protection, detection, and extinction for WSS carrying acids

3.11.1 Personnel Safety Protection

Although PPE is the last line of defense with acid handling, personnel should be provided and should always wear **appropriate protective clothing** necessary to prevent any possibility of skin contact with hydrochloric acid and hydrogen chloride mists or solutions such as acid impervious clothing, gloves, boots, splash proof goggles and others.

Personnel should keep upwind of the spill, and if it is necessary to enter the spill area, a **self-contained breathing apparatus** should be worn. People who are not involved with handling acid, leak or spill should be kept away.

Contact with the acid liquid draining from the equipment should be avoided.

Before entering tanks or opening pipelines that have contained hydrochloric acid, they should be drained or pumped out and thoroughly flushed with water.

The following rule requirements are applicable and recommended:

•Adequate supply of PPE shall be provided and used where appropriate.

•The following personnel protective equipment shall be provided (but not limited to) as appropriate:

•Protective clothing, boots, and gloves to a recognized standard.

•Suitable protective equipment, including eye protection, shall be provided for protection of crew members engaged in handling operations of well stimulation substances, taking into account the character of the substances.

•Protective equipment shall be kept onboard in suitable locations as required by the IMO International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) Res. MSC.4(48) as amended, for carriage of hydrochloric acid.

•Enough protective equipment (in accordance with IBC Code Section 14.1) and safety equipment (in accordance with IBC Code Section 14.2) and Emergency equipment (in Accordance with IBC Code Section 14.3) shall be provided.

•A suitably marked decontamination shower and eye washer(s) shall be fitted and made readily available on deck in convenient locations as per the IBC Code. The shower and eyewash are to be operable in all ambient conditions including under freezing conditions. Temperature control of the water shall be provided in order to avoid excessive temperatures.

•Additional BA sets as per for carriage of chemicals as cargo or dangerous goods should be provided.

•Self-contained positive pressure air-breathing apparatus incorporating full face mask, not using stored oxygen, and having a capacity of at least 1,200 l of free air; each set should be compatible with that required by SOLAS regulation II-2/10.10.

•The Self-contained breathing apparatus should have a duration of service of at least 15 min; and emergency escape respiratory protection should not be used for firefighting or cargo handling purposes and should be marked to that effect.

•Suitable respiratory and eye protection should be provided sufficient for every person on board for emergency escape purposes, subject to the following:

a-*Filter-type respiratory protection is unacceptable.*

b-Steel-cored rescue line with belt; and

c-Explosion-proof portable lamp.

A typical example of PPE provided, namely: PVC suites, Face Shield Attached with Helmet, Rubber Gloves, Rubber Boots, Chemical Protective Cloths, Chemical Goggles, and Escape Respirator Set 15 minutes (1 each for crew), Self-

Contained Breathing Apparatus 30 minutes), Safety Signages including warning tape, safety cones, and similar, first aid Kits, and Safety Data Sheets for acids & additives used.

The Safety Barriers here are based on inherent safe design and equipment, skill training, awareness, instructing procedures, monitoring, and alarming.

3.11.2 Fire protection and Fire Fighting System

The passive (structural **fire protection**) and active firefighting (portable and fixed **fire-fighting** systems) requirements are driven by the potential impact and consequences that the fire hazards in the surrounding spaces may have on the installed equipment.

Consideration needs to be given to the interaction between fire-fighting systems required for the acid system and those required by other regulations linked to the ship type.

The following rule requirements are applicable and recommended:

•Special attention shall be given to fire protection and measures for firefighting, arrangements for firefighting stations, fixed fire extinguishing systems and portable fire extinguishers are to be in accordance with relevant LR as appropriate.

•The requirements of Fire Protection, Detection and Extinction Requirements of LR Rules for Ships are to be complied with so far as they are applicable.

•Additional fire safety measures may be required if the well stimulation installation can be shown to present a special fire hazard.

•Various symbols in fire control plans and legend shall be in accordance with MSC. Assembly Resolution 952(23).

•Bulkhead between paint store and CO2 room shall be A-60 Class.

•WSS control room shall be provided B-Class boundary to the corridors.

•Watertight bulkhead and identify its arrangement shall be provided in complying with IACS UI 156.

•Deck Foam system shall be provided.

•Fixed deck Fire-Extinguishing System of the Dry Chemical Type shall be provided.

Since the deck is crowded and almost completely covered with mechanical and electrical equipment, water system as a firefighting media is not recommended and ineffective.

Vessels current fire protection system will be more adequate with considering additional portable fire extinguishers in areas where flammable materials or spill are potential.

These combined Design, Installation and Operation Safety Barriers are based on extinguishing, instructing procedures, isolation, separation, monitoring, and alarming.

3.12 Training, Familiarization, and Crew Competency

A change in mind-set and safety culture for ordinary OSV vessels is required when considering these vessels carrying HCl and other acids. The lack of familiarity of the ship crew and port facilities personnel with acid handling and the associated safety aspects remain a challenge for the prospective vessels storing and handling acids. Personnel should be properly trained in the handling of hydrochloric acid and should read and ensure familiarization with the Material Safety Data Sheet (MSDS) before handling hydrochloric acid.

The following rule requirements are applicable and recommended:

•Only trained and properly protected personnel should be allowed to enter areas where hydrochloric acid is present or spilled.

The Safety Barriers here are based on skill training, awareness, and instructing procedures.

International Journal of Novel Research in Engineering and Science
Vol. 13, Issue 1, pp: (54-82), Month: March 2026 - August 2026, Available at: www.noveltyjournals.com

3.13 Documentation Requirements

The key required documents in WSS are given in this section.

3.13.1 List of Plans and Drawings Required for Submission, Review and Approval for WSS

The plans, drawings, information, calculations, and particulars where applicable, which are required to be submitted for review and approval for WSS are given in Table (2). [14][15] [16] [17][18][19] [20]

Table (2) Plans and Drawings Required for Submission, Review and Approval for WSS	
The following plans and information, calculations, and particulars where applicable, are to be submitted for approval:	
Hull Plans	A general arrangement plans of the vessel, showing arrangements and disposition of the well stimulation plant including hazardous area/zone.
	Classification and chemical storage area definition, as well as decontamination and eye-washing facilities, and personnel protective equipment location.
	A plan showing structural arrangement in way of the Well Stimulation Equipment fitted. The drawings of foundations for such equipment shall be considered as integrated into the structure of the vessel considering the acting loads likely to occur during the stimulation process as well as due to the operation of the vessel.
	Arrangements, details, and particulars of acid storage tanks whether integral and independent tanks, including support and stays of independent tanks.
	Structural drawings of acid tanks include vent arrangements, including information on non-destructive testing of welds, strength and tightness testing, and specification of protective linings.
	Documentation for liquid nitrogen tanks (if applicable).
Machinery, Piping, Pumping and Systems	Plans and particulars for Pumping and piping arrangements.
	Pumping arrangement including diagrams of piping, pumps, mixing units, and blenders for acid, nitrogen and liquid additives, details of flange connections and pipe clamping/securing as well as specification and data on high pressure flexible hoses with end connections.
	Arrangement plans and particulars of mechanical ventilating arrangements and access to control rooms or other closed and semi-closed spaces containing acid tanks.
	Plans and particulars for the arrangement of venting systems, ventilation pipes, and Tank sounding from acid tanks.
ELECTRICAL & CONTROL	A plan showing Hazardous Area designations.
	Details of the flammability, toxicity or reactivity of any substance/fluid utilized or stored onboard.
	Electrical equipment installations. Including electrical diagrams of well stimulation systems including single line diagram for intrinsically safe circuits, control and monitoring systems for cargo tank level gauging, overflow protection and emergency shutdown, as well as indication equipment for hydrogen, hydrogen chloride and oxygen (as applicable).
	List of explosion-protected equipment together with certificates and references to specific diagrams and/or plans.
	Control engineering systems including Instrumentation and control for handling and storage of fluids/substances used for well stimulation purposes.
	Emergency shutdown arrangements.
Fire Safety	Structural fire protection details.
	Fire protection, detection, and extinction arrangements.
Calculations	Calculations demonstrating adequacy of propulsion power required for the vessel to maintain station during well stimulation operations.
	Stress analysis of supporting structure in way of flexible hose storage reel(s).
	Stress analysis of liquid nitrogen piping (if any) and heat exchangers.
Intact and Damage Stability	The vessel shall comply with the requirements for intact and damage stability. Calculations demonstrating the adequacy of the vessel's stability: ▪ The Trim and Stability Booklet. ▪ Tank Plan or Capacity plan, or table with centres of gravity and tank free surface corrections. ▪ Body Lines plan or Offset Table. ▪ Hydrostatic curves or table. ▪ Cross curves of stability.

	▪ Confirmed Lightship particulars.
	For well stimulation vessels that carry an amount of hazardous and noxious liquid substances that is greater than the lesser of 800 m3 or a volume in cubic meters equal to 40% of the vessel's deadweight calculated at a cargo density of 1.0, the vessel shall comply with the damage stability requirements occurring anywhere in the ship's length at any transverse watertight bulkhead.
Operations Manual for well stimulation	Information, instructions, and procedures regarding the safe operation of the ship under well stimulation operating conditions and processing shall be submitted for review and is to be provided onboard.
	The operation manual shall give particulars on-but not limited to: ▪ Operation Manual for well stimulation procedures. ▪ Personnel protective equipment scope, types, numbers, and locations. ▪ Storage and handling of fluids and dry additives. ▪ Transfer operations. ▪ Emergency shutdown and disconnection and isolation procedure.
Position Keeping	Well stimulation ship shall be capable of maintaining its position safely during well stimulation operations. This may be fulfilled by thrusters, or a mooring system with anchors or dynamic positioning system.
	Station Keeping with Anchors and Cables Position mooring with anchors, cables and mooring winches are to fulfill the requirements for position mooring systems. Safety precautions are to be considered to prevent damaging seabed equipment and installations by anchor deployment, recovery and station keeping.
	Dynamic Positioning System Dynamic positioning systems, when used to maintain the vessel's position during well stimulation. operations, are to comply with the requirements for the LR class notation DP(AA) or DP (AAA).
Flag Administration Requirements	Requirements additional to those given in these Rules may be imposed by the National Administration with whom the vessel is registered or by the Administration within whose territorial jurisdiction the vessel is intended to operate. Approval of structural fire protection, fire extinguishing equipment and/or stability of the vessel by a National Administration, in accordance with requirements equivalent to those by class, may be considered as complying with the class requirements provided such approval can be satisfactorily documented.

The Safety Barriers here are based on inherent safe design and equipment and instructing procedures.

3.13.2 Emergency Response Plan and Procedures

Below is a non-exhaustive list of selected items of Acid Leakage Contingency Plan: [3]

a-An adequate supply of water and lime or other neutralizing materials should be available to neutralize any acid spillage.

b-Stop operation instantly at any leak occurrence even minor ones. Shoot the leak by water and then repair it.

c-When diluting the acid, pour it in the water slowly and stir the water constantly.

d-Never repair the acid containing equipment, pipes during acid handling operations.

e-While hydrochloric acid gas is easily dissolved in water, a water spray must be used to eliminate any leaked hydrochloric acid gas.

f-Wash the place where any hydrochloric acid has been spilled with a large quantity of water.

g- Provide the rooms for using or storing hydrochloric acid with hoses, water taps and drain outlets so that a large quantity of water can be supplied.

h-From containers of highly concentrated hydrochloric acid or heated hydrochloric acid, hydrochloric acid gas that is a little heavier than air will be generated.

i-Flush away hydrochloric acid that has been spilled on any corrosion sensitive materials with water and promptly neutralize it with soda ash or lime.

j-Suitable quantity of soda ash should be delivered along with acid carboys to neutralize the acid in case of acid spill. The following proposed rule requirement is applicable and recommended:

•***The Acid Leakage Contingency Plan document should be developed, established, and placed on board WSS.***

3.13.3 PROCEDURES AND ARRANGEMENTS MANUAL

For compliance with Appendix 4 of MARPOL Annex II (Standard Format for the Procedures and Arrangements Manual.

3.13.4 Material Safety Data Sheet (MSDS)

•***MSDS should be made available and crew before handling hydrochloric acid should be familiar.***

The Safety Barriers in the above subsections are based on inherent safe design and equipment, skill training, awareness, and instructing procedures.

4. THE OVERALL SAFETY BARRIERS (LAYERS) WHEN CARRYING ACIDS IN WELL STIMULATION SHIPS

From the extensive discussion addressed in this paper, we can conclude that the design philosophy of WSS carrying acid has been to focus on applying sufficient safety barriers in order to prevent or to limit the consequences of the potential hazards or to keep the risk within acceptable limits.

The safety philosophy combines the design and operation of the entire system - from acid supply, storage, handling, and operation process to consumers - and includes everything from shut-down functionality to crew training and awareness.

The Rule's latent concepts are always considering "what if the worst-case scenario happened? Are we prepared? Do we have the necessary safety barriers, control, and measures in place to prevent or to contain and mitigate the consequences?"

Examples in applications are wide and options are many: Use drip trays at potential leak points, to safeguard non- acid system materials on board the ship, passive/ active fire safety, venting, ex-proof spark free equipment, containment, inter-barriers, air locks, ESD, isolation, insulation, protective locations, certification, increasing awareness and training, isolation, separation, use of sensors and control technologies, etc.

The author extracted the implied concepts of the Safety Barriers (Layers) embedded within the applicable and recommended rules requirements and made it explicit as illustrated as Swiss cheese model as [23] shown in Figure (2). This provides a helpful tool to interested maritime stakeholders in particular to field/ new construction surveyors and plan approval engineers.

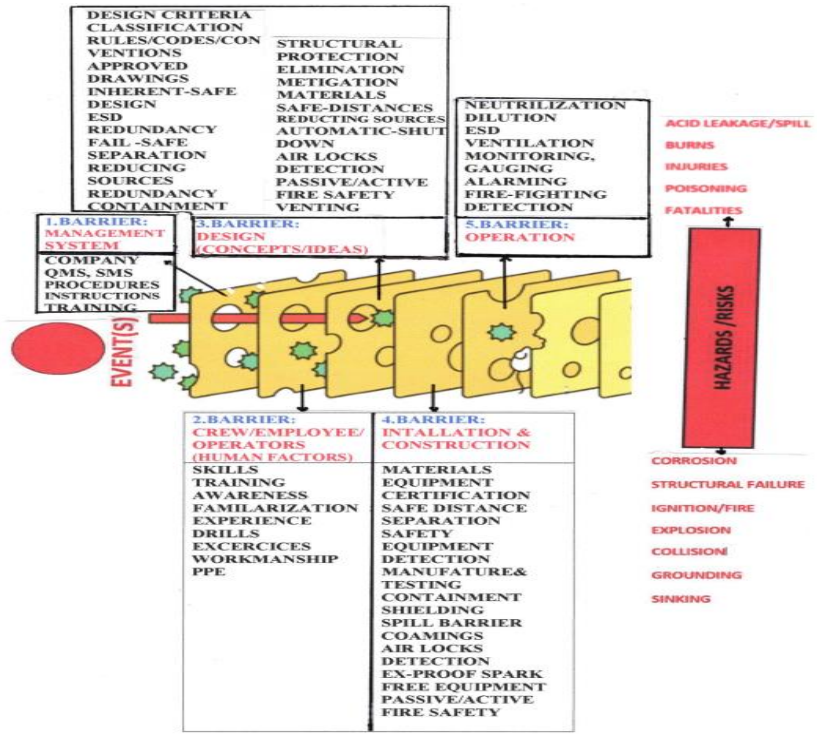

Figure (2) Swiss Cheese Concept of Safety Barriers (Layers) for Well Stimulation Ships

5. CONCLUSION

The work presented in this paper studied "Safety and Technical Considerations in Well Stimulating Ships and Proposed Rule Requirements".

From the study, the following conclusions can be drawn:

1-A brief insight into well stimulation ship type features, hazards, and operation are explored and presented in simplified Tables and Figures as drawn in Part-I of the paper.

2-The needed set of rule guidance was given in detail as a basis for establishing solid guidelines and rules for well stimulation ships to provide support to stakeholders, field, new construction, conversion surveyors and plan approval engineers.

3-The proactive measures implied by the proposed rules requirements are made explicit and illustrated through the analysis and are presented in a simplified form showing the Safety Barriers (Layers) for well stimulation ships.

ACKNOWLEDGEMENT

My gratitude and special thanks go to Captain **Omar Mousa**/ owner and Captain **Mohamed Elbadry**/ DPA of OML (Overseas Marine Logistics L.L.C.) for allowing using photos of ship and also my colleague **Matthew Blyth,** for the language proof-read and the great editing efforts and to my daughter **Mariam** for suggesting ideas, production of graphs and the support in editing this paper.

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