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Evaluating the safe disposal of hydrocarbons present in the oil and gas plants prior to the periodic maintenance operation on the occupational safety and health

Khalid El-Borhamy[1,2], Ahmed M. Elgarahy[3], Ali Maged[4,*], Sherif Kharbish[4]

[1] Chemistry Department, Faculty of Science, Suez University, Suez, 43518, Egypt.

[2] HSE Department, Badr Eldin Petroleum Company, Egypt.

[3] Egyptian propylene and polypropylene company (EPPC), Port-Said, Egypt.

[4] Geology Department, Faculty of Science, Suez University, Suez, 43518, Egypt.

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ABSTRACT

Human intervention and inevitable interaction are substantially associated with the everyday production processes as well as maintenance activities on the platforms of oil and gas, thus immensely influencing the worker's performance in the challenging operational environment. Globally, multi-hazard industrial incidents have gained growing attention as they have much more severe repercussions than single-hazard accidents. Maintenance is a crucial function process in which equipment, units, or whole plants undergo periodic maintenance tasks in safe and reliable conditions to guarantee the specified safety term of safety-critical equipment. Depending on the plant's productivity, it may be classified industrially into five primary types: corrective, predetermined, condition-based, preventive, and predictive, depending on the plant's productivity. Moreover, it may be performed daily, monthly, or annually, considering the mechanical integrity and the unit's operational state to ensure that equipment functions within the design specifications and avoid failure. Indeed, the hazardous gaseous freeing (purging) process is substantially regarded as one of the most pivotal processes in oil and gas plants. It effectively mitigates potentially severe hazards to human health. Therefore, the present work dissects, identifies, and analyzes the potential hazards associated with periodic maintenance works. Moreover, it provides intelligent solutions for safety practitioners to prevent critical hazards during maintenance jobs, which consequently improve the global progress toward inherent safety, as well as future environmental management and industrial planning.

1. Introduction

The chemical processing industry primarily compromises refineries/petrochemical, pulp, paper, food processing plants, as well as generating power. From time to time, the technicians of the process may need to inspect and maintain the malfunctioning equipment (i.e., pumps and compressors), units, and part/whole plants to comply with the planned or emergency shutdown plans and simultaneously minimize the probability of emergency scenarios (Villa et al. 2016). To meet these requirements, the technician of the process should have an extensive experience with systems, equipment, as well as tools. During the process, technicians usually employ hand tools in order to conduct minor maintenance tasks on the running/stopping machinery. Process specialists play an essential preventative maintenance function because, in certain circumstances, simple maintenance may effectively mitigate the probability of major equipment damage (Chin et al. 2020).

Equipment is categorized into stationary and rotary. Electric motors, as well as steam turbines, are two of the most prevalent rotary equipment harnessed in the industrial sector whilst the stationary equipment comprises pressurized vessels, columns, storage tanks, heat exchanges, etc. Usually, process equipment in different industrial facilities undergoes periodic inspections and maintenance works. Therefore, it is majorly important to distinguish between the hazard and risks terms (Pandit et al. 2019).

Hazard is the potential to cause harm. It is an inherent physical, chemical, or biological characteristic that can potentially inflict facility damage, environmental damage, human injury, or all together (Cui et al. 2021). Hazards can be classified into four main categories; (i) major accident hazards, (ii) occupational health hazards, (iii) occupational safety hazards, and (iv) environmental hazards. The significant accident hazards at the site are "uncontrolled occurrences" that can lead to devastating or severe consequences impacts on individuals, as well as the reputation of the company, and thus a significant likelihood of escalation. The term "major accidents" expressly excludes "occupational accidents," which may also have

* Corresponding authors at Suez University

E-mail addresses: ali.maged@suezuni.edu.eg (Ali Maged)

disastrous or severe outcomes. Occupational hazards can be defined as the possibility of triggering "occupational accidents" such as electrocution, drowning, crushing, trips, slips, and falls. Contrarily to the main accident hazard, an occupational hazard cannot lose escalation and control, leading to additional primary consequences (Syed-Mohamad et al. 2021). The occupational safety hazards can be further categorized into flammable materials, electricity, contact with hazardous substances, elevated temperatures, objects under induced stress, and fires / open flames.

In contrast, health hazards can be divided into; physical, chemical, biological, ergonomic, and psychosocial. The environmental aspect is often interpreted as a component of the organizational services, products, and activities, which may impact the environment. In general, various environmental aspects include utilizing natural resources, wastewater discharges, air emissions, waste management, and energy release (i.e., radiation, heat, and noise) during different industrial processes (Warheit et al. 2008). Moreover, the environmental aspects can be classified into; planned (i.e., venting during start-up, flaring, and combustion products from power generation), un-planned (i.e., fugitive emissions, loss of containment such as leaks and spills), and emergency (i.e., emergency venting, and emergency flaring) (Moore et al. 2022). Table 1 summerizes the commonly process safety definitions in oil and gas industries.

Table 1: Commonly process safety definitions in oil and gas industries.

ALARP	ALARP is an abbreviation for "As low as reasonably practicable," which denotes alleviating the level of risks to the point where the effort and expenses (time and trouble) of more decreased risks are extensively disproportionate to the reduced risks accomplished. The critical factor for attaining ALARP is the complete adherence to the standards of BAPETCO as well as procedures.
Cryogenic plug	It is a method involving freezing the liquid contained inside a pipe utilising an externally provided coolant to generate pressure-resistant plugs. These plugs can be employed to achieve temporary isolation, enabling plant or pipeline portions to be repaired, maintained, and modified. Cryogenic plugs can tolerate very high pressures and be kept in place permanently if the pipe's outside is continually cooled.
Deflagration	Combustion that propagates through gas at subsonic rates through a gas, propelled by heat transfer.
Design pressure	The DP (also known as the upper DP, UDP) is the gauging pressure measured at the equipment top in its operational state to define equipment parts' minimal thickness. The process engineer chooses the DP, which is then finalized in close collaboration with the mechanical design engineer. Because the DP is tied to the equipment top, the designer must determine the corresponding DP for other equipment components by considering the maximal pressure drop generated via flow through the equipment and the fluid static head.
Detonation	Sonic Combustion. Detonation results in greater overpressures compared to a similar Deflagration
Gas-freeing	This is the process of establishing a safe environment inside the process equipment/pipes before opening. Gas-freeing is often performed concurrently with the flushing as well as draining operations.
Maximum Operating Pressure	In order to attain appropriate flexibility for the management of the targeted processes, the MOP is normally 105 percent of the OP. Except in pressurized LPG storage sites, in which the MOP equals the pressure of vapour at the calculated maximal operating temperature as well as the evaluated LPG composition, the MOP should be at least 1.0 bar above the OP. A greater MOP must be provided if this margin is insufficient for control, shutting down, starting up, or other particular processes. The cause for the higher MOP will be specified in the remainder of the paper.
Purging	This is the atmosphere within the equipment/pipework process when an inter gas (N_2) purges hydrocarbons before breaking containment. In some areas, N_2 purging may be used to displace air prior to the introduction of hydrocarbons to avoid the formation of an explosive mixture.
Quads	A bank of cylinders containing N_2, in a purpose-built frame, which has a common manifold with a standard high pressure fitting for the connection of a regulator.
Vacuum Test	Testing to guarantee that fluid from outside sources does not enter the apparatus. Usually necessary for any device designed to work in a vacuum environment.

1.1 Fire hazards

Tanks and equipment with a flammable gas service as well as a diminished flashpoint flammable liquid are characterized by elevated vapor and flammable gas concentrations, and their atmospheres will first be over the limit of upper explosive (flammable) (for the stored product). As new air is pumped into the tank during the mechanical gas-freeing operation, the gas as well as vapors are diluted (Bariha et al. 2016). As the vapor-in-air (gas-in-air) combination gets gradually diluted, the atmosphere in the tank/equipment will convert from "too rich" into the flammable range and eventually fall below the limit of lower flammable or become "too lean to burn." The certified person or the responsible supervisor must ensure that the gases or vapors emitted from tank equipment do not generate dangerous emissions outside the tank. Because certain hydrocarbon vapors are denser than air, discharging near the tank's top or elevated height allows for rapid dispersion (when degassing is not utilized or needed) (Zhen et al. 2019). This precautionary action prevents flammable gases or vapors from lying at ground level and moving to an ignition source, where they will ignite and flashback into the equipment or the tank.

Throughout the preliminary vapor and gas-freeing stages, and equipment or the tank still has elevated flammable gas and vapor concentrations, the certified person or the supervisor must limit any maintenance activities in the area near the equipment or the tank. All ignition sources in the area must be prevented during gas and vapor freeing—narcotic effects of Hydrocarbons. Paint vapours often consist of Aromatic Hydrocarbons that standard gas detection devices will not adequately identify. During painting inside confined spaces, gas detection devices must be used in order to detect such vapours (Okamoto et al. 2021). Table 2 shows the initial codes generated for inherently safer hazard prevention strategy.

1.2 Toxic hazards

Qualified staff, supervisors, as well as operations must be familiar with the possible exposure to hazardous and toxic vapours, gases, or dust released from the tank while freeing the gas or vapour (degassing) operation, in addition to implementing or developing strategies for the prevention or control of worker exposure to these chemicals (Wassenaar and Verbruggen 2021).

1.3 Physical hazards

Before the operation onset, HSE and operations must assess the utilized technique for freeing and ventilating gas and vapour, and the construction and condition of the equipment or the tank for determining the possible hazards. If the tank/vessel is subject to a positive pressure but small during gas freeing and ventilation, it shall be ensured that relief (e.g., PVV for tanks) is provided and the tank/vessel is not allowed to be pressurized. If a vapour recovery system or joint vent header links the storage tank, positive isolation must be provided, and a secondary means of relief and venting provided (Rahimpour et al. 2011).

Table 2: Initial codes generated for inherently safer hazard prevention strategy (Ahmad et al., 2019).

Code Number	Code Name	Description
1	Substitution	Replace the existing hazardous construction materials, chemicals, equipment or process design with less hazardous processes and alternatives.
2	Additional Installation	Adding extra equipment or materials to ensure the safety level of the process.
3	Reduce/Elimination	Reduce or eliminate the chemicals, materials or equipment that have been identified as the causes of accidents.
4	Safety Precaution	Refers to inherent safety assessment, modification or installation of safety equipment.
5	Review	Re-visiting the process design, equipment sizing or process safety management in order to prevent the same accident from re-occurring.
6	Optimization	Optimization of process condition to ensure that safer process conditions can be achieved without compromising the output of the process.
7	Improve	Improving the process design in preventing the accident from re-occurring.
8	Control	Refers to flow control of the chemicals that can result to accident.
9	Attenuate	Utilizing hazardous materials under less hazardous condition.
10	Storage	Refers to the storage of the chemicals the storage needs either to be reduced or properly confined.
11	System	Related to control system or safety system in the process.

1.4 Atmospheric hazards

When vessels or tanks are situated close to regions in which internal combustion engines are operated or in low lying areas below the surrounding ground level, the possibility of drawing exhaust gases, toxic fumes, or flammable vapours into vessels or the tanks throughout freeing gas and vapour as well as ventilation operations (in which vapours are accumulating). The certified staff or supervisors must be familiar with these circumstances and take necessary steps to ensure that only fresh, unpolluted air reaches the vessels or tanks (Wojtacha-Rychter and Smoliński 2019).

2. Maintenance

Cleaning is commonly performed before the start-up of new construction facilities and operating facilities following maintenance. Vessels, as well as pipelines, could include hydrocarbons, oil, scale, debris, scale, oxides, and oil have to be eliminated if the plant is to function appropriately (Zhen et al. 2021). Process systems, pipelines, and tanks must be maintained as clean as feasible in order to continue operating at optimal performance. Some of the usual byproducts of working operations include scales, sludge, precipitates, sludge, scales as well as metal deposits. These build-ups foul the tanks and pipelines, reducing system efficiency and triggering clogging and unit failure (Vinnem et al. 2016). The current work outlines the steps needed to guarantee that hydrocarbon process equipment is adequately hydrocarbon-freed prior to breaking the pressure containment; any explosive substances must be purged prior to being returned to hydrocarbon process service, and leak checked guarantee pressure containment is affirmed. This study should be utilized in tandem with the Confined Space Entry Scope and Process Equipment Procedure. In addition, it focuses on purging, gas freeing, as well as hydrocarbon process equipment, and piping leaking tests. Preoperational chemical cleaning is part of the pre-commissioning operations, while maintenance chemical cleaning or post-operational is part of routine shut down activity.

2.1. Preoperational chemical cleaning

It is commonly carried out to eliminate any remaining foreign material from the construction process, either on system fabrication or the pipe. Primary procedures in the preoperational stage include temporary protective coatings, grease, oil, sand, mill scale, weld scale, dirt, corrosion products, and other construction debris.

2.2. Post-operational cleaning

It is carried out for numerous reasons, such as safety, lower flow, as well as diminished heat transfer (e.g., ammonia, H_2S, LELs, and pyrophoric iron), decreased surface area (e.g., catalyst), and access to a full inspection. The frequency and type of post-operational cleaning vary with operation history, operating requirements, system design, and fluid/water treatment.

3. Gas-freeing and purging of the process equipment

One of the most dangerous activities is gas-freeing. The production department must ensure that the responsible staff, testers, supervisors, entrants, standby persons, attendants, workers, and rescuers are aware of possible toxic and flammable hazards and that control measures and adequate prevention are in place during gas-freeing operations (Sklet 2006). When air is introduced into a polluted facility holding hydrocarbons, it might cause a fire or explosion if a source of ignition is present (e.g., pyrophoric materials or static electricity). The introduction of hydrocarbons into a system containing air (oxygen) results in the formation of a flammable/explosive combination (Han et al. 2019). If pure N_2 is inhaled, just a few breaths are required to exchange the air in the lungs for N_2, and unconsciousness will occur immediately. Since cryogenic liquids cool quickly, exposed body parts that come into touch with uninsulated pipework or containers carrying these liquids may cling quickly owing to moisture in the skin. Moreover, cryogenic liquids are characterized by decreased boiling points and rapidly form clouds of vapours or gas at ambient temperature, which may cause lung damage if exposed for an extended time interval. Short exposure to vapours or liquids causes immediate damage to the eyes. Still, exposure to other tissues of the skin has comparable impacts to a burn, and extended exposure may cause frostbite (Jain et al. 2021). Paint fumes often include aromatic hydrocarbons that are not detected by typical gas detection systems. When painting in confined places, gas detection instruments capable of detecting such vapours must be employed (James et al. 2022).

3.1 Draining of process equipment (i.e., pipelines and vessels)

Before pipelines and vessels can be gas freed, they need draining and flushing. Draining should be via the closed drain system whenever possible, in a controlled manner to prevent overloading the system, which requires close coordination between the draining of vessels and an observer at the API/CPI tank or closed drain vessel. Water used for flushing hazardous drains shall also be drained via the closed drains/open drains and requires the same controls around coordination of the operation (Han et al. 2022). In the case of pipelines, it may be impracticable to drain the pipelines to a dedicated drain system. Proven isolation must be applied to the pipelines, and the contents then drained to a temporary drain tank. Since pipelines may cover a long distance and changes in elevation, the focus shall be given to areas of trapped liquids that have not been evacuated during draining, which may discharge when the intrusive activity is executed on the pipelines (Almeida and Vinnem 2020). Criteria for draining vessel process equipment should consider the following: it is a fundamental requirement to verify that the following conditions are met before flushing or draining operations are commenced. If the liquids to be drained include H_2S, NORM, or Mercury; otherwise, specialized waste management and disposal contractors must be utilised. The risks correlated with draining and flushing procedures are LOW (following the placement of controls as part of the TRA). All listed dangers may be safely addressed if the pipework, vessel equipment, and system are depressurized above atmospheric pressure. Several precautions should be considered during the draining of flow lines, vessels, and pipework, including trapped liquids (flow line elevation changes), liquid volume, open vents at high points, flanged sections, pipework size, as well as medium type, i.e., hydrocarbon/water; hydrocarbon, H_2S content, location, oily water, pressure, work type, concurrent activities, and Hazard and Associated Risks of the operation identified (Risk Assessment required) (Sarvestani et al. 2021). Table 3 summarizes the themes identified and reviewed.

Table 3: summarizes the themes identified and reviewed.

Themes	Codes Generated	Grouping Characteristics
Materials	Substitute Material	Change the material used for equipment that encourages accident prevention.
	Improve Design	Improve the design in the process involved to be a safer design.
	Install Additional Instruments	Install additional instruments to improve the process design to be a safer design.
	Substitution	Change the design to a safer design.
Design	Reduce or Eliminate	Eliminate an aspect of the design that can cause accident.
	Safety Precautions	Modify the safety precaution aspects of the design.
	Review	Review the design aspects in order to determine their hazard level.
	Optimization	Optimize the process to minimize accident risk by not affecting the process output.
	Safety Precaution	Implementation of safety measures to prevent operating errors.
	Optimization	Optimize the operating condition for accident prevention.
Operating	Control Operating Condition	Control the operating condition to prevent accident.
	Review	Review or check the operation and operating condition so that similar accidents can be prevented.
	Substitution	Change hazardous chemicals to less hazardous chemicals.
	Reduce or Eliminate	Avoid chemicals that can be the cause of accident.
	Attenuate	Utilizing hazardous materials under less hazardous condition.
Chemicals	Review	Check for the safest measures to handle hazardous chemicals.
	Storage	Store the chemicals in the right way to prevent chemical reactivity.
	Additional Installations	Add solvent or chemical that can help in reducing the hazard level of the process.
	Safety Precautions	Improve the hazard notification system such as the alarm system.
Control	Flow Control	Control of the chemical flow.

3.2 Gas-freeing and purging

Before commencing the purging process, the type and qualities of the substances to be expelled must be considered. Process equipment containing 96 percent N_2 by volume is deemed gas-free (hydrocarbon). The following are the major phases in the N_2 purging procedure and the gas-freeing: Separate from all other equipment, lower pressure, remove vapours and hazardous liquids via depressurization, flush with water if necessary, purge with N_2, and ventilate so the atmosphere can support human occupancy. N_2 for purging operations must be delivered in significant amounts through tankers or portable large volume liquid N_2 tanks. A professional contractor shall supply the N_2 tanks and accompanying equipment, as well as qualified employees to operate the equipment (Gao et al. 2017). Nevertheless, this does not absolve the operations team of overall supervision and safe execution of the task under the permission to work (PTW) System. Figure 1 shows some of the utilized tools during the hydrocarbon freeing process. Figure 1(a) illustrates the pressure gauge, an essential instrument used by industry to measure the pressure in a system as a quality check measure and to ensure the consistency of products. For safety reasons, pressure gauges monitor fluids, gases, and steam for leaks or a build-up of pressure in a system. Figure 1(b) demonstrates the combustible gas leak instrument which can be used to detect combustible, flammable and toxic gases and oxygen depletion. This device is used widely in industry and can be found in locations, such as on oil rigs, to monitor manufacturing processes and emerging technologies such as photovoltaics. The combustible gas leak instrument may also be used in firefighting. Figure 1(c) shows the Mercury test instrument used to detect mercury levels in solids, liquids, or gases for environmental and safety reasons. Figure 1(d) shows the compressed gas (N_2) cylinders. Nitrogen (N_2) is an inert gas. At room temperature and atmospheric pressure, Nitrogen is colorless, odorless, and tasteless. Nitrogen is commonly shipped in cylinders at pressures between 2,000 to 2,600 psi. Nitrogen is widely used during sample preparation in chemical analysis. It is used to concentrate and reduce the volume of liquid samples. Nitrogen is also important to the chemical industry. It is used in the production of fertilizers, nitric acid, nylon, dyes and explosives.

Figure 1. Shows some of the utilized tools during hydrocarbon freeing process; (a) Pressure Gauge, (b) Combustible Gas leak instrument, (c) Mercury test instrument, and (d) Compressed Gas Cylinders (N_2).

Explosions in flare stacks and their associated knock-out drum have occurred a number of times in the past. Because a source of ignition is always present, the possibility of an explosion cannot be excluded, and thus modern flare stacks and seal vessels are designed to withstand one (Sarkari et al. 2022). As the equipment is opened up, air enters equipment that may have been inadequately freed of hydrocarbons and can then form a flammable mixture. This mixture is then drawn up the stack by the chimney effect and ignited by the hot flare stack. The ignited flare (the flare invisible and believed to be extinguished but, in fact, still on) or by an adjacent flare. The flame front travels back into the equipment and is vented via the point of air ingress. Oxygen intrusion may induce the formation of combustible air/fuel mixtures in the stack, which can create a flashback if ignited, which is most probably to be a deflagration, although it might lead to a detonation under specific circumstances. Combustion that propagates through gas at subsonic speeds, driven by the hot product gases re-igniting a new fuel/air combination, is called deflagration (Alhameedi et al. 2022). Detonation is supersonic combustion accelerated by a shock front, resulting in more significant pressures and faster energy release (Zipf et al. 2014).

Before purging, liquid hydrocarbons should be removed wherever possible. When a tiny amount of hydrocarbon liquid is evaporated, it produces a large amount of gas. The relative densities of the gases to be purged should be considered. Downflow purging must be used to displace propane or heavier gases, while up-flow purging should displace ethane or lighter gases (Amer et al. 2021). Specific equipment, notably filter beds, would need to be purged in just one direction. Typically, this will be in the direction of the support structure but always follow the manufacturer's directions. Indeed, there are many N_2 purge techniques available demonstrated in this paper. One or more of these techniques is utilized under normal conditions (Rozuhan et al. 2020).

3.2.1. Atmospheric pressure scenario

This method depends on displacing the contents of the system via a flowing N_2 purge. Whenever possible, purge the system in the direction of the natural flow of the process, i.e., from upstream to downstream. This technique is more efficient when applied to the pipework. The N_2 volume must be at least 120 percent of the piping volume. The vent gas should be routed with extreme caution. It should stay at or near atmospheric pressure in order for the flow to occur. In more intricate systems, blending N_2 as well as the purged gas happens, and the concentration of any element of the purged gas is reduced by dilution rather than displacement to a greater or smaller amount. The sampling technique governs the efficacy of the purging operation at all times (Farzaneh-Gord et al. 2018).

3.2.2. Cyclic pressure purge scenario

The equipment to be purged is pressurized with $N_{2,}$ and a period is then allowed for complete mixing. This approach is efficient in tanks and plants where convolutions, as well as baffles, make flow purging ineffective or when pressure is necessary to displace remaining liquids. This approach is limited to equipment that can resist the requisite pressure; however, a relatively decreased pressure is needed for accurate gas mixing. A simple pressure/volume correlation may be used to determine the volume of N_2 required: If a zero-pressure hydrocarbon system is pressured to 1bar (g) using N_2, the element of hydrocarbon will reach 50 percent. Four one-bar cycles use four volumes of N_2 and yield 6.25 percent hydrocarbons, but a single purge to nine bars uses nine volumes of N_2 and yields 10% hydrocarbons (Borths et al. 2021). It is critical to ensure that the purge does not compromise low-pressure instruments. In most cases, the needed purge will be acquired using consecutive purges, with the number required dependent on operating experience but always controlled by the sampling technique.

3.2.3. Water displacement scenario

In the case of flow lines, where an intrusive activity is planned, e.g., cold cutting, water flush will assist in displacing hydrocarbons but will not remove any trapped pressure due to hydrostatic head caused by elevation changes. The flush shall be conducted from upstream of the isolation and, whenever possible, all the way through to the production plant. Flushing should continue until clean water is detected at the inlet of the processing facility. Due to the internal resistance of the pipework, high backpressures may be experienced while flushing. Therefore, a high flow rate pump may be required and shall be supplied by the N_2 contractor. Controls should be applied to ensure that the MOP of the flow line is not exceeded (Ismael et al. 2016). Once flushing of the flow line has been completed, it can then be purged with N_2 to try and sweep any water from the line. Nonetheless, this will not remove any water trapped in low points unless the line has been pigged. The pressure hazard posed by the hydrostatic head will not have been removed, but the hydrocarbon hazard will have been drastically reduced. The equipment for vessels and interconnecting pipework is first cleansed with water, and any vessels are filled to enable oil to drift out at a high point. N_2 then drives out the contents and replaces them. This approach works well in oil process trains when the cleansing water is driven from vessel to vessel along the typical oil flow channel (Wanderley Neto et al. 2020). The N_2 pressure simply has to be high enough to overcome the liquid head. Because there is minimal mixing, the concentration of N_2 is not diluted. The needed volume of N_2 is just 100% of the process equipment volume; nevertheless, a subsequent N_2 purge (100% of process volume) will assure more efficient outcomes. When this method is adopted, checks are necessary to make sure that the additional weight incurred as the process is filled with water does not exceed the limits of structural design.

3.2.4. Series purging

When plants or vessels can be pressure purged in series, considerable time and N_2 benefits may be achieved by advancing each cycle purge to the next vessel prior to releasing to the vent or flare.

3.2.5. Displacing to air

After purging, it is common to disperse the N_2 in the system or vessel with air to confirm that it is safe to work on, which is accomplished by utilizing forced ventilation educators. The exhaust should be directed downwind of any work parties using flexible trunking.

3.3. Purging following inspection/maintenance works

When opening a piping or vessel system, it must be purged with N_2 to eliminate any remaining oxygen before reintroducing hydrocarbons. The purging for the removal of oxygen may necessitate any or combinations of the processes described in Purging for Gas Freeing. The main difference between purging following inspection or maintenance and purging for gas freeing is that the sampling is for another gas (HC or Oxygen, respectively) to confirm that the vent lines are not releasing an explosive combination (Acheampong and Kemp 2022).

3.4. Sampling

It should be noted that while purging hydrocarbons with N_2, the detector utilised must have the potential to sense a hydrocarbon gas in an inert atmosphere. One example of a detector that may be utilised is the Ultra-fast gas chromatographic with flame ionization detector (UFGC-FID) (Nespeca et al. 2019). The N_2 contractor may be able to supply a suitable detector if requested in adequate time. The checks should be made for both flowing and cyclic purges at the recognized vents and any dead legs in the system. It is also critical to do representative tests while purging the N_2 from the system using air. The entrance criteria are stated in the "Confined Space Entry Procedure.".

4. Leak testing

This section aims to ensure the process equipment integrity that was reassembled following maintenance, repairs, inspection, modifications, and replacement before it is returned to service, which is essential to prevent the loss of process fluid containment, hence guaranteeing the safety of all workers associated with, or near, the plant and maintaining the system's integrity. In addition, it addresses the decision-making process (Reinstatement Policy) for determining the tests necessary prior to reintroduction process fluid into a system following maintenance and invasive inspection. If necessary, the standard requires N_2/He leak testing or inert medium testing utilising an N_2/He mix (Vinnem 2013). Only if reaching the standard is "Not Practicable" and was "Risk Assessed" as acceptable may in-service leak testing be used. MOP (Minimum In-service Reinstatement Pressure) is described in 1.6 above and must be utilised in "Low Risk" situations with five or fewer flanges affected.

4.1. Method options in order of priority

- The leak testing of N_2/He utilizing N_2 /He to 95% RV setpoint pressure - Acceptance criteria is an allowable leak rate of 100scf/year across any flange (Measured by a mass spectrometer).
- Testing N_2 to 95% RV setpoint pressure - Acceptance criteria is 15 minutes holding pressure.
- Gross N_2 Leak Check (10% of MOP or 10bar maximum), then an In-service Leak Test to the system "s operating pressure. Option 3 is only considered if options 1 and 2 are "Not Practicable," the impacted flanges are five or less, and a Risk Assessment has been performed.

Prior to reinstating plant items, all connections disturbed (i.e., flanges and blinds) must be reinstalled according to approved procedures (i.e., gasket type and torque settings).

4.2. N_2/He leak testing of systems

The N_2/He leak testing helps to ensure that our facilities are safe to operate. N_2/He leak testing can detect leaks as small as 0.1 scf/year, whereas bubble-forming solutions only indicate leaks greater than 350 scf/year. N_2/He leak testing will quantify the magnitude of leaks from specific flanges (Yuan et al. 2022). Specialist equipment is required, which shall be supplied from the N_2 contractor, consisting of a "mass spectrometer" and a pre-mixed N_2/He gas, typically of a 5% He mix. N_2/He leak testing shall always be the preferred means of demonstrating that our assets are free of leaks when being reinstated. In order to perform the N_2/He leak testing, the following preparations are required; any connections that have been disturbed to be reinstated as per the recommended flange management system, all disturbed connections to be recorded in a flange break register, all disturbed connections to be recorded on marked-up P&IDs, N_2/He Envelopes to be prepared on marked-up P&IDs (should be incorporated with the above bullet point), all disturbed connections should be "masked" by the N_2 contractor, valid PTW and all associated precautions, and all controls identified and implemented, similar to N_2 purging (Jahangiri et al. 2016).

Method statement for the leak testing, including the sequence of execution of the envelopes, i.e., commence testing on the "upstream envelopes." Consequently, when testing is complete on the respective envelope, the N_2/He mix can be decanted to the next "downstream envelope" where ever possible. Valve closure for the implementation of the N_2/He envelopes to be employed and verified on the plant. Once the entire above is in place, pressurization of each envelope may commence, implementing the following: Pressurize in 25% (of 95% of RV pressure) increments, with a 15-minute hold at each point, monitoring for any pressure decay. Once 95% of RV pressure is reached, the N_2 contractor, in the presence of operations, shall carry out the leak checks on each identified connection using the mass spectrometer, N_2 contractor to supply a detailed report of leakage across all connections. If a connection or flange leaks. The pressurization of that envelope should cease immediately until the leak has been resolved. On completing the N_2/He leak test, the N_2 has to be depressurized to nearly 2 psi (g) for inert blanketing of the system. Remove all tape from disturbed connections or flanges as it shall act as a trap for moisture and may accelerate corrosion.

4.3. N_2 leak testing of systems

It is not often feasible or practical to engage a contractor for N_2/He to leak testing to replace or reinstate valves and pipelines. In such cases, this N_2 leak test utilized in conjunction with bubble forming solution should be used instead, utilizing operations/maintenance personnel and on-site N_2 supplies. This test is a direct pressure technique of bubble leak testing to find leaks in a pressurized component via applying a solution that forms bubbles as leakage gas passes through it, indicating any greater leaks 350scf/year. In the leak test, 100-percent N_2 gas from cylinders or an N_2 skid is utilised to carry out N_2 leak testing. The following preparations are required; any connections that have been disturbed to be reinstated as per the recommended flange management system, all disturbed connections to be recorded in a flange break register, all disturbed connections to be recorded on marked-up P&IDs, N_2 envelopes to be prepared on marked-up P&IDs (should be incorporated with the above bullet point), valid PTW and all associated precautions, and all controls identified and implemented, similar to N_2 purging (Gezerman 2016).

4.3.1. Bubble forming solution

The bubble generating solution (i.e., Snoop) must produce a film that does not detach from the testing area, whereas the generated bubbles must not break quickly owing to low surface tension or air drying. Bubble testing solutions should not be substituted with household soaps or detergents. If the surface conditions in the research region generate concern regarding the formation of a coherent soap film, the technique must be illustrated in another area. The bubble forming solution must be temperature suitable to the test circumstances. Throughout the inspection, the temperature of the components' surface must not be lowe than 7°C or over 50°C. Local heating or cooling is acceptable as temperatures maintain between 7°C and 50°C throughout the test. Other surface temperatures may be authorised if the technique is shown adequately when compliance with the above temperature constraints is impossible (Winter et al. 2022). Via brushing, spraying, and flowing the solution over the inspection regions, the bubble generating solution is applied to the surface to be studied. To eliminate the issue of masking bubbles formed by leakage, the number of bubbles formed in the solution must be limited.

4.3.2. Acceptance criteria for N_2 leak testing (Bubble Test)

Continuous bubble formation on the material's surface denotes leaking through an orifice passage(s) in the area under study. When no continuous bubble development is detected, the region under test is acceptable. When a leak is discovered, the leak's location (s) must be identified and documented. The system will then be depressurized in preparation for corrective action. Following repairs, the restored portions must be retested according to this approach.

4.4. Performing the in-service reinstatement test

In-service testing includes leaks testing with the re-commissioning activity of process medium reintroducing. This reinstatement method may be adopted only if a maximum of five flanges or connections have been disturbed. Gross N_2 leak check is carried out successfully up to 10% of MOP. In all cases of a proposal to use a flammable fluid to conduct an in-service reinstatement leak testing, that proposal has to be approved by the Field Manager at the planning stage (Ahmad et al. 2019). In addition, the test should be performed to the "Maximum Operating" pressure. The process medium should be added gradually. The pressure should be raised in increments up to 20 percent of the maximum pressure attainable or 10 bars (g), whichever is larger, up to 80 percent of the maximal pressure attainable, and then in increments of 10% or 10 bars (g). All disturbed flanges or joints must be checked for leaks by an Authorized Gas Tester at each step of pressurisation. For the test to be approved, the Production Supervisor must be sure that there are no indications of process fluid in any of the related regions.

4.5. Vacuum testing

Some models are developed for vacuum service and must be tested first. It is critical to ensure that any testing equipment is intended for vacuum conditions2 and is adequately isolated prior to testing. The vacuum should be 0.1 bar absolute and should be maintained for a while after shutdown. If the equipment is in hydrocarbon service, any significant air leak inwards might result in an explosive air/hydrocarbon combination. In addition to the vacuum test, items for vacuum service will be tested to a positive pressure of 1.0 bar (g) with either N_2 or air.

4.6. Reinstatement testing of relief valves connected to the flare or relief headers

The removal of system "relief valves" for replacement, repair, and recalibration necessitates a reinstatement leak test on the flanges on the process and flare / relief sides of the valves. With regard to the process side, this may be accomplished by exposing the flange to N_2 or another appropriate inert medium at 95% of the relief valve set point. The flare / relief flange is generally exposed to ambient pressure, which is "practically impossible" on open-ended systems like relief headers and flare (Stewart 2016). In this case, it is adequate to carry out the following; ensure that approved procedures, such as gasket type and torque settings, have been adhered to: First, flanges shall be "masked," and a "single" hole made for testing when using N_2/He leak testing (or in case of service testing Hydrocarbons). Second, normal operating conditions (temperature & pressure) must be achieved. Third, the flange shall be "leak checked" from the single hole and measured for the presence of He or hydrocarbons (in case of a service test) using the appropriate type of gas detector. In the case of the Stand-by relief valve philosophy with proper isolation, a replacement can be carried out during normal operations with the proper precautions (Hellemans 2022).

5. Systematic procedures Gas freeing and ventilating of hydrocarbon storage tanks

The scope of this section is to cover the preparation of the storage tank for gas freeing and ventilation. The storage tank should be out of service before the gas freeing and ventilation activities can be employed. The main activities include removing (emptying) the product, isolation, and flushing the tank (He et al. 2022). Numerous precautions should be considered during the storage tank preparation for gas freeing and ventilation, including; (i) boundary isolation of tanks with a relevant marked up P&ID to facilitate the draining and inserting, (ii) approved isolation certificate with relevant isolation detail sheet, LOTO and associated PTW to allow positive isolation of the tank, (iii) approved Isolation method statement, (iv) flange management to be applied around the insertion of blinds, and (v) toolbox Talk at the worksite with specific TRA. When work on the tank cleaning is first scheduled, and the tank still contains product, operations shall ensure that the tank's inventory has been lowered operationally to the lowest allowable level. No further filling of the tank is possible by closing the tank inlet and outlet valve(s) and any balance connections (Thangam et al. 2021). Where the tank is not blanketed, ensure the vacuum is not pulled on the tank by confirming the vacuum breaker is online during this operation, complemented by a low-pressure feed of N_2 (at a pressure equivalent to the normal operating pressure of the tank). Further removal of the product should be done by draining to the drain system or a suitable pit /dedicated waste tank and then recovering the product using a vacuum tanker (Havinga et al. 2021).

5.1. Isolation

Once the entire recoverable product is removed, the tank requires to be positively isolated for confined space entry, in accordance with the isolation of process equipment procedure. Ignition and energy sources shall also be isolated at this point. These can include but are not limited to electrical, hydraulic, and mechanical connections and all tank equipment, including, but not limited to, tank mixers, heaters, sensors, and other instrumentation.

5.2. Flushing

Flushing shall take place against proven isolation prior to applying positive isolation.

5.3. Cathodic Protection

If the tank or tank lines have cathodic protection, operations shall ensure that, when a tank valve or line is disconnected, isolation of process equipment procedure shall be ensured. For further information, refer to API 2003. Ensure the tank is mechanically isolated, turn off and isolate the cathodic protection system, install a bond wire from the tank to the lines, disconnect and remove the valve or line, and remove the bond wire only after the valve or line is disconnected.

5.4. Control of Ignition Sources

Responsible Supervisors shall assure that all ignition sources in the area are eliminated or controlled before permitting any work to be conducted that might involve the potential release of flammable vapours into the atmosphere around or inside the tank.

5.5. Control of Vehicles

Vehicles shall be restricted to designated safe areas and upwind where possible.

5.6. Electrical Tank Equipment

Prior to issuing a PTW, the responsible supervisor must ensure that all electrical equipment is disconnected, isolated, locked, as well as tagged out, such as alarms, metering devices, overflow protection systems, sensors, electrical heating coils, cathodic protection systems etc.

5.7. Electrical Bonding and Grounding (Earthling)

Bonding/grounding clamps and cables must be examined by a certified person prior to use to ensure excellent condition, integrity, and adequacy as well as frequently and as needed during use. Prior to issuing PTW, the certified staff and responsible supervisor must check that equipment susceptible to causing a spark upon disconnection is correctly bonded and grounded (earthed) by testing before issuing PTW. Refer to API Std. 2015 for more detail.

5.8. Ignition Sources from Compressed Air

Operations shall require, and responsible Supervisors shall ensure that air compressors are equipped with appropriate filters to remove moisture, scale, rust, and oil from the compressed air so as not to generate static electricity, which may become a source of ignition. Entry supervisors shall assure that any compressors used to provide fresh air (non-breathing air) into a tank for vapour and gas freeing, degassing, and ventilation are grounded (earthed) and bonded to the tank.

5.9. Pyrophoric iron sulfide deposits

Responsible Supervisors shall ensure that approved procedures are in place and adequate precautions are required and implemented to prevent pyrophoric iron sulfide deposits (often found in tanks containing sour crude petroleum or petroleum products containing hydrogen sulfide) from becoming an ignition source.

5.10. Gas-Freeing and ventilating of hydrocarbon storage tanks

The process of gas freeing and ventilating a hydrocarbon storage tank removes the flammable hydrocarbon atmosphere and replaces it with inert gas. Where possible vapours and gas should be discharged to the flare system. Any residual shall be displaced to the atmosphere in a controlled manner (e.g., via properly secured and rated hoses to a discharge point downwind of any work activities/areas occupied by personnel or non-ex-rated equipment. Any vapours shall be degassed for sour gas by discharging through a vapour treatment or recovery system.

5.11. Site Precautions during Gas-Freeing and Ventilation

During the gas-freeing process, the hazardous atmosphere of the tank may be progressively evacuated to the environment outside the tank (in the case of tanks not connected to the flare system), where it disperses. As a result, the region surrounding the tank and/or the area where the vapours are vented through hose or trunking should be considered potentially dangerous. In order to alleviate the risks, the following controls are needed to be put in place; gas monitoring for hazardous atmospheres around the tank, Barricading off the area to prevent unauthorized access, venting of the tank gases to a high point or safe area, removal of all ignition sources, and provision of portable fire equipment.

5.12. Gas-Freeing Requirements

The method of gas freeing and ventilation will be decided based on the following; identify the product or material (crude oil, hydrocarbon, additive, or petroleum) stored in the tank, the amount remaining in the tank after removal of the recoverable product, the potential for hazardous toxic and exposures during vapour and gas freeing and regulatory requirements for degassing vapours. The size, design, type, configuration, location, and condition of the tank, including (but not limited to) tank openings, relief devices, flame arrestors, vents, seals, floatation devices, and tank characteristics such as inlet and outlet locations. Regulatory and environmental considerations and requirements for releasing, recovering, or treating liquids, gases, and vapours. The availability of inert gas or water for displacement or purging. Requirements for vapour recovery, burning, and treatment facilities (for sour services). The surrounding area and activities therein could affect or be impacted by vapour and gas freeing (degassing) operations.

5.12.1 Mechanical Gas-Freeing

Gas freeing is required for entry into tanks, for hot works, or washing for clean sludge of the tanks. Gas Freeing is one of the most hazardous operations routinely undertaken inside tanks and the additional risk created by gases expelled from the tanks may be toxic, flammable and corrosive. It is therefore extremely important that all care is exercised during gas freeing operations as the consequences of an inadvertent error can be serious and have far-reaching consequences for personnel and the environment. The gas freeing process can be defined as one of the most dangerous operations in oil and gas plants. The aim of the process is to remove explosive or poisonous gases from the tanks and raise the level of oxygen in atmosphere conditions. Mechanical Gas freeing is used for ventilation of hazardous zones and tanks of oil and gas plants. Fresh air supply and drying of tanks when cleaning.

When the tank needs to be cleaned, it should be subjected to two options :

1- Purged by an inert gas, i.e., Nitrogen (the most effective option).

2- Getting the approval from the technical authority to try the cleaning mechanically using explosion-proof blowers, Educator and extractor fans.

Figure 2 illustrates the most appropriate method to use mechanical ventilation. Mechanically, introducing fresh air into a tank can remove vapors or gas from a storage tank. The tank design, size, type, configuration, condition and location and the product stored in the tank.

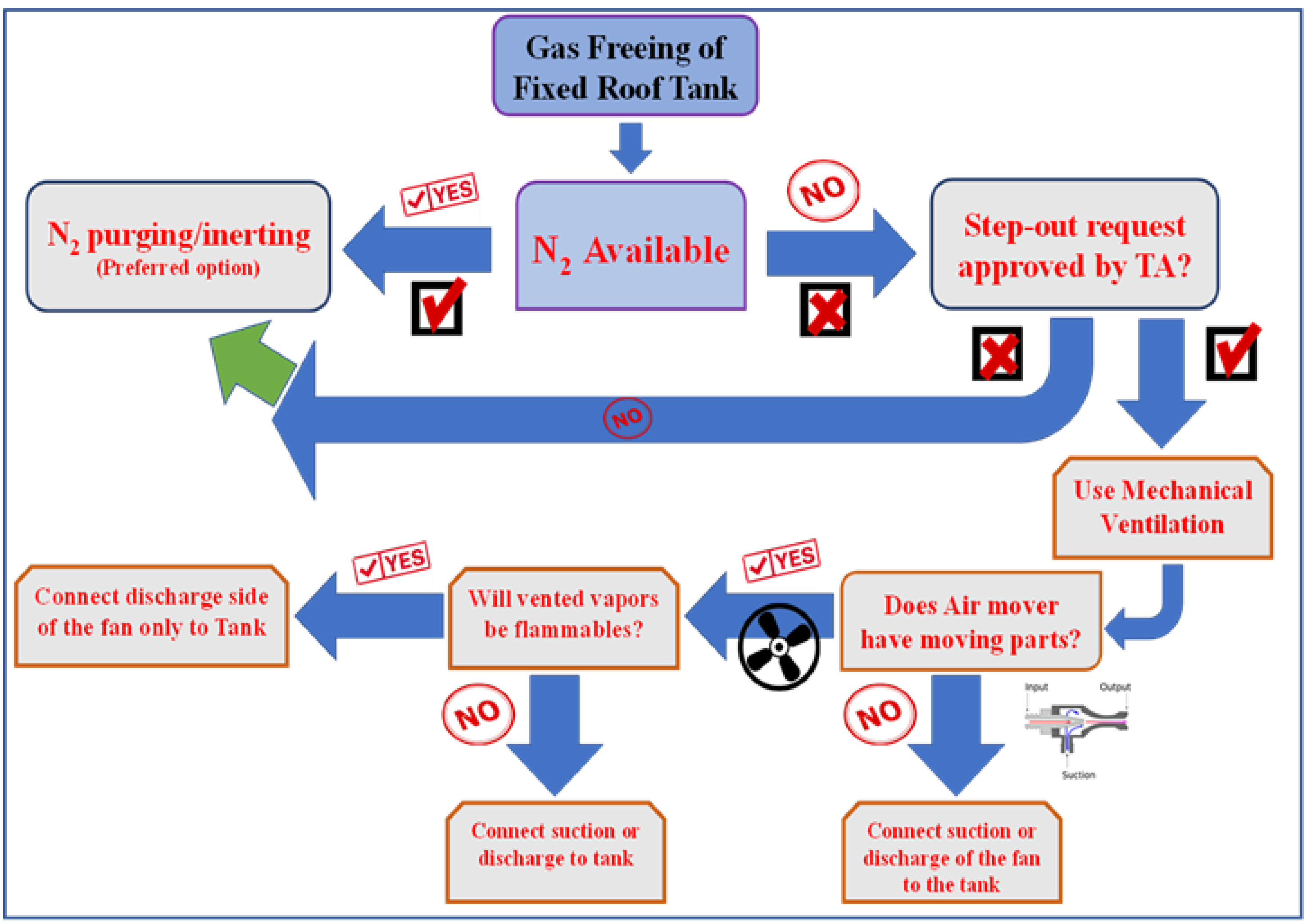

Figure 2. Tank Gas Freeing and ventilation Guide.

5.12.2 Mechanical Gas-Freeing Fixed (Cone) Roof Tank

Figure 3 shows the commonly used methods for mechanically Gas-Freeing Fixed Roof Tanks. For fixed roof tanks, the hazardous vapors inside the tank can either be extracted or displaced. When pulling, an educator creates a slight negative pressure inside the tank that draws in fresh air into the tank at a low level and expels the vapors at a high level. Slight positive pressure is created using a blower at a low level and displacing the vapours at a high level. Vapors expelled or from the tanks can be vented to a safe area or sent to a vapor recovery system for treatment. Educators and air blowers may be operated by compressed air, approved explosion-proof electrical motors or steam.

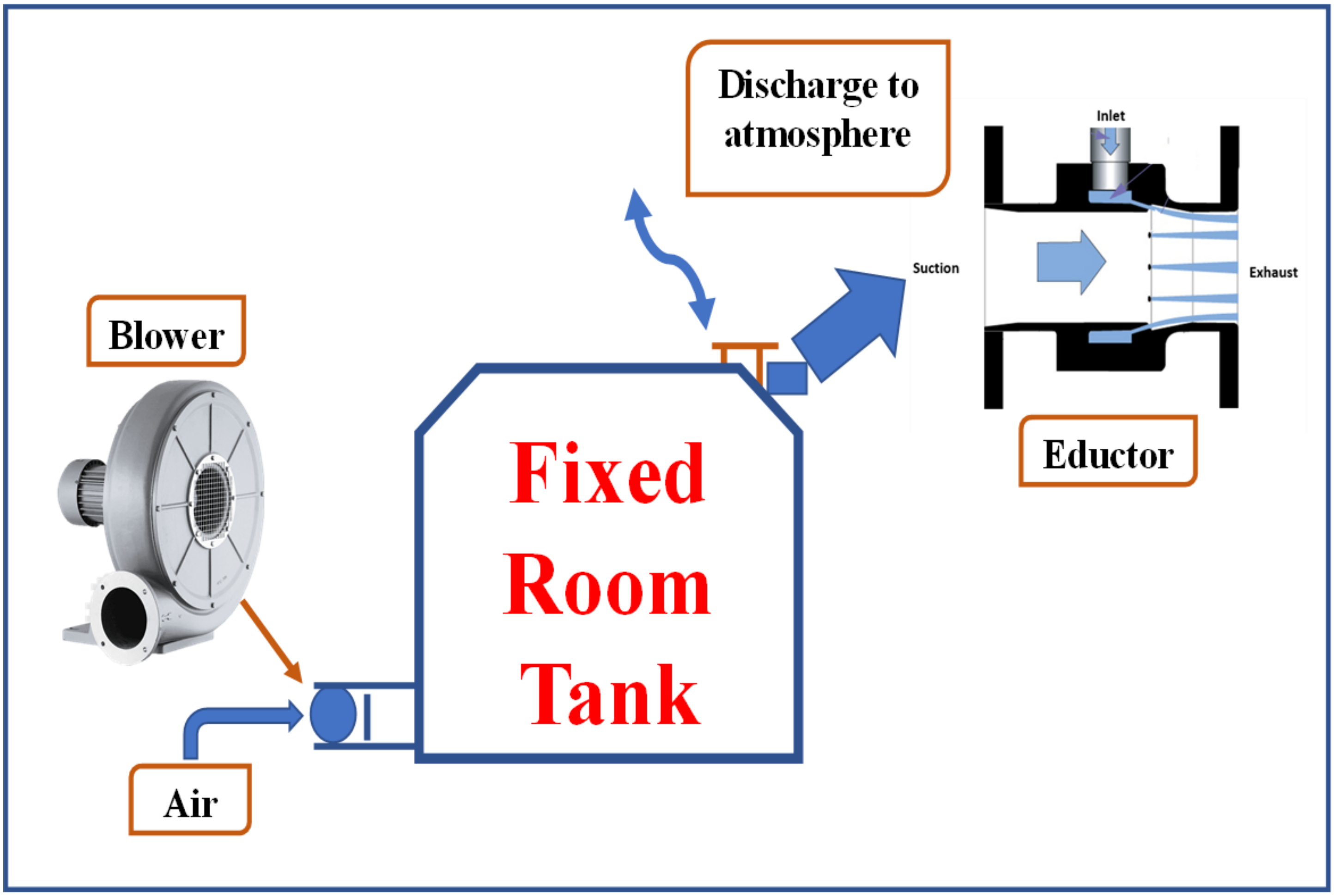

Figure 3. shows the commonly used methods for mechanically Gas-Freeing fixed room Tanks.

Conclusion

Increasing the number of fire hazards and explosions resulting from maintenance operations becomes one of the significant safety concerns due to their impact on human health, equipment status as well as the reputation of the organization. This research proposes an integrated strategy for relating process system dependability to human reliability in the event of a fire or explosion in an oil and gas facility. The possibility of process upsets is considerable, and failure of a safety system may lead to hydrocarbon discharge in an industrial site. Human dependability also has a role in hydrocarbon release. The technique shown here may serve as an effective tool for providing more accurate estimations of human and system dependability in onshore facilities. It combines process system dependability and human reliability to better assess fire and explosion accidents, which might aid in reducing the incidence of such accidents and thereby averting fire and explosion caused by hydrocarbon release.

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