Layout Safety Review

CO_2 Capture Facility

Kårstø, Norway

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Contents

1.0 INTRODUCTION

This document describes the FEED stage Layout Safety Review for the CCC Plant.

The basic requirements for the review are addressed in Fichtner-Gassnova document number 10112936-FI-B-CON-0012 ("Appendix A2 - Explanation of Deliverables"), clause 3.8 "Layout Safety Review Report".

In general, the review requirements and content for the Layout Safety Review are supplied in NORSOK standards S-001 "Technical Safety" and S-002 "Working Environment". As well, clause 3.2 of Fichtner-Gassnova document number 10112936-FI-B-CON-0140-05 ("Exhibit E8.1 - HSE Requirements") will be applied in the completion of the FEED stage Layout Safety Review.

2.0 DISCUSSION

The design basis in facility layout and design should seek to reduce both the probability and the consequence(s) of accidents through location, separation and orientation of areas, equipment and functions. Fichtner-Gassnova HSE Requirements require that probability-reducing measures take priority over consequence reduction.

Safety principles applied in layout design should:

- segregate hazardous and non-hazardous areas from each other,
- minimize the possibility of a hazardous accumulation and spread of flammable fluids (liquids and combustible gases) or combustible liquids ,
- minimize the possibility of hazardous accumulation and spread of toxic hazardous liquids and/or gases,
- minimize the probability of ignition,
- minimize the consequences of fire and explosions to reduce escalation risk,
- facilitate effective emergency response (fire and rescue),
- provide adequate arrangements for escape to a safe location,
- provide adequate arrangements to minimize the risk of occupational injury in each working environment

The elements of the layout design are reviewed in the subsections below. Where issues in the design are identified, appropriate recommendations for action are detailed and summarized in the Conclusions and Recommendations in section 3.0.

The project development stage for this review is FEED. Further detailed layout evaluation must occur throughout detailed engineering and coordinated with the 3D Model review process.

2.1 LAYOUT IN OVERVIEW (HAZARD SEGREGATION)

Under ideal design conditions (e.g. green field design), the chosen plot space permits unrestricted location flexibility in the orientation equipment and buildings to reduce the probability and consequences of damage under loss incident conditions from within or outside the facilities.

The chosen plot space for the CCC Plant limits the ability to orient equipment and facilities with respect to wind direction. The layout design philosophy has been to optimize location of process equipment within process areas, and locate utilities and support buildings at battery limits. This physical isolation of hazardous areas to non-hazardous areas is a fundamental feature of safe design.

The plot space made available for the Kårstø CO2 Capture and Compression (CCC) Plant is an area approximately 270 m (east to west) by 70 meters (north to south). The design basis requires that all process and utilities equipment and necessary buildings and support area be located within this plot space. Appropriate roadway and access requirements further define limitations on the plot space available to locate and space equipment and isolate hazardous from non-hazardous areas.

The CCC Plant is essentially two distinct process areas – the Amine section and the Compression/Liquefaction/Sendout section. These systems will be fully engineered using materials and methods to maintain the systems under normally closed operation in normal conditions. These areas are considered hazardous areas.

The Amine Section of the plant is designed as mostly open area to promote natural ventilation. The use of enclosures that would require mechanical ventilation are considered only in cases where weather exposure to equipment is of concern (e.g. CGMS building housing sample points and instrumentation) or for noise controls (e.g. Flue Gas Blowers).

The CO2 Compression, Liquefaction and Pumping facilities are designed as an enclosed space for weather protection of major equipment and for noise control.

The CCC Plant is designed with additional areas that house the equipment for all necessary utilities, services and stores to support the plant. These areas are located at or near the battery limits of the plant to promote accessibility at the battery limits. These are treated as essentially non-hazardous areas and are isolated from the process portions of the plant by clear space, piperacks with clear space below and above, fire rated construction or barriers to reduce the potential for dimensioning of an accident to greater severity.

The facility employs both hazardous and non-hazardous drain systems to isolate chemical usage areas.

The basic plant process design is a "normally closed" system. The design permits reinjection of effluents from the CO2 section and Amine sump back into the process

to maintain hazardous substances in circulation and segregation from the remainder of the plant.

2.2 FLAMMABLE FLUIDS/COMBUSTIBLE LIQUIDS CONTROLS:

The basic layout design features of the CCC Plant should minimize the probability or consequence of:

- A hazardous accumulation of any flammable fluid (liquid or gas) or combustible liquid in the facility area, AND;
- The spread of flammable fluid (liquid or gas) beyond the leakage area.

Sections below address the main facility layout features that mitigate against a dimensioning load under a release case.

2.2.1 Flue Gas and CO2 Compressor Building

The flue gas ductwork system routed from the Naturkraft CCPP HRSG tie-in through to the CCC Plant absorbers does not present a flammable liquid or gas exposure.

The CO2 Compression, liquefaction and send out sections of the CCC Plant do not present a flammable liquid exposure.

However, both these systems will employ lube skids for machinery lubrication. The lube skids will be located within the associated buildings for the Flue Gas Blowers and the CO2 compressor stages. Appropriate containment is provided in the design to catch spills and prevent a dimensioning loss beyond the spill point. Potential for misting oil is considered low based on the systems pressures being below 10 bar(g).

2.2.2 Amine Section

The main process systems (Amine section) and compression systems (CO2 Compression and Liquefaction sections) are designed as "normally closed" processes, with the exception of the atmospheric Absorber Towers. Amine section operations are located over paved surfaces in a central area in the facility treated as "hazardous".

The absorber towers exhaust stack emissions are not considered ignitable gas mixtures composed mostly of water vapour and inert gas (e.g. N2, Oxygen and Argon).

The rich and lean amine circulating in the process are considered potentially combustible were a leak to occur in the presence of an ignition source.

Operations on these portions of the amine section of the CCC Plant are normally closed, including outdoor sample points and those in the CGMS building. The plant

design greatly limits the potential for a leakage scenario except under accidental or process upset loss of containment conditions.

All equipment drains in amine services are hard piped to the closed drain system, with the closed amine sump as destination. Under contained conditions, a large-scale leakage event is unlikely.

Under a loss of containment, the amine process sections of the CCC Plant are provided with area drainage. This is considered hazardous area drainage and is routed to the amine sump to prevent accumulation on the ground. This is considered in the design of the CCC Plant. Potential fuel for a fire is taken away from the spill area. The design limits possible accumulation of liquids in the leakage area and there is no foreseeable spread to a non-hazardous area.

The main area piperack do not have any equipment located underneath. Piperacks are located within the amine section of the CCC Plant nearby equipment to reduce piping runs. This layout arrangement minimizes piping length and number of fittings, reducing the probability of flange leaks. Drainage for the areas is to the closed drain system if a leak occurs to prevent liquid hold up in these areas. The Fire and Explosion Strategy (Fichtner-Gassnova document number 10112936-PB-S-HSE-0014) will define further requirements for fireproofing of equipment supports or piperacks to prevent dimensioning of a loss. Combustibility of water-amine solutions is considered limited if pooling were to occur, minimizing the need for passive fire protection for structures in the amine section of the plant. Cabling for critical systems will be fire rated as required by Gassnova Exhibit E4.1 - "General Technical Requirements, Field Equipment."

2.2.3 Amine Tankage

Concentrate amine and bulk lean amine are stored in a dedicated and bunded area with piping and equipment in the bunded area minimized. The bunded space can accommodate 110% of the largest tank and limits surface area of leakage.

The bunded space is drained to the amine sump (closed drain systems) if a leak occurs to prevent liquid hold up in these areas.

2.2.4 Main Transformers

The main facility transformers are to be mounted on a pad with drainage to an underground sump capable of holding the oil contents of the largest transformer.

2.2.5 Main Stores

Main stores of lubricants and any flammable liquids, paints, varnishes are to be segregated in a heated and ventilated storage room at the main Control/Shop/ Stores Building or flammable liquid storage cabinets. The storage room design shall include proper containment for the storage volumes required to prevent escape of containment from the room.

2.2.6 Plant Gas Detection Coverage to Reduce Spread

The plant will be provided with both point and line of sight types of combustible gas detection to detect leaks internal to the facilities and from outside (e.g. Gassco ethane leak). Annunciation is provided at strategic points around the CCC Plant to permit effective escape. The detectors all alarm in the Control Room to allow operators to effect a plant shutdown, call for an escape or communicate with the main site Central Control Room for instruction.

All HVAC inlets for buildings or rooms are fitted with redundant gas detectors interlocked to shutdown the HVAC to prevent spread of gas to within an enclosure.

2.3 POTENTIALLY TOXIC LIQUID/GAS CONTROL:

The basic layout design features of the CCC Plant should minimize the probability or consequence of:

- A hazardous accumulation of any potentially toxic fluid (liquid or gas) in facility area, AND;
- The spread of potentially toxic fluid (liquid or gas) beyond the leakage area.

Toxic release cases present the potential for worker injury if not contained or detected and isolated or alarmed quickly. Escape to safe areas is essential.

Sections below address the main facility layout features that mitigate against a dimensioning load under a release case.

2.3.1 Flue Gas

The flue gas ductwork system routed from the Naturkraft CCPP HRSG tie-in through to the CCC Plant absorbers presents a possible toxic gas potential exposure. The systems are normally closed and not subject to leakage under normal conditions.

However, under a leakage case, flue gases could leak into the Flue Gas Blower Enclosures in sufficient concentrations to either deplete the oxygen level, or cause a build up of CO2 or NOx at levels above the DLI 361 OEL.

The ductwork routing is in open air well above grade in a steel structure. In a leakage case, this open air design would benefit from dilution effects. Further study during detailed engineering should attempt to model this flow and dilution of CO2 and NOx.

The design of the system employs components and quality of construction that reduces the probability to a reduced level. The presence of low O2, CO2 and NOx detectors with area annunciation is a further layer of protection against injury and escalation of loss or injury. Under detector annunciation, the area will either be evacuated or not entered.

The impact of flue gas duct leakage to the administration complex for the adjacent Naturkraft facilities requires further study to reduce possible impact to the building occupants. The aspiration of toxic gases into building HVAC systems must be prevented.

The ductwork terminates at the flue gas blowers and runs along the western boundary of the CCC Plant. The western portion of the facility is open at grade. The facility employs point type gas detection for NOx and CO2 at grade with annunciation to warn of a leakage condition. Alarming will permit operators in the Control Room to effect a process or emergency shutdown to minimize the degree of dimensioning of the release.

In the event of a gas leak in either Flue Gas Blower Building, of the CGMS building, the building design should contain the leakage. However, the buildings are not gas tight and some leakage will occur. Toxic gas detection (CO2 and NOx) within these buildings and point gas detectors outside them (and nearby) provide a means of detection of a leak case. Alarming will permit operators in the Control Room to effect a process or emergency shutdown to minimize the degree of dimensioning of the release.

2.3.2 CO2 Section

The CCC Plant contains carbon dioxide at supercritical conditions. In the event of leakage or equipment failure, the released carbon dioxide will reach extremely low temperatures causing a hazard to surrounding equipment and personnel. Additionally the concentrations of carbon dioxide may reach dangerous levels.

The CO2 section of the facility is contained within a dedicated structure for containment. The building is fitted with CO2 detectors in all areas with annunciation in the building and the Control Room.

Under a leakage condition, the Control Room operators can depressure the system. The depressuring arrangements intend to prevent further equipment damage from low temperatures to prevent a dimensioning loss and the compressor shall be shut down in order to limit the depressuring volume to the CO2 supercritical part only.

Venting carbon dioxide is to be routed to the absorber stacks to mix with the exiting flue gases to ensure buoyancy necessary to disperse the carbon dioxide.

The design will choose the best available materials and techniques to maintain containment. The CO2 section is segregated to a cut off building with dedicated HVAC. Full equipment instrumentation and automation for the CO2 compression and pumping operations will alert operators to a developing condition or isolate and depressure the compression section in a safe manner under closed conditions to protect the equipment and personnel.

Efficiency of escape paths in the event of an emergency condition are provided in the design and the CO2 compression, liquefaction and pump facilities are intended to

run automatically for normal operation. CO2 sampling and analysis is undertaken in a cut-off analyzer room as a further layer of protection in the design.

2.3.3 Amine Section

The two absorber tower emissions contain components that are toxic (CO2, NOx) in sufficient concentrations at the exhaust point that the upper platform of each absorber should be treated as a restricted access location while the CCC Plant is in operation. Additional PPE requirements will be required if the platforms must be accessed while the unit is in operation.

However, the rich and lean amine circulating in the process are considered potentially toxic were a leak to occur nearby a worker.

Under a loss of containment, the amine process sections of the CCC Plant are provided with area drainage. This is considered hazardous area drainage and is routed to the amine sump to prevent accumulation on the ground. This is considered in the design of the CCC Plant. These portions of the amine section of the CCC Plant are normally closed, including outdoor sample points and those in the CGMS building. The plant design greatly limits the potential for a leakage scenario except under loss of containment conditions that present a toxic potential to workers.

All equipment drains in amine service are hard piped to the closed drain system, with the closed amine sump as destination. Under contained conditions, a large-scale leakage event is unlikely.

2.3.4 Amine Storage

Concentrate amine and bulk lean amine are stored in a dedicated and bunded area with piping and equipment in the bunded area minimized. The bunded space can accommodate 110% of the largest tank and limits surface area of leakage.

The bunded space is drained to the amine sump (closed drain systems) if a leak occurs to prevent liquid hold up in these areas.

2.3.5 Soda Ash Storage

Soda ash will be supplied as a solution in water in tote tanks, with a typical content of 1672kg. The soda ash solution will only be consumed during reclaimer operation and it is envisaged that during reclaimer operation the tote tank will be require changing every 12 to 24 hours. The tote tank change will require using a forklift truck. Tote tank changeout will occur in the drainage area of the Amine section of the plant, which is drained to the closed drainage system. Washdown stations will minimize the extent of a leak. Soda ash solution was selected to reduce the occupational exposure risk to workers as compared to caustic soda.

It will be necessary to maintain additional tote tanks in heated storage and a stock of 14 tote tanks providing for 1-week reclaimer operation is envisaged. The stock and in service tote tank shall be stored together close to the reclaimer facilities and provided with a containment bund.