TECHNICAL PROPOSALS FOR THE CONSTRUCTION AND EQUIPMENT OF LOADING AND UNLOADING MODULES

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Author(s)		Chinese T. Malabotti S.
Reviewed by		Taccani R., Capobianco M.
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Financial/Administrative Coordinator	
Project Coordinator Name	Mr. Loris COK
Project Coordinator Organization Name	NAVALPROGETTI Srl
Address	Via dei Papaveri, 21 34151 TRIESTE (Italy)
Phone Numbers	0039 040 212918,
Email	loris.cok@navalprogetti.net gasvessel@navalprogetti.net
Project web–sites & other Access Points	www.gassvessel.eu

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Foreword

The present document describes the on–board loading and unloading system for compressed natural gas (CNG) designed to serve the needs of GASVESSEL for all possible scenarios.

Chapter §1 briefly introduces the state of art of CNG ship transportation and CNG loading and unloading systems based on the available public information as hint for the development of GASVESSEL loading and unloading system. A review of applicable standards and regulations for the overall system and for the most important components is introduced in Chapter §2.

The general arrangement of the on-board gas distribution system (primarily piping and valves) is analysed in Chapter §3 while the main components of the loading and unloading system are introduced and discussed respectively in Chapter §4 (Compressors), Chapter §5 (Compressors' accessories) and Chapter §6 (Heat Exchangers).

The loading and unloading philosophy and the detailed description of the processes and the sequence of operations are introduced in Chapter §7.

We recall that piping and piping distribution as well as sizing of power system, of compressors, and of heat exchangers have been defined in relation with the needs and the outcomes of WP5. Valves, including Emergency Shutdown valves and Pressure Relief Valves location and specification take in consideration the outcomes of the activity of WP8.

It is worth to note that in addition to the compressors that are necessary to reduce the time required for loading and for unloading, a fundamental role is played by the heating and cooling systems, especially to maximize the commercial loading capacity.

For a better understanding of the loading and unloading system design, please refer to the joint P&ID document "180GASV–DRW–050–T02A01 Loading and Unloading System P&Id".

1 Introduction

1.1 Alternative solutions for CNG ship transportation

The increasing demand in natural gas will involve a change in forms of transport. Transport technologies represent a fundamental part of natural gas chain and establish a reference point for the economic viability of the field development. The expansion of the gas market, linked to the increase in supplying countries and the growth of currently developing markets, give rise to the commercial development of numerous transport technologies which have so far remained relegated to the experimental or design phase.

The shift towards LNG (Liquid Natural Gas) for long distance transport has already begun and a rapid increase in supply is forecasted in many geographical areas. At present, there are numerous alternatives for the transport of gas, all aiming to improve the ratio of volumetric transport capacity to associated energy content by its liquefaction or compression. Several alternatives to LNG have been evaluated:

- GTL: gas–to–liquids, conversion of natural gas in easily transported hydrocarbons;
- GTW: gas–to–wire, production of electricity through natural gas at the producing field and transportation by high–voltage direct current transmission lines over long distances;
- CNG: compressed natural gas, a solution that avoids the cost of liquefaction;
- GTS: gas–to–solid, conversion of gas into solids formed of gas hydrates for storage and transportation.

Among these technologies, the only one used commercially until 2004 was LNG, which accounts for just over 25% of the natural gas transport market. GTL is in the expansion phase, with two operational plants: one in South Africa belonging to Sasol, and one in Malaysia belonging to Shell, with a further 14 plants planned to come into operation. GTW is already in a commercial stage, but still requires technology development in order to improve efficiency. The two latter options (CNG and GTS) have been studied a lot in order to verify their potential and their economic feasibility, but there aren't solutions available on the market yet.

Concerning CNG technologies the ongoing projects expect to be able to transport gas in containers at high pressures, typically 125 bar to 300 bar.

This technology is interesting for those scenarios where pipelines are not feasible because of long distance, ocean topography, limited reserves, modest demand, or environmental factors, or where LNG is not economical due to its high cost of liquefaction and regasification facilities.

Another interesting field of application of the CNG technology is the valorisation of the flare gas in the oil fields. Indeed, oil extraction is associated with a limited natural gas production, which often it is not economically feasible to recover and is hence burned. This is not environmentally sustainable and is increasingly being forbidden in many countries.

CNG has a density which is one third of that of LNG, and the compression in gaseous phase has a high energy cost, however the plant is much simpler compared to an LNG treatment plant, since liquefaction and regasification are not required. The safety of the process, and in particular, risks associated with the storage of a flammable material at high pressure, represented a limitation to the applicability of gas transport in the form of CNG. The development of advanced engineering technologies has allowed the transport system to become more efficient and safer: in particular, gas storage systems with a higher degree of intrinsic safety have been developed using composite materials.

The threshold volume of gas reserves is relatively low for commercial viability, providing shipping costs can be kept low. The main advantages of CNG compared to LNG can be summarized as follows:

- containment system operates at ambient temperature, avoiding high capital cost required for liquefaction facilities;
- shorter project development time allows earlier production and greater returns on investment;
- 60%–85% of the CNG value chain is moveable, whereas fixed facilities represents 60% of the cost of an LNG project;
- CNG can be stored indefinitely without boil–off;
- 5%–8% gas used during CNG transport process, compared to 15% for LNG.

Concerning CNG advantages over pipelines:

- lower cost over longer distances;
- transport capacity can be more easily reconfigured in the event of field or consumer developments;
- 60%–85% of the CNG value chain is moveable. Pipelines cannot be redeployed upon reservoir depletion;
- CNG projects can span deep water trenches and are unaffected by challenging sea–floor formations and conditions;
- CNG projects are usually not subject to the same cross–border issues that challenge pipeline projects.

1.2 Compressed natural gas ship transportation

The first projects for CNG transportation by ships were developed in the late sixties. In 1968 Ocean Transport Pressure System designed a ship in which Natural Gas was stored in vertical vessels at 80 bar and 60°C. Other possible designs were conceived in the '70s at slightly higher pressures, but these projects never reached the market because of the extremely high costs of the pressurized containers.

Following the development of other transport technologies (LNG), and the evolution of the oil and gas market, a new type of pressurized tank has been developed and named Coselle (from the words `coil' and `carousel'); the potential generated by this innovation has renewed interest in the marine transport of CNG. Since then various other technologies have been developed, such as EnerSea Transport's Volume Optimized TRANsport and Storage (VOTRANS), Knutsen OAS's Pressurized Natural Gas (PNG), TransCanada's Gas Transport Module (GTM) and Trans Ocean Gas's Composite Reinforced Pressure Vessel (CRPV).

Table 1.1 reports the main characteristics of the ongoing projects of ship transporting compressed natural gas.

Table 1.1 – State of Art of CNG ship transport technologies

NAME	TYPE	ARRANGEMENT	PRESSURE (bar)	TEMPERATURE (°C)	GAS WEIGTH/ TANK WEIGHT	CAPACITY (million Sm^3)	ON BOARD COMPRESSORS
COSELLE	Small diameter wrapping of steal pipes 6''	Coselle in holds	200-275	Ambient	0,12 – 0,18	1,5 - 15	No
OPTIMUM	Steal pipes API 5LX80	Horizontal pipes in hold	200-250	Ambient	0,4	5,5 – 12,5	No
VOLTRANS	Steal X-80 Cylinders	Vertical tanks modules or horizzontal pipes	125	-30	0,35-0,39	2 - 30	No?
Kunutsen PNG	Steal cylinders 1 m of diameter and 20-40 m of lenght	Vertical modules	250	Ambient	0,21	2 - 35	No?
TransOcean TOG	HDPE tanks with glass fiber coating	Cassette moduels with vertical cylinders	250	Ambient / -30	0,34 – 0,47	7	No?
TransCanada GTM	Steal tank with composit material coating	GTM modules	206	Ambient	1,5	0,3 - 3	No?
CETech	Composit material cylinders / X -80 steal pipes	Vertical /horizontal	150 - 250	Ambient / -30	0.7 (composit) 0.24 (steal)	7 – 15 (composit) 8 – 35 (steal)	No?
Fincantieri CNG32000	6000 steal cylinders of 5,35m3	Vertical	166	25°C	-	6,34	Yes
Bima Putrajaya	Cylinders	Vertical	100 - 250	Ambient	-	4,16	No

1.2.1 Coselle technology

Coselle technology is based on a on–board storage system using pipes (see Figure 1.1). The system involves wrapping a pipe of small diameter (about 6") around a carousel, giving a total length of about 15 km, a coil diameter of 20.5 m and a container weight of 40 ton. Every coil has a capacity of roughly 120 000 Sm^3 and natural gas is compressed at 275 bar at 27°C. These units are installed within the ship one over the other, in order to strengthen the ship itself, thereby reducing the amount of steel necessary to reinforce the vessel. These CNG carriers have a capacity between 1.8

and 15 millions Sm^3 with a number of coils which varies from 16 to 128. To ensure insulation from potential sources of fire hazard, the holds are saturated with nitrogen. However, this transport system requires a pre–treatment of the gas to dehydrate it, in order to avoid the formation of hydrates and other deposits which might obstruct the pipes and reduce the capacity and efficiency of transport, as well as compromising safety. The presence of many pressure vessels to be manifolded together makes the system very complex with a big number of valves, connecting pipes, flanges and fittings which represent potential sources of leakage.

The Coselle transportation system requires the presence of on shore facilities to load and off–load the ship. Facilities for the dehydration, cooling and compression (which is carried out on shore) of the NG are needed at the loading point and the ones for scavenging compression and heating are required at the off–loading point.

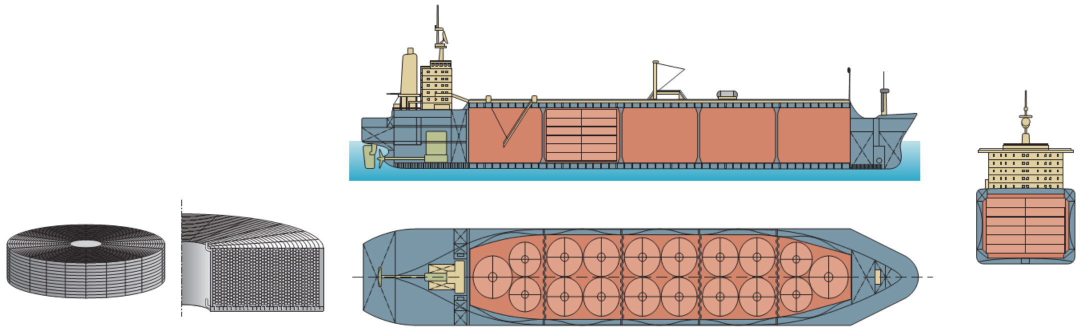


Figure 1.1 – Coselle general arrangement

1.2.2 VOTRANS technology

The VOTRANS system, developed by EnerSea Transport of Houston (see Figure 1.2), is an innovative transport system based on an optimization of the volumes occupied, on specially designed carriers similar to other CNG transportation options, but at lower pressure and temperature. The vessels are designed with horizontal or vertical tanks in carbon steel, giving a total storage capacity of between 10 and 60 million Sm^3. An individual VOTRANS storage tank consists of a series of six to twenty–four tanks with small diameter, connected to one another to form a single storage system. There is also the option of converting existing single–hulled vessels to the VOTRANS system, with the aim of speeding up the time required for facilities to become operational, and lowering costs. As far as safety is concerned, EnerSea has conducted numerous studies to demonstrate that the proposed system does not present greater risks than other gas transport systems.

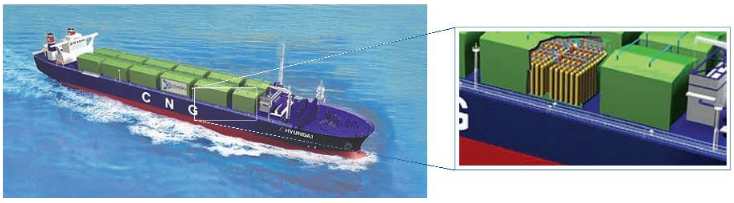


Figure 1.2 – VOLTRANS technology – ship rendering

Another option is the Volume Optmized TRANsport and Storage (OPTIMUM) system, in which the vessels have very small diameter (below 100 cm) but a length compared to the one of the ship. This solution is often referred to as "pipelines", since the vessels are pipelines sealed at both ends. Storage occurs at 30°C and in a pressure range between 110 and 170 bar. Both The VOTRANS and OPTIMUM systems need the gas to be compressed and cooled prior to being loaded on board .
In this technology, during the loading and unloading phases, a smart system based on the displacement of a chilled liquid is used to maintain constant both temperature and pressure of the gas.

1.2.3 GTM technology

The GTM (Gas Transport Module) (see Figure 1.3) system is based on pressurized tanks in a reinforced composite material, consisting of large diameter pipes in High Strength Low Alloy steel (HSLA), reinforced with high–performance composites. This material has a high resistance to corrosion and a mechanical resistance of over 650 MPa. If GTM tanks are compared to equivalent tanks made of steel alone, it becomes evident that the former are about 35–40% lighter, thus allowing for applications which were previously impossible, at a lower cost.
As already mentioned, the GTM system is based on large diameter pipes in HSLA steel with both ends welded. The pipework thus obtained undergoes the patented reinforcement process with composite materials based on glass fibre, increasing resistance while minimizing the increase in weight. The glass fibre increases the circumferential resistance, whilst the steel, which contributes only partly to circumferential resistance, absorbs all longitudinal loads. A typical storage tank is about 24 m long, with a diameter of 1–1.5 m. The working pressure is about 200 bar, whereas the maximum allowed pressure is 250 bar.

Figure 1.3 – GTM Technology – ship rendering

1.2.4 PNG technology

The design scheme developed by Knutsen (see Figure 1.4) for the transport of CNG is based on the use of cylindrical steel tanks in a vertical arrangement grouped to form storage units. The tanks always have a diameter of 1 m and a thickness of 33.5 mm, whereas their length depends on the capacity of the vessel. Knutsen has developed three different vessels, with a capacity of 3.4 million

Sm^3, 20 million Sm^3, and 30 million Sm^3. The vessels contain 870, 2672 and 3900 cylinders respectively.

For loading and unloading operations, the possibility of connecting through the keel of the vessel has been studied. This allows for both direct loading from subsea satellites at a depth of between 50 and 500 m, and the use of a specially designed mooring system for safe loading/offloading operations from the coast. In this context, Knutsen has developed an offloading terminal using the same storage technology as the vessel, in other words a series of vertical tanks. This type of terminal has the purpose of shortening the time required to offload the vessel, and allowing the delivery of natural gas to the network to be regulated. Knutsen claims a great simplicity in the design and operation due to the simple infrastructure requirements, operation in ambient temperature that prevent costly temperature control systems and insulations and the benefits of the all–steel design the allows an easy heat handling compared to the composite materials.

This technology allows both on–shore and off–shore loading so the compression phase can be carried out both on–shore or off–shore

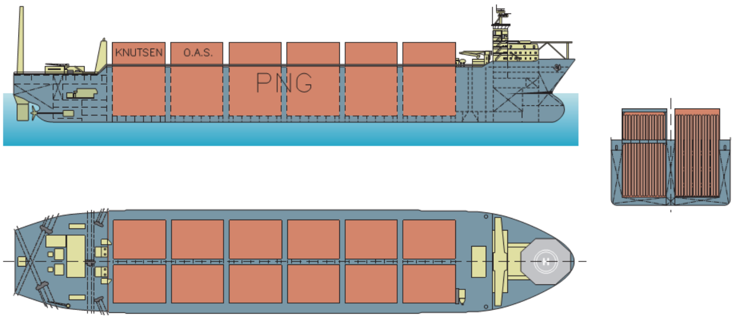


Figure 1.4 – PNG technology general arrangement

1.2.5 CRPV technology

Trans Ocean Gas (TOG) proposes the CRPV technology for the transport of natural gas, based on the use of tanks in a composite material grouped into modules and inserted vertically one inside the other within the vessel's hull. Tanks in a composite material (CPVs, Composite Pressure Vessels) are lighter and safer than their steel counterparts, moreover they are corrosion resistant. Each individual element has a diameter of about 1 m and a length of 12 m, and is designed to withstand a pressure of 250 bar. Trans Ocean Gas believes that it is preferable to use glass fibre rather than carbon fibre for CNG transport, with the aim of containing costs at the expense of lightness. In fact a CPV covered in glass fibre only weighs one third of a conventional steel tank, and it is thus possible to use a carrier with a larger storage capacity and higher sailing speed. The modular system developed by TOG consists of a framework containing about 18 CPVs arranged vertically and linked to one another at both ends. These modules, known as cassettes, can be arranged in several tiers depending on the size of the vessel; for example, a ship with a tonnage of 60,000 ton has two tiers of cassettes.

The transport system is completed with valve systems placed on the main deck and a conventional cooling system, used to maximize storage capacity and inhibit the formation of hydrates during the loading and offloading phases. The compression unit placed on board can be used for loading and offloading at offshore mooring terminal.

1.3 State of art for CNG loading and unloading systems

At present, the shipping of compressed natural gas still at its early birth stage and hence, no real application is fully developed, while on–shore storage of compressed natural gas is already a well proved technology. Even if the field of application is different the loading and unloading process design still quite similar, it is hence interesting to briefly analyse an example of existing CNG compression system as an example and hint for the design of the GASVESSEL loading and unloading system.

For this sake it is reported in Figure 1.5 a description of the Mondarra gas storage facility in Dongara, Western Australia.

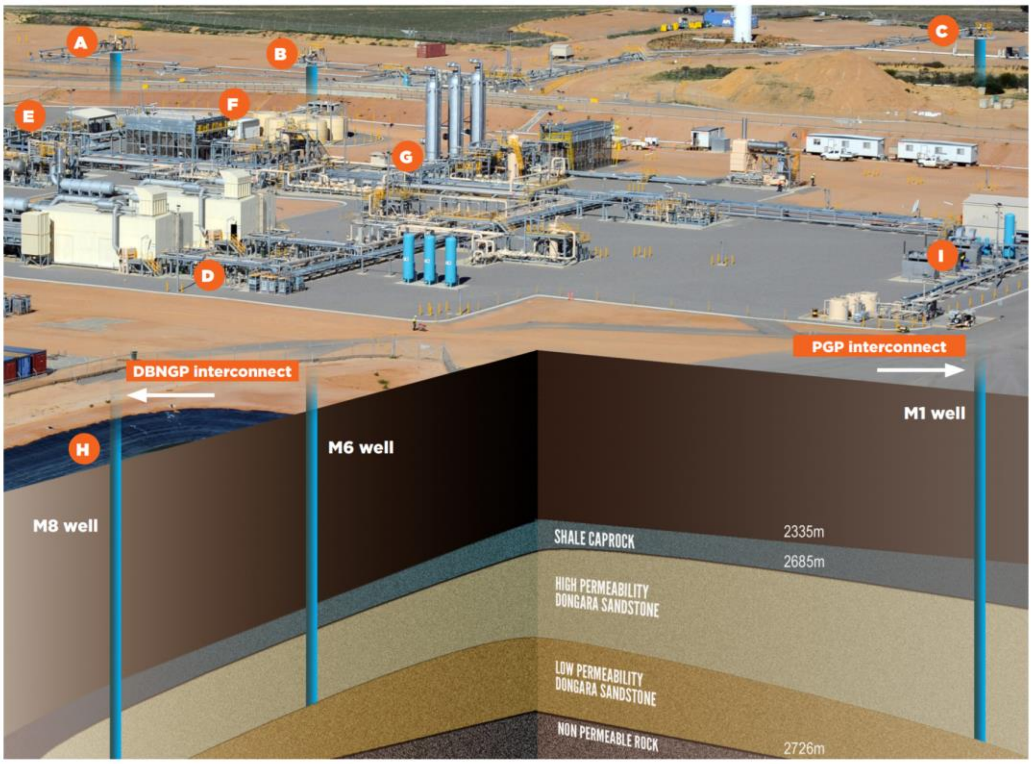


Figure 1.5 – Mondarra gas storage facility main layout

Table 1.2 reports the main components list of the Mondarra gas storage facility.

Table 1.2 – Mondarra gas storage facility main components

Tag	Name	Description
A	M8 well	All 3 wells can be used for both injection and/or withdrawal
B	M6 well	Each well is approximately 2.7 kilometres in depth
C	M1 well	

Tag	Name	Description
D	Aerial reciprocating compressors	2x driven by Caterpillar 3612 gas engines including filtration facilities used for both injection and withdrawal. The reservoir is operated at a higher pressure than gas in pipelines.
E	Raw Gas Processing	("slug catcher") removes any free liquid that is produced in the wells during withdrawal as part of the gas stream.
F	Production Cooler and Separator	gas being withdrawn from the reservoir can be up to 100°C. The production cooler cools the hot gas to pipeline temperature specification. The separator captures any liquid that is knocked out of the gas stream when it is cooled by the production cooler.
G	Silica Gel Gas Conditioning Package Unit	this package dries and conditions the gas to ensure it meets pipeline specifications. Gas is streamed through the compressors and production filter before entering into either the DBNGP or PGP
H		All water and impurities captured in the slug catcher and production separator are sent to the evaporation pond where disposal is via natural evaporation.
I	Gas Engine Alternators	gas engines that generate all the electrical power to the site.

In the Mondarra gas storage facility natural gas is stored in a reservoir able to store up to 18 petajoules of gas. The gas is stored 2,700 metres below the surface in a porous sandstone reservoir capped by an impermeable layer of shale. Gas can be held in the reservoir indefinitely without leakage or deterioration in quality.
Three wells access the reservoir and, boosted by the use of two compressors, allow the injection of up to 70 terajoules or the withdrawal of up to 150 terajoules of gas per day. Associated processing equipment ensures the extracted gas meets all pipeline specifications. The facility can be expanded by tying–in additional wells, compressors and gas processing equipment.

As shown in Figure 1.5 the Dampier to Bunbury Natural Gas Pipeline (DBNGP) and APA's Parmelia Gas Pipeline (PGP) are connected to MGSF flow in a north to south direction. Gas supply for the storage facility can only be injected from the DBNGP, however gas withdrawn from the MGSF can be sent south to Perth using either the DBNGP or PGP depending on the customer's preference/transport arrangement.

To inject gas into the underground reservoir, the gas must be raised to a higher pressure than the reservoir pressure. This is done using the compressors that deliver the compressed gas via injection pipelines through to any of the three high pressure wellheads (A, B, C) for injection into the reservoir. Gas can be injected up to rates of 70 TJ/day (2.92 TJ/hour).

Gas can be repeatedly injected and withdrawn from the storage facility and can also stay in the storage reservoir indefinitely without leakage or deterioration in quality.

Gas can be withdrawn either by free flow or using the compressors at rates up to 150 TJ/day (6.25 TJ/ hour). The gas goes through a series of processing and conditioning procedures to ensure it meets pipeline specifications before being delivered into either the DBNGP or PGP for transport south to Perth.

1.4 Basic Requirements and Reference Scenario for Loading and Unloading System Design

In WP2, CHC performed the identification of different scenarios corresponding to different geographical regions in which GASVESSEL could operate.

The definition of GASSVESSEL volume is issued by an analysis performed by Navalprogetti with the help of the modelling tool developed by ESTECO. This study allowed the identification of the size of the ship that could satisfy the gas volume demand for the considered scenarios. The size has been chosen in order to minimize the gas transport tariff but keeping a reasonable size from the marine point of view, considering accessibility to ports and manoeuvrability and cruise speed.

This analysis brought to the choice of two ships, one with capacity of about 12 millions Nm^3 (commercial volume) of gas stored at 300 bar (@40°C) in 272 tanks with a liquid volume of 155 m^3 each and the other one with a commercial volume capacity of 9 millions Nm^3 of gas stored at the same conditions.

For the design and dimensioning of the loading and unloading system to be installed on board, receiving and delivering pressures are crucial for the definition of the needs of compression and hence the identification of the technical option for loading and unloading system. Gas composition and temperature are also two important parameters that can influence the choice of the compression technology.

The design and dimensioning of the on–board piping system and compression station has been performed for the 12 millions Nm^3 (commercial volume) ship using a reference scenario with the conditions reported in Table 1.3:

Table 1.3 – Selected scenario for design and dimensioning of loading and unloading system

Receiving Pressure	Receiving Temperature	Gas Composition	Storage/Transport Pressure	Delivery Pressure
240bar	25°C	100% Methane	335bar	80bar

Different technological options have been taken into account for the determination of the compression system to be installed on board. In particular Table 1.4 reports the technological options analysed to best fit the defined scenario.

Table 1.4 – Technological Options

Technology	Options
Compressing Technology	• Reciprocating compressors • Centrifugal compressors • Reciprocating + centrifugal/ICL compressors
Powered by	• Electric Motor • Gas Turbine
Cooling technology	• Air Exchange • Sea Water Exchange • Chillers

Two main available compression technology are reciprocating compressors or centrifugal compressors. Hybrid solutions have also been taken into account, such as parallel operation of independent centrifugal and reciprocating compressor or ICL compressors[1].

All type of compressors can be powered either by an electric motor or by a gas turbine. The choice of the power system must be performed carefully taking into account: volume, weight, efficiency, and maintenance issues for the two powering solutions.

Relevant pressure and temperature values are defined as follow:

- Normal storage pressure pw (ISO working pressure @ 15°C) = 260 bar
- Maximum allowable operating pressure pmax (ISO maximum pressure @ 65°C) = 370 bar
- Relief valve set pressure = 375 bar
- Design pressure p0 = 385 bar
- Test Pressure ph= 1.5 x pw= 390 bar (According to ISO code)
- Burst Pressure pb = 2.43 x ph = 950 bar (According to ISO code)

[1] The ICL (Integrated Compressor Line) is a fully integrated compression system by BHGE, incorporating a high speed electric motor drive and a centrifugal compressor in a single sealed casing.

2 Review of applicable Standards and Regulations

2.1 Generalities

The guideline published by ABS for "VESSELS INTENDED TO CARRY COMPRESSED NATURAL GASES IN BULK" [1] is the leading reference document in the design process of GASVESSEL project. This guide is based on the ABS requirements for transport of Liquefied Natural Gas (LNG) defined in the: "Rule Requirements for Vessels Intended to Carry Liquefied Gases in Bulk" (Part 5C, Chapter 8 of the ABS Rules for Building and Classing Steel Vessels) [2].

This last document is in full agreement with the IMO IGC Code [3] but do not envisage the carriage of Compressed Natural Gas (CNG). However, it is considered that the requirements indicated in this document are an excellent starting point for ABS to establish requirements for the safe transport of CNG by sea.

IMO Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule–Making Process [4], should be used as well to qualify such a novel concept. In accordance with Chapter 19 of the IGC Code, a vessel transporting methane is required to comply with the requirements for a type 2G ship, or 2PG if of 150 meters in length or less, as defined in 2.1.2 of the Code. Accordingly, ABS would consider the same to be applicable for the CNG carriers [1].

2.2 Considerations about Risk Assessment and Risk Management

Some of the hazards applicable to LNG carriers, such as methane vapour release, fire, explosion, toxicity, collision and grounding, would also be applicable to CNG carriers. However, there are additional hazards or possible increased risk from the same hazards due to the differences between LNG and CNG. In particular, following recommendations reported in [1] the following aspects need to be taken into consideration:

- possibility of critical structure being exposed to low temperatures from impingement of auto–cooled escaping gas.
- gas dispersion analysis must be carried out to demonstrate that areas normally considered gas safe will not be engulfed during a venting or blow–down of high pressure gas or during an upset condition. Depending on the results of the gas dispersion analysis, a vessel Emergency Shut–down system may be required to protect against the migration of methane gas into spaces normally containing a source of vapour ignition.
- since the gas is stored at high pressure in containers in cargo holds, a rapid gas release due to container or piping system failure could result in an overpressure condition in the cargo hold jeopardizing the integrity of the vessel's hull. Accordingly, overpressure protection for cargo hold spaces should be provided. The relief devices should have sufficient capacity to handle a rupture of the largest cargo tank, assuming rupture at any location. In addition to these relief devices, hatches shall be provided in each hold space cover. Discharge from the hold spaces shall be routed to a safe location.
- While the IMO Gas Code includes requirements for active and passive fire protection systems applicable for liquid methane fires, it does not envisage a high pressure (jet) fire which could result from the ignition of a high pressure gas flow from a ruptured pipe. Accordingly, means to protect against such an occurrence will be required to be demonstrated for CNG carriers.

ABS will require specific qualitative and quantitative risk assessments as well as consequence studies to be conducted in order to obtain class approval. Specifically, the submitted risk assessment plan must as a minimum contain the following studies: Hazard Identification (HAZID), Containment and Cargo Handling

System Hazard and Operability Study (HAZOP) and Quantitative Risk Assessment (QRA) of CNG Carrier Critical Systems

As a minimum, ABS requires the following consequence modelling related to the containment, loading and discharging systems [1]:

- Gas dispersion – Of particular interest are the dispersion characteristics and the potential for explosive fuel air mixtures covering both “normal” and inadvertent release scenarios.
- Smoke and gas ingress – Of particular interest is the potential impact on accommodations or other normally–manned spaces.
- Explosions (fragmentation and overpressure effects, as applicable).
- Jet fires – Particular focus should be placed on flame impingement on containment system components and ship structure which may result in escalation as applicable.
- Thermal radiation effects – Of particular interest is the potential impact on normally–manned spaces, such as the accommodations, emergency routes and muster areas, as well as the potential impact on adjacent gas–retaining components and tank and structure which may result in escalation.

Det Norske Veritas AS (DNV) published in 2011 a Guideline establishing the rules for classification of Natural Gas Carriers [5]. In this guide a minimum acceptable safety level for a CNG vessel is compared with the minimum acceptable safety level for an LNG vessel reported in Table 2.1.

Table 2.1 – Minimum LNG and CNG safety levels

	Historical data LNG	*Target Safety Values for CNG*
Individual risk for crew members (due to major accidents)	1.2×10^{-4}	1×10^{-4}
Total loss due to collision	1.2×10^{-4}	1×10^{-4}
Total loss due to cargo hazards (fires and explosions)	2.4×10^{-4}	1×10^{-4}
Individual risk from cargo cylinder failure	–	1×10^{-5}
Individual risks for public ashore	–	1×10^{-5}

To achieve this target, following a similar approach to ABS guideline, technical recommendations are reported for general ship arrangement, cargo rooms and tanks, piping systems, mechanical ventilation, fire protection and extinction as well as control and monitoring systems.

In order to perform the Formal Safety Assessment (FSA), as suggested by [1], the methodology reported in [4] should be used following the flowchart reported in Figure 2.1.

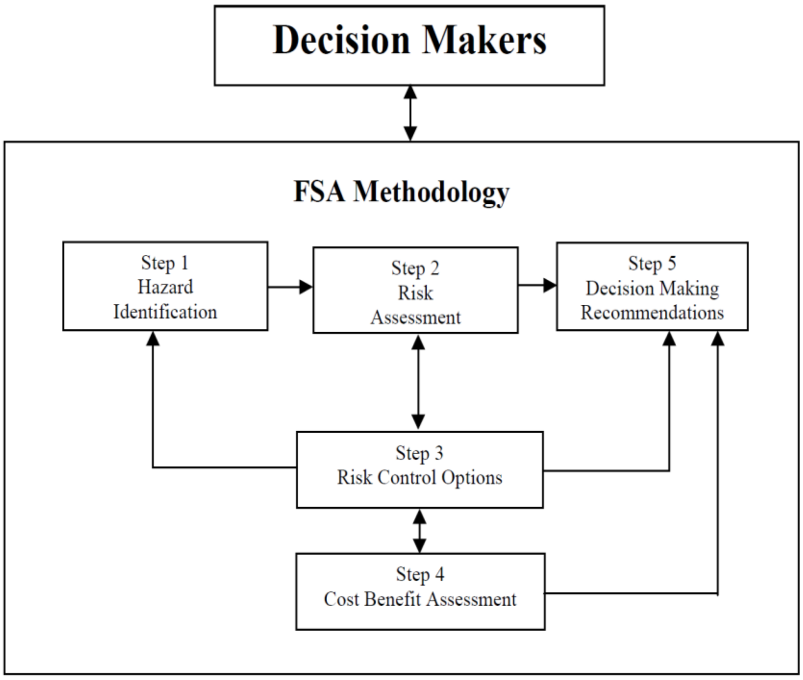


Figure 2.1 – FSA Methodology flowchart *[4]*

The first step of Hazard identification aims to create a list of hazards and associated scenarios prioritized by risk level specific to the problem under review. This purpose is achieved using standard techniques to identify hazards, which can contribute to accidents, and by screening these hazards using a combination of available data and judgement.
The second step consists in a detailed investigation of the causes and consequences of the more important scenarios identified in the first step.
The third step consists in suggesting effective and practical Risk Control Options (RCO) comprising the following four principal stages:

- Identification of areas needing control
- Identification of Risk Control Measures (RCM)
- Evaluation of the effectiveness of RCM by revaluating the second step
- grouping RCMs into practical regulatory options

Step 4 identifies and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3.

The purpose of step 5 is to define recommendations based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits and the identification of those risk control options which keep risks as low as reasonably practicable.

2.3 Recommendations about CARGO ROOMS and TANKS

Concerning the rooms containing cargo handling systems and equipment are to be situated above the weather deck and located within the cargo area, unless specially approved. Such spaces are to be treated as cargo pump rooms for the purpose of fire protection according to regulation 11–2/58 of the 1983 SOLAS amendments [6].

Cargo and fuel gas handling equipment is to be located in the process area. Any enclosed space in the process area handling cargo gas is to be treated as a cargo pump rooms for the purpose of fire protection according to regulation 11–2/58 of the 1983 SOLAS amendments [6].

All valves necessary for cargo handling are to be readily accessible to personnel wearing protective clothing. Suitable arrangements are to be made to deal with gas freeing of such spaces.

If CNG is carried at a temperature below –10°C, suitable insulation, as detailed in Chapter 5, Section 9, is to be provided to ensure that the temperature of the hull structure does not fall below the minimum allowable design temperature as given in the *ABS Rules for Materials and Welding*

The requirements for process pressure vessels are to meet recognized pressure vessel codes and the *ABS Rules for Building and Classing Facilities on Offshore Installations* [7].

This Division 3 of Section VIII of the ASME – "*Boiler and Pressure Vessel Code"* [8] provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures generally above 10,000 psi.

Emergency blowdown for each cargo tank is required and is to be designed in accordance with the requirements of the *ABS Rules for Building and Classing Facilities on Offshore Installations* [7].

Vent and relief headers and their capacity for each cargo tank are to be determined in accordance with the requirements of the *ABS Rules for Building and Classing Facilities on Offshore Installations* [7] and Chapter 9 of the *"Vessel Intended to Carry Compressed Natural Gases in Bulk"* guide [1].

For cargo tanks, all connections, except safety relief valves and liquid level gauging devices, must be equipped with a manually operated stop valve and a remotely controlled emergency shutdown valve.

One remotely operated emergency shutdown valve is to be provided at each cargo transfer manifold connection.

Total volume of cargo carried on the CNG carrier should be subdivided in an appropriate number of individual cargo tanks within cargo holds. Each cargo hold is to be separated as required in Chapter 4 of *"Vessel Intended to Carry Compressed Natural Gases in Bulk"* guide [1].

Each cargo tank should be provided with an independent relieving system connected to an appropriate relief header.

No cargo communication is allowed between holds in normal and emergency situations.

Each cargo tank is to be fitted with at least two pressure relief valves of approximately equal capacity, suitably designed and constructed for the prescribed service.

Each cargo tank must be provided with a piping system allowing safely gas–freeing and safely purging.

Each pressure relief valve installed on a cargo tank is to be connected to a venting system, which is to be built in such a wat that the discharge of gas will be directed upwards and arranged to minimize the possibility of water or snow entering the vent system. The height of vent exits is to be not less than the maximum between B/3 and 6 m, above the weather deck and 6 m above the working area and the fore–and–aft gangway.

2.4 Technical Regulations on PIPING SYSTEM and LOADING AND UNLOADING PROCESS

Piping may be arranged to permit Bow, Stern and Turret (Internal/External) loading and unloading.

Cargo piping and related piping equipment outside the cargo area must have only welded connections. The piping outside the cargo area must run on the open deck and must be set at least 760 mm inboard, except for athwart ships shore connection piping. Such piping is to be clearly identified and fitted with a shutoff valve at its connection to the cargo piping system within the cargo area. At this location, it is also to be capable of being separated by means of a removable spool piece and blank flanges when not in use.

Piping system must be allowed to be purged and gas–freed after use. When not in use, the spool pieces are to be removed and the pipe ends be blank–flanged. The vent pipes connected with the purge are to be located in the cargo area.

In order to protect the piping, the piping system components and the cargo tanks from excessive stresses due to thermal movement and from movements of the cargo tank and hull structure, designer must provide offsets, loops, bends and mechanical expansion joints or similar suitable means of protection.

Low–temperature piping is to be thermally isolated from the adjacent hull structure, where necessary, to prevent the temperature of the hull from falling below the design temperature of the hull material.

Where cargo tanks or piping are separated from the ship's structure by thermal isolation, electrically bonding must be guaranteed for both the piping and the cargo tanks. All gasketed pipe joints and other nonconductive connections are to be electrically bonded.

All piping or components that are pressurized with cargo and may be isolated must be provided with relief valves. Relief valves must be able to discharge the cargo from the piping system into the cargo vent system.

Temperature of the gas in the pipes must be carefully studied, indeed, the use of flanged joints at either high or low temperatures shall take into consideration the risk of joint leakage due to forces and moments developed in the connected piping or equipment. At temperatures above 200°C for class 150 and above 400 °C for other classes designations, flanged joints may develop leakage problems unless care is taken to avoid imposing severe external loads, severe thermal gradients, or both [9]. Some materials, in particular some carbon steels, may undergo a decrease in ductility when used at low temperatures to such an extent as to be unable to safely resist shock loading, sudden changes of stress, or high stress concentration. For temperature below −29°C impact testing for applications is required. Pressure–Temperature rating as well as Material specification are reported in [9].

The wall thickness of pipes must be greater than [1]:

$$t = \frac{t_0 + b + c}{1 - \frac{a}{100}} \, mm$$

Where:

t_0 = theoretical thickness = PD/(20 Ke + P) mm
P = design pressure, in bar, (maximum gauge pressure to which the system may be subjected in service)
D = outside diameter, in mm
K = allowable stress, in N/mm^2
e = efficiency factor

b = allowance for bending, in mm. = $\frac{Dt_0}{2.5r}\ mm$
r = mean radius of the bend, in mm
c = corrosion allowance, in mm
a = negative manufacturing tolerance for thickness, %.

An appropriate corrosion allowance thickness of the pipes must be used in the design. If a design is accepted with no additional thickness margin for corrosion, a suitable and acceptable means of thickness monitoring is to be provided to confirm that there is no corrosion during the service life of the CNG carrier. The design of any piping system where corrosion inhibition is expected to be utilized should consider the installation of additional wall thickness in piping design and/or reduction of velocity to reduce the effect of stripping inhibitor film from the pipe wall. In such systems it is suggested that a wall thickness monitoring method be instituted [10]

The piping is to be full penetration butt welded and fully radiographed, regardless of pipe diameter and design temperature. Butt welds are to be either double–welded or equivalent to a double–welded butt joint. Flange connections in the piping are only permitted within the cargo area and at the shore connection. Flexible pipes used in transfer operations offshore with buoys must follow the requirements of the *ABS Rules for Building and Classing Facilities on Offshore Installations* [7].

Pipes must be subjected to stress analysis when: operating at high temperatures or low temperatures, connected to sensitive equipment, subject to vibration due to internal forces, connected to pressure relief valves and rupture discs, along the derrick and the flare tower, affected by movement of connecting equipment or by structural deflection, long vertical lines (>20m), Lines 3" NPS and larger with wall thickness in excess of 10% of outside diameter, thin walled piping of 20" NPS and larger with wall thickness less than 1% of the outside diameter [11].

In lines where pressure drop does not have a cost penalty, gas velocity shall not exceed limits which may create noise or vibrations problems. As a rule of thumb the velocity should be kept below [12]:

$V = 175\left(\frac{1}{\rho}\right)^{0.43}$ or 60 m/s, whichever is lowest.

API 14E RP [10] define the method to calculate the flow velocity:

$$V = \frac{60ZQ_gT}{d_i^2P}$$

Where:

V = gas velocity (feet/second)

d_i = inner pipe diameter (inches)

Q_g = Flow rate (million cubic feet/day at 14.7 psia and 60°F)

T = operating temperature (°R Ranking)

P = operating pressure (psia)

Z = gas compressibility factor

Pressure drops inside the pipe, can be calculated through Weymouth Equation, Panhandle Equation or Spitzglass Equation [10] depending on the pipe geometry, the operating pressure and Reynolds number of the gas flow.

Material Specification List, Pressure–Temperature ratings and minimum wall thickness for valves and flanges are reported in [13]. Valve sizing and design criteria are specified in [14].

Piping manufacturing process, material definition and welding criteria are reported in ASME B31.8 [15] and in API 5L [16], while ASME B31.8s [17] gives an integrity management plan to allow correct long term operation of piping distribution systems. Mitigation activities identified in this standard refers to three main categories of threats: time dependent, stable and time–independent.

Time dependent typical threats are: internal and external corrosion, stress corrosion and cracking. Stable threats are typically: defects of construction of the piping system and defects on the welding, while time–independent threats are mechanical damage, incorrect operational procedure, whether related damage.

Welding process of piping system must follow prescription of API 1104 [18] which presents methods for the production of high–quality welds through the use of qualified welders using approved welding procedures, materials, and equipment.

Concerning the requirements and guidelines for pressure reliving and depressuring systems, ATI 521 [19] lists the principal causes of overpressure, determines individual relieving rates and gives guidelines for selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks.

When CNG carrier loading and unloading operation is performed offshore using SPM or Turret, appropriate dynamic loads are to be determined for the duration of this operation using the *ABS Rules for Building and Classing Single Point Moorings or ABS Rules for Building and Classing Offshore Installations*.

Suitable means must be provided to relieve the pressure from cargo loading and discharging headers and other cargo pressurized lines to the suitable location before disconnecting from the loading or offloading facility.

2.5 Technical Regulations on COMPRESSORS AND COOLING SYSTEM

Natural gas compressors can be divided in two main categories: reciprocating and centrifugal compressors. Reciprocating compressors must undergo to ISO 13707 [20], ISO 13631 [21] and API 618 [22] standards, while centrifugal compressors must respect prescriptions of API 617 [23], API 619 [24], API 672 [25].

In these standards, basic design requirements, material characteristics, dimensioning of rotating elements or compressor cylinders, as well as rod and gas loads, critical speeds and all accessorises technical characteristics for minimum safety requirements are reported.

The standard API 673 [26], covers centrifugal fans that can be used for the air cooling system of the compressor, engine or engine room.

The refrigeration system must consist of one or more units able to maintain the required cargo pressure/temperature under conditions of the upper ambient design temperatures [1]. A stand–by unit consisting in a compressor with its driving motor, a control system and any necessary fittings to allow independent operation must be provided. A stand–by heat exchanger must be provided as well, unless the normal heat exchanger for the unit has an excess capacity of at least 25% of the largest required capacity.

If water cooling is required in the refrigeration systems, an adequate supply must be provided by a pump or pumps used exclusively for this purpose. These pumps must have at least two sea suction lines, where practicable, leading from sea–chests, one port and one starboard.

In the vent piping system, means for draining liquid from places where it may accumulate must be provided. The pressure relief valves and piping must to be arranged in such a way that liquid cannot accumulate in or near the pressure relief valves.

Cargo compressors are to be arranged to shut down automatically if the emergency shutdown valves occur to be closed.

3 Onboard GAS Distribution System

3.1 Piping Configurations for onboard Gas Distribution and Collection

Building upon the configuration defined by NAVALPROGETTI for the vessels (Figure 3.1, Figure 3.2), the compressor room and the landing area, the assessment of the piping configurations has been undertaken applying the following priorities:

- Minimising length and weight of the piping system
- Minimising number of connection/welding in large diameter pipes
- Avoid implementing bellows or omegas in large pipes
- Maximise symmetry of the system to allow uniform velocity in pipes

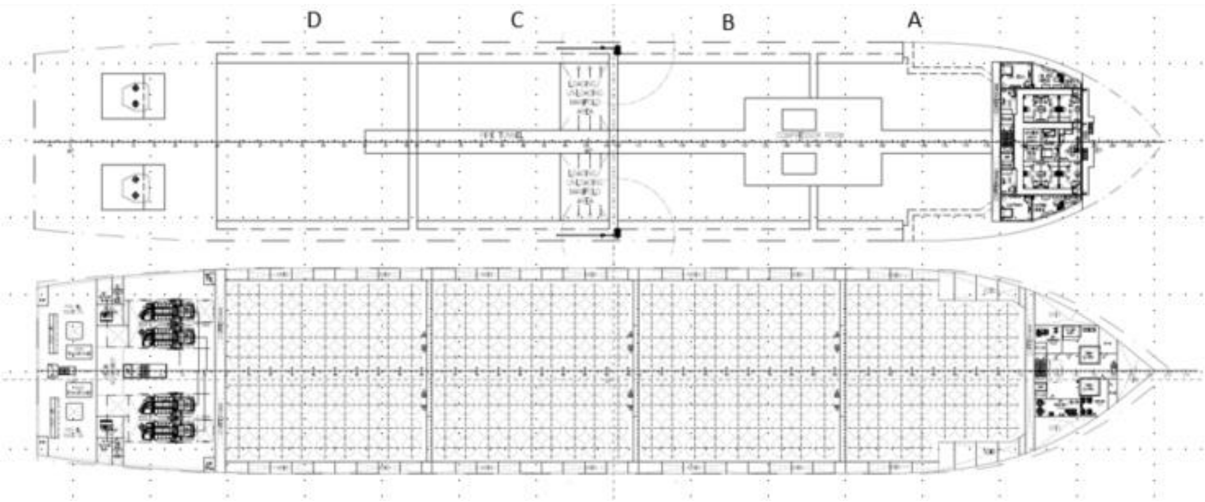


Figure 3.1 – Reference layout for GASVESSEL

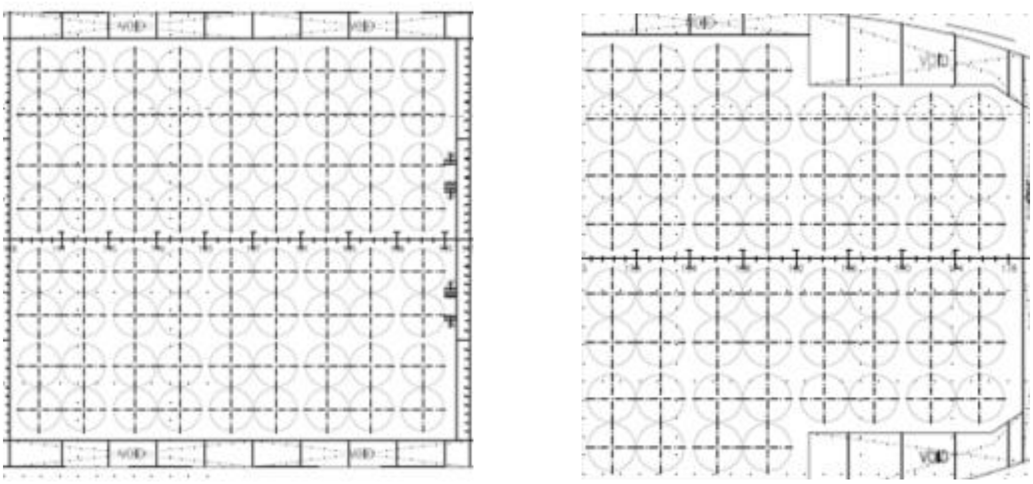
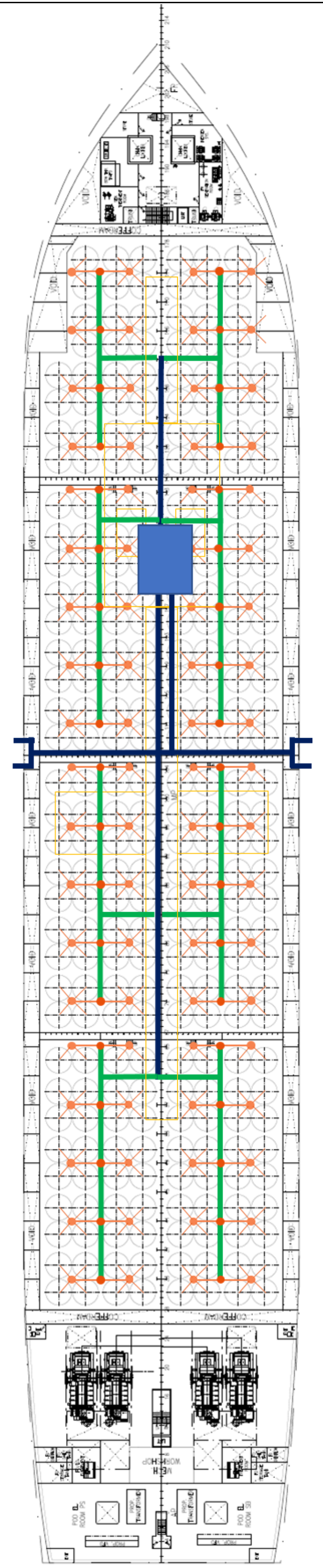
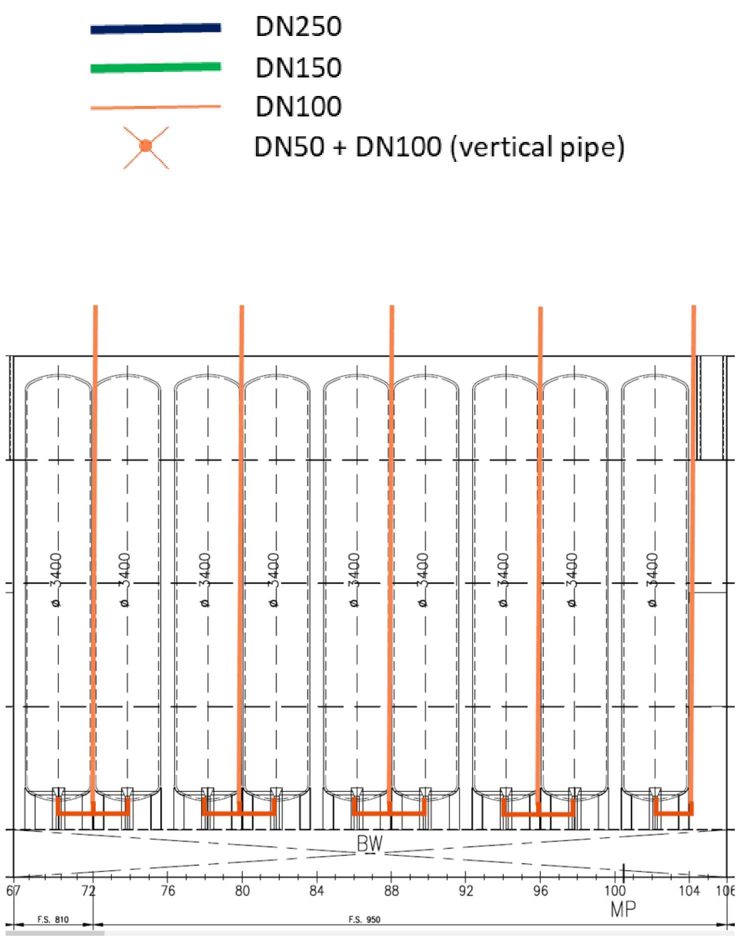


Figure 3.2 – Main holds and front holds (tanks organized in groups of 4)





Total pipe length and weight			
Pipe diameter	*Length (m)*	*Weight - XS (kg)*	*Weight - XXS (kg)*
DN250	244	19 893	37 844
DN150	360	15 322	28 512
DN100	2 318	51 738	95 038
DN50	952	7 121	12 757
TOTAL	**3 874**	**94 074**	**174 151**

Figure 3.3 – Piping system general layout

The sizing and connections choice for the pipelines has been performed following the ASME B16.5 and Norsok P–002 standards.

Minimum pipe diameters are defined from the estimation of the speed limits.

In lines where pressure drop does not have a cost penalty, gas velocity shall not exceed limits which may create noise or vibrations problems. As a rule of thumb the velocity should be kept below [12]:

$V = 175\left(\frac{1}{\rho}\right)^{0.43}$ or 60 m/s, whichever is lowest.

The suggested configuration consists in two main DN250 lines one at bow and one at stern. From these main pipelines, eight DN150 lines enter the eight holds and reaches the bundles of four vessels that constitute the cargo tank. From here a DN100 line goes down to the bottom of the vessels and it branches off in four DN50 lines that reaches the four vessel inlets. (see Figure 3.3).

As shown in Figure 3.4, each pressure cylinder is connected with a DN50 pipe to a main vertical line DN100 that leads out of the hold above Deck 27 500 ABL, where the manual shut–off valve and the Emergency Shut Down Valve (In Figure 3.4, 1P–ESDV7) is positioned. Prior to the manual shut–off valve two vent lines branches off. Each vent line is provided with a Pressure Relief Valve set at a value that must be lower than the design pressure.

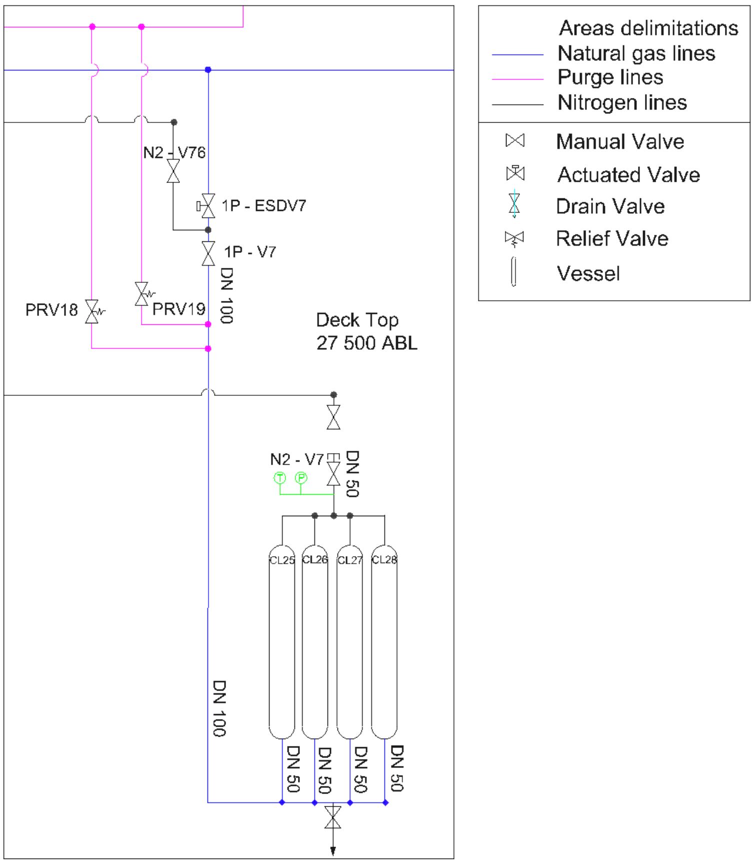


Figure 3.4 – Pressure cylinder bundle layout

A DN50 nitrogen line is provided between the manual shut–off valve (In Figure 3.4, 1P–V7) and the emergency shut off valve (In Figure 3.4, 1P–ESDV7) to allow access for maintenance. After the Emergency

Shut Down Valve the DN100 pipe of each cargo tank connects into a DN150 line for each cargo hold, where a manual shut–off valve is set. The eight DN150 lines connect to a main DN250 line that leads to compressor room and to the manifolds.

All the cargo deck piping and valves are positioned above the cargo holds dome, in a central position.

All the CNG pipes and valves are butt–welded without flange connections with exception to the piping system of the compressors room.

The cargo holds are protected from the overpressure due to high inert gas pressure, accidental release of cargo in hold due to containment failure, variation in ambient pressure and temperature, etc. thanks to pressure relief valves set at 0.2 bar allow the overpressure protection in case of CNG leakage in the cargo holds. These valves blow directly to a dedicated venting line. In addition, suitable relief hatches set at 0.2 bar protect the cargo holds and the piping area structures venting directly to the atmosphere. Hold spaces will be provided with a proper drainage system separated from drainage of the machinery and steering area above Deck at 9000 ABL. Means for detecting leakage of water into the hold space shall be provided. Piping systems common to multiple cargo holds are arranged so that release of gas from one hold space shall not leak into other hold spaces.

The nitrogen system is designed with redundancy to the extent necessary for maintaining the safe operation of the Ship. The nitrogen supply system is arranged to prevent back flow in case of overpressure in hold spaces. The pipes, as the cargo holds, shall be inerted with nitrogen at a positive 50 mbar pressure. Figure 3.5 shows the on–board loading and unloading process diagram.

Structure and supports shall be suitably shielded from piping system leakage.

Cargo piping, in general, shall be fitted with pressure relief valve for preventing overpressure.

Cargo Cylinders provided with a blow down system and an automatic pressure relief system. The Blow Down system shall meet the principles set for in the Rules. The system shall ensure safe collection and disposal of pressurized gas during normal operations and in emergency conditions. Arrangement for gas freeing provided for all parts of the cargo system.

Butt–welded joints with complete penetration at the root may be used in all application. Butt welds are to be either double–welded or equivalent to a double welded butt joint. This may be accomplished by use of a backing ring, consumable insert or inert gas back–up on the first pass.

Flanged joints avoided as far as practicable. In case, flanges of welded neck type of a recognized standard, manufacture and testing should be used. All butt joints shall be 100% radiographed.

Cargo and process pipes, intended as complete lines and each single pipe spool have to fully satisfy the QA/QC procedures in terms of traceability, material certificates, welding materials used, heat treatment if required, operators qualification, welding procedures, testing and controls, etc. A comprehensive documentation shall be recorded all over the project execution phases and delivered with the Ship on works completion.

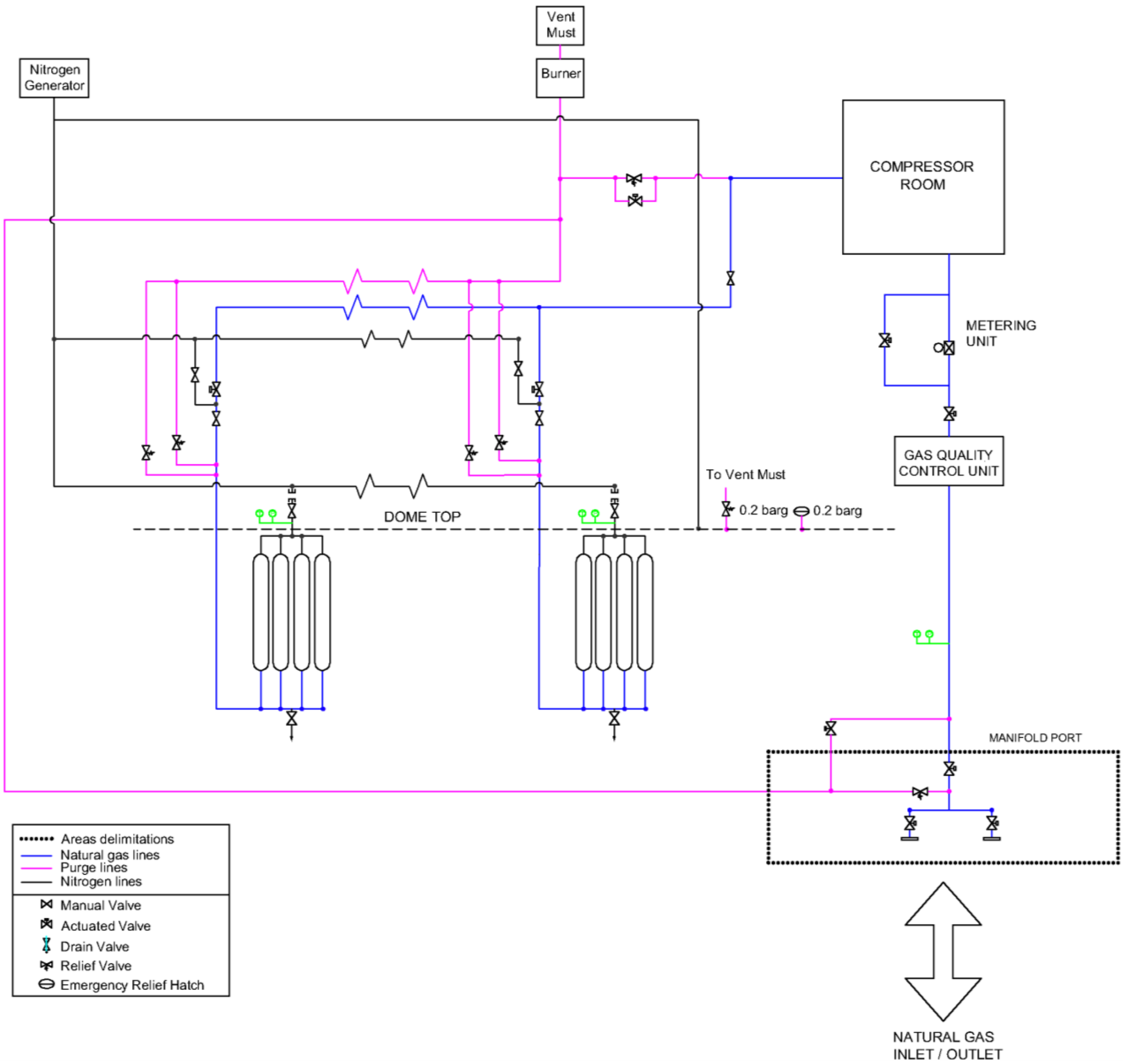


Figure 3.5 – Loading and unloading process diagram

CNG piping system characteristics are reported in Table 3.1 – CNG piping specifications

Table 3.1 – CNG piping specifications

DN	OD	Material	Thickness	Weight
mm	*mm*	*name*	*mm*	*Kg/m*
50	60.3	AISI 316	11.07	13.4
100	114.3		17.12	41.0
150	168.3		21.95	79.2
250	273		25.40	155.1

Suitable expansion joints shall be provided everywhere it is necessary.

Piping supports shall be of a type suitable to allow sliding due to expansion of pipes consequent to temperature and pressure variations.

All piping network, equipment, accessories, instrumentation ecc.. including electric cable traces shall be efficiently grounded to avoid accumulation of static electricity.

3.2 Valves

Valves play a fundamental role in the overall management of the loading/unloading plant. Valves shall be selected in accordance to API600, ASMEB16.34 standards. Valves main specifications are reported in Table 3.2 and typical valves materials are reported in Table 3.3. A schematics of a typical pressure seal gate valve is reported in Figure 3.6. This is the most used type of valve used in the loading and unloading system plant. Special valves characteristics are reported in Appendix D and Appendix E.

Table 3.2 – Valves specifications

Name	DN	Valve type	No. of valves	Pressure Range in Pipeline	Temp. Range in Pipeline	Actuator	Closing Time	Loss of Control Opening Position	Valve Weight
Manual									
N2–V1 to N2–V204	20	Gate Valves SR Class ASME 150 (PN 20)	204	3 ÷ 6 bar	–20°C ÷ 60°C	Manual	no requirements	N/C	~10 kg
1P–V1 to 4S–V9	100	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	68	10 ÷ 335 bar	–70°C ÷ 100°C	Manual	no requirements	N/O	~140 kg
V1 to V8	150	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	8	10 ÷ 335 bar	–70°C ÷ 100°C	Manual	no requirements	N/O	~390 kg
V13 to V36	200	Pressure Seal Bonnet Gate Valves SR Class ASME 150 (PN 20)	24	3 ÷ 6 bar	7°C ÷ 12°C	Manual	no requirements	N/O	~123 kg
V9 to V12	250	Pressure Seal Bonnet Gate Valves SR Class ASME 150 (PN 20)	4	3 ÷ 6 bar	– 5°C ÷ 40°C	Manual	no requirements	N/O	~203kg
Actuated									
N2–VM3 to N2–VM12	20	Gate Valves SR Class ASME 150 (PN 20)	10	3 ÷ 6 bar	–20°C ÷ 60°C	Oleodinamic	no requirements	N/C	~10 kg (+ 25kg)
N2–VM13 to N2–VM28	50	Gate Valves SR Class ASME 150 (PN 20)	16	3 ÷ 6 bar	–20°C ÷ 60°C	Oleodinamic	no requirements	N/C	~15 kg (+ 25 kg)(*)

Name	DN	Valve type	No. of valves	Pressure Range in Pipeline	Temp. Range in Pipeline	Actuator	Closing Time	Loss of Control Opening Position	Valve Weight
N2–VM1 N2–VM2	100	Gate Valves SR Class ASME 150 (PN 20)	2	3 ÷ 6 bar	–20°C ÷ 60°C	Oleodinamic	no requirements	N/C	~43 kg (+ 25 kg)(*)
VM1 to VM4	50	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	4	10 ÷ 420 bar	–100°C ÷ 150°C	Oleodinamic	no requirements	N/C	~115 kg (+ 25 kg)(*)
VM74 to VM77	100	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	4	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~370 kg (+ 68 kg)(*)
VM95 to VM98	200	Gate Valves SR Class ASME 150 (PN 20)	4	3 ÷ 6 bar	– 5°C ÷ 40°C	Oleodinamic	no requirements	N/O	~123 kg (+ 68 kg)(*)
VM49 to VM73 VP0, V0S	250	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	27	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~2380 kg (+ 129 kg)(*)
VP1,VP2 VS1,VS2	150	Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	4	80 ÷ 240 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~1570 kg (+ 68 kg)(*)
1P–ESDV1 to 4S–ESDV9	100	Emergency Shut Down Valves Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	68	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	30s	N/C	~383 kg (+ 68 kg)(*)
ESDV49, ESDV50	250	Emergency Shut Down Valves Pressure Seal Bonnet Gate Valves SZ 2500 Class ASME 2500 (PN 420)	2	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	30s	N/C	~3081 kg (+ 129 kg)(*)
CRV1, CRV2	250	Pressure Control Valve Linear Globe SZ 2500 Class ASME 2500 (PN 420)	2	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~3081 kg (+ 129 kg)(*)
PRV1 to PRV141	50	Emergency Pressure Relief Valves SZ 2500 Class ASME 2500 (PN 420)	141	10 ÷ 420 bar	–100°C ÷ 150°C	Oleodinamic	no requirements	N/C	~115 kg
PRV–A1 to PRV–A8	250	Gate Valves SR Class ASME 150 (PN 20)	8	1 ÷ 1.5	–20°C ÷ 60°C	Oleodinamic	no requirements	N/C	~200 kg

Name	DN	Valve type	No. of valves	Pressure Range in Pipeline	Temp. Range in Pipeline	Actuator	Closing Time	Loss of Control Opening Position	Valve Weight
ASV01 to ASV04	250	Antisurge Valve SZ 2500 Class ASME 2500 (PN 420)	4	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~3081 kg (+ 129 kg)(*)
BDV01 BDV02	250	Blowdown Valve SZ 2500 Class ASME 2500 (PN 420)	2	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~3081 kg (+ 129 kg)(*)
LMV1 LMV2	250	Lamination Valves SZ 2500 Class ASME 2500 (PN 420)	2	10 ÷ 335 bar	–70°C ÷ 100°C	Oleodinamic	no requirements	N/C	~3081 kg (+ 129 kg)(*)
TWV01 to TWV04	200	Three Ways Valves SR Class ASME 150 (PN 20)	4	3 – 6 bar	– 5°C ÷ 40°C	Oleodinamic	no requirements	–	~164 kg (+ 68 kg)(*)
TW05, TW06	250	Three Ways Valves SR Class ASME 150 (PN 20)	2	3 – 6 bar	– 5°C ÷ 40°C	Oleodinamic	no requirements	–	~ 270kg (+ 129 kg)(*)
ERH1 to ERH8	590	Emergency Relief Hatches	8	1 ÷ 1.5 bar	–20°C ÷ 60°C	–	no requirements	N/C	84 kg
(*) actuator weight									

Table 3.3 – Typical valve materials

#	Valve Element	Material
1	BODY	ASTM A 351 GR CF8
2	BONNET	ASTM A 182 GR F 304
4	WEDGE	ASTM A 351 GR CF8 + AWS A5.21 ERCoCr–A
5	SEAT	AISI 304 + AWS A5.21 ERCoCr–A
6	SEATING SURFACE	AWS A5.14 ERNiCrMo–3
7	BACKSEATING SURFACE	AWS A5.21 ERCoCr–A
9	STEM	ASTM A 276 TYPE XM–19
11	GLAND	ASTM A 276 TYPE 316
12	FOUR PIECES RING	ASTM A 276 TYPE XM–19
18	P.S. GASKET	AISI 316 L
29	YOKE	ASTM A 351 GR CF8
30	FIRE SAFE GASKET	GRAPHITE
31	YOKE BOLT + NUT	ASTM A 193 GR B8 cl.2 / ASTM A 194 GR 8
36	SPACER RING	AISI 316
39	LOCKING FLANGE	ASTM A 276 TYPE 316
40	SCREW	BS EN ISO 3506 A4–80
42	HEXAGONAL HEAD SET SCREW	BS EN ISO 3506 A4–80
47	BONNET HALF RING	ASTM A 276 TYPE XM–19
70	LIP SEAL + CHEVRON PACKING	PTFE + PEEK +ELGILOY
139	PUPS	AISI 304
149	TRANSITION PIECES	AISI 304

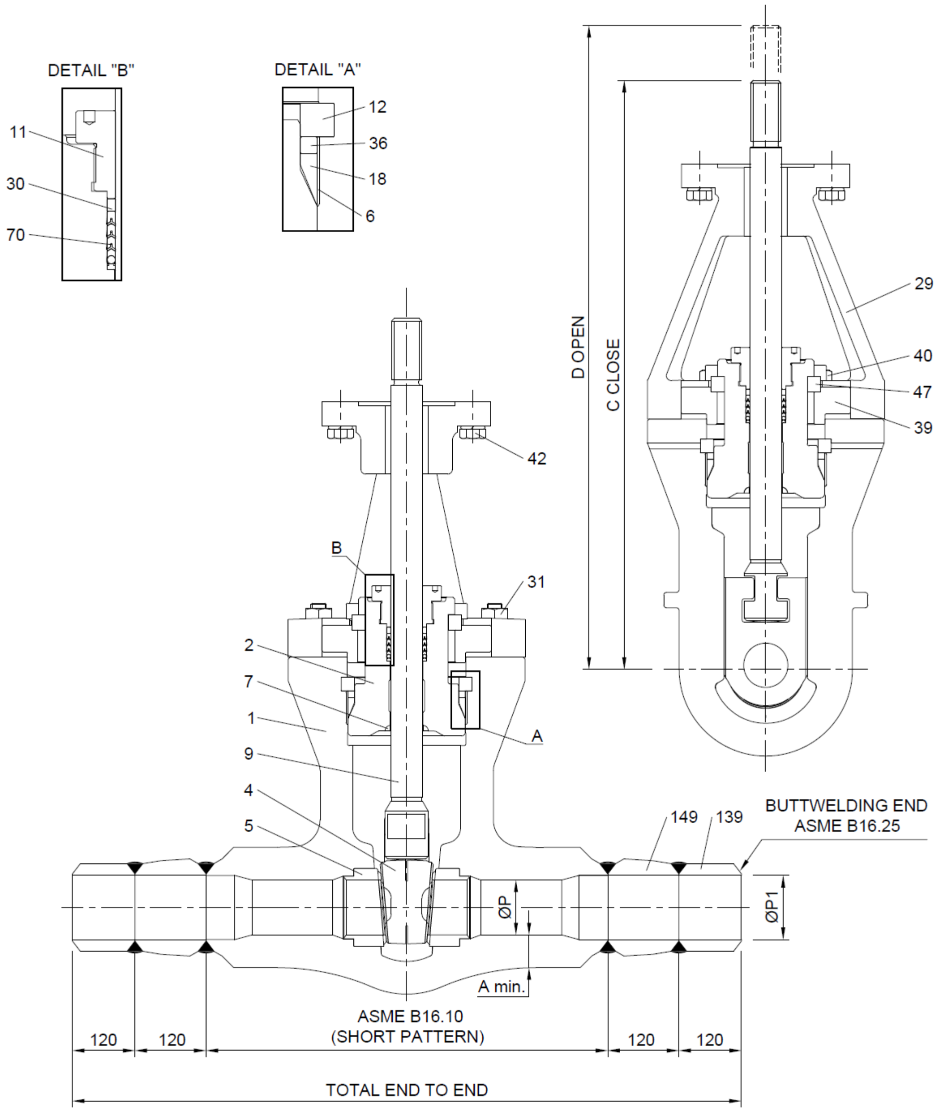


Figure 3.6 – Typical pressure seal gate valve layout

Actuated valves shall be controlled by a Valve Remote Control (VRC) System Hydraulic type, 2 Hydraulic Power Units (HPU's) and 8 control cabinets to control up to 30 valves each. Remote control valves of cargo system will be operated by a separate system from other valves on board.

To fulfil functional capability and redundancy of main function, plant architecture shall be divided in two section (PORT & STBD) and each of them in different further zones according to the P&I design. The hydraulic VRC system will be completely interfaced with the Ship Automation System, therefore, in addition to the remote control from the Central Station, all valves will be controlled with independent local electric modules (WCM), operable inside the valves control cabinets in case of remote control failure. The remote and local back up control will run independently so that a failure in one system will not jeopardize the operation of the others. The full redundant Hydraulic Power Unit (HPP's), each one with two hydraulic pumps (with 100% capacity and one of them to be used as a stand–by), will be installed in an area "safe for location" and they supply the control cabinets located in the same room at Mezzanine Deck at 13 000 ABL (H.P.U. Room in AFT part of the ship). Each panel is equipped by a stored power unit in way to survive, even in case of failure of the HPU's. Valve control cabinets are connected to the HPU's via two main rings for Pressure and Return lines with a third line at high pressure to charge the hydraulics accumulators. Winners WCM is an intelligent distributed VRC system, characterized by electronic and electrohydraulic actuators, E–TorkLT and E–RAM, and electric control modules WCM.

VRC systems main specifications are reported in Table 3.4.

Table 3.4 – VRC system main items specification

Main Item	**Height**	**Width**	**Depth**	**Weight**	**Controlled Valves (including spares)**
	mm	*mm*	*mm*	*kg*	*No.*
Hydraulic power unit 1	1800	1650	1200	200	–
Hydraulic power unit 2	1800	1650	1200	200	–
Solenoid Rack 1	2010	1200	500	800	30
Solenoid Rack 2	2010	1200	500	800	30
Solenoid Rack 3	2010	1200	500	800	30
Solenoid Rack 4	2010	1200	500	800	30
Solenoid Rack 5	2010	1200	500	800	30
Solenoid Rack 6	2010	1200	500	800	30
Solenoid Rack 7	2010	1200	500	800	30
Solenoid Rack 8	2010	1200	500	800	30

3.3 Loading/offloading pipes

In order to absorb small relative movements between the ship and the shore, it is necessary to use flexible pipes for the connection of the on–board/on–shore manifolds. There are two types of standardized flexible pipes especially used in the offshore oil industry: unbonded and bonded flexible pipes. The unbonded flexible pipes were standardized by API Spec 17J Standard between 1994 and 1997, the bonded pipes by API Spec 17K between 1996 and 2002.

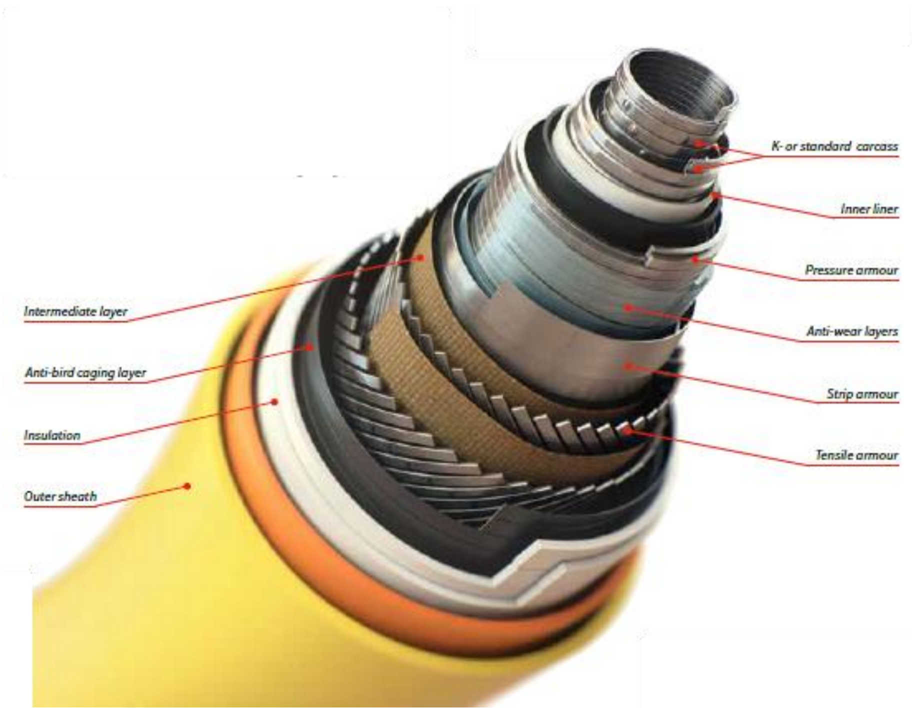


Figure 3.7 – Typical Bonded Flexible Pipe

The loading/unloading connection point shall be equipped with a manually operated stop valve and a remotely operated valve in series.

The remotely operated cargo cylinder valves and load/unload valves required here above shall have emergency shutdown (ESD) functions.

The ESD valves arranged so that they close automatically in case of high pressure, sudden pressure drop during loading/unloading operations and in the event of fire. The ESD valves arranged for manual operation from cargo control room.

The cargo compressors shall shutdown automatically in case of activated ESD system.

The onboard manifold is connected to the on–shore manifold through two bonded type, 7’’ flexible hoses. Flexible hoses characteristics shall respect standards API Spec 17K. Specification of the selected bonded flexible lines are reported in Table 3.5.

Connection between flexible hoses and ship manifold shall be provided by quick releasing connection valves of approved type.

Table 3.5 – Flexible lines specifications

Inside Diameter	Type	Rated working pressure	Test Pressure	Safety Factor	Outer Diameter	MBR (*) Static	MBR (*) Dynamic	Weight
Inches		*Bar*	*Bar*		*mm*	*m*	*m*	*Kg/m*
7.0	Fire rated	293	440	2.25	299	2.2	2.9	117
	Fire rated c/w st. wrap				312	2.2	2.9	135
(*) MBR: minimum bending radius								

Variation in the definition of the flexible pipes characteristics may occur depending on external environmental parameters, flowline parameters, risers parameters.

In particular, concerning external environmental parameters, it must be carefully analysed:

- Location: geographical data for the installation
- Water depth: design water depth, variation over pipe location and tidal variation
- Seawater data: density, pH value and minimum and maximum temperatures
- Air temperature: minimum and maximum during storage, installation and operation
- Soil data: description, shear strength or angle of internal friction, friction coefficients seabed scour, sand waves and variations along pipe route
- Marine growth: maximum values and variations along length
- Ice: maximum ice accumulation or drifting icebergs and ice floes
- Sunlight exposure: length of pipe exposed during operation and storage conditions
- Current data: as a function of water depth, direction and return period, and including the known effects of local current phenomena
- Wave data: in terms of significant and maximum waves, associated periods, waves spectra, spreading function and scatter diagrams, as a function of direction and return period
- Wind data: as a function of direction, height above water level and return period

Concerning flowline parameter:

- Flowline routing: route drawings, topography, seabed/soil conditions, obstacles, and installed equipment and piplines
- Guides and supports: proposed geometry of guides, I–tubes, J–tubes, and bellmouths through which flowline is to be installed
- Protection requirements: Trenching, rock dumping, mattresses, and extent of protection requirements over length of pipe. Design impact loads, including those from trawl boards, dropped objects and anchors.
- On–bottom stability: allowable displacements
- Upheaval buckling: specification of design cases to be considered by manufacturer
- Crossover requirements: crossing of pipes (flexible and rigid), including already installed pipes and gas lines
- Pipe attachments: bend restrictors, clams and attachment methods
- Load cases: definition of yearly probability for installation and normal and abnormal operation. Specification of accidental load cases and yearly probability

Concerning risers parameter:

- Riser configuration: specification of any requirements for the configuration, including description, layout and components. Selection of configuration or confirmation of suitability of specified configuration
- Connection system: description of upper and lower connection system, including quick disconnection systems and buoy disconnection systems, connection angles and location tolerances
- Pipe attachments: bend stiffeners, buoys, ect., and attachment methods
- Attached vessel data: data for attached floating vessels, including the following:
    - Vessel data, dimension, draft, and the like
    - Static offsets
    - First (RAOs) and second order motions
    - Vessels motion phase data
    - Vessels motion reference point
    - Mooring systems interface data
    - Position tolerances
- Interference requirements: specification of possible interference areas, including other risers, mooring lines, platform columns, vessel pontoons, tanker keel, and so on, and definition of allowable interference/dashing
- Load cases: definition of yearly probability for installation, and normal and abnormal operation specification of accidental load cases yearly probability.

4 Compressors

4.1 Possible Compressing Technologies

Commercial available compression technologies can be divided into two main classifications, based on the way of transferring the energy from the machine to the fluid.

- Dynamic compressors
- Volumetric compressors

The dynamic compressors are those machines provided of high speed rotative blades which gives to the fluid an increasing of static pressure and kinetic energy, afterward transformed in pressure energy in the fix pipes of the machine. In dynamic compressors, flow is continuous and can follow either the direction parallel to the main axis of the machine (Axial compressors) or radially (Centrifugal compressors).

Volumetric compressors are those machines in which the increasing of the pressure is given by cyclic and progressive reduction of the volume where the fluid is enclosed. This volume reduction can occur either in a machine composed by cylinder, piston, rod and crank (Alternative compressors) or using specific rotating gears (Rotative compressors).

In order to select the technology for the gas compression system of GASVESSEL, some main criteria have been analysed:

- High flow to reduce loading time
- Reduced size of the compressor
- Low maintenance
- Flexibility
- Efficiency
- Power needs

Axial technology as well as rotative technologies, based on gears have been abandoned since the operational range in terms of flow and pressure ratio are out of the operative range of these technologies.

For this reason available commercial technologies study of possible compressors that could satisfy the needs of GASVESSEL can be mainly divided into two main categories:

- Reciprocating compressors
- Centrifugal compressors

The main advantages of reciprocating compressors with respect to centrifugal ones are:

- High efficiency for high compression ratios
- Relative low cost for low size machines
- Smaller sensitivity to variation in gas composition and density
- Ideal for fluids characterized by low specific volume and high compression ratio

The main advantages of centrifugal compressors with respect to alternative ones are:

- High efficiency at design point of operation
- Simple design, less moving components
- Low maintenance
- No vibration or pulsation of flow
- Ideal for fluids characterized by high specific volume and low compression ratio

4.2 Reciprocating Compressors

Reciprocating compressors have the advantage of being able to operate with variable compression ratios and hence be more flexible and suitable for a large range of receiving and delivery pressures. This is an important advantage when considering that a single boat configuration could be maintained for all geographical scenarios and for all loading and unloading conditions with no strict limitation in pressure. This could allow as well, a better use of the GASVESSEL available storage volume on board, allowing to empty more the vessels at each roundtrip increasing in this way the amount of transported gas.

The main disadvantage of this technology is the low flowrate that makes increase the loading and unloading process time and the higher power needs.

An increased attention to maintenance aspects must also be kept during the operational life of the compressor. Eventually, no (or really limited) liquid fraction is admitted in this compressors, hence stronger control of condensation conditions must be performed during operation.

4.3 Centrifugal Compressors

Centrifugal compressors have the advantage to be able to manage a larger amount of gas per unit of time reducing the duration of loading and unloading time during GASVESSEL operation. This is one determining criteria, indeed reducing the loading/unloading time has an important economic impact on the gas transportation tariff.

However, these compressors have a much smaller operative range and hence must be designed for a specific application. Each scenario will hence need a specific design and optimisation of the compression system. Moreover, in order to avoid exiting the operating map of the compressor, a higher amount of gas should be left inside the tanks at the end of the unloading process, reducing the total storage volume of GASVESSEL.

This type of compressors, can handle a small amount of condensate (up to 5%), which can allow a less strict thermodynamic control of the loading/unloading phase during the operation of GASVESSEL, and they also have less maintenance issues during their operative life with respect to reciprocating compressors.

An additional technology for centrifugal compressor has been taken into account for its reduced size and high performance: the ICL (integrated compression line) technology. The ICL combines the centrifugal compressor technology with an electric motor driver in a single, completely sealed casing that provides an efficient and easily installed compression solution.

4.4 ICL Compressors

The ICL (Integrated Compressor Line) consist in a compact design of a centrifugal compressor powered by a high–speed electric motor fully integrated with the compressor in a single sealed casing. This technology has the main purpose to reduce as much as possible the size of the system and it is ideal for any applications with space constrains.

Both the multistage and the single–stage ICL compressor casings are directly flanged onto the motor, avoiding any alignment requirements. The single–stage ICL compressor rotor uses a single impeller, directly mounted on the motor shaft through a hirth coupling. The multistage ICL compressor rotor features a shaft on which up to nine impellers can be stacked. The rotor is connected to the motor through a flexible coupling, eliminating the need for complex tuning of the bearing system and simplifying future rewheeling of the compressor.

4.5 Choice of the compressors

The choice of the compressor has been performed referring to the selected scenario for the dimensioning of the whole loading and unloading system (see Table 1.3). The choice has been performed taking into account the following considerations:

1) The dimensioning of the compression system has been done for a specific selected scenario at fixed and constant receiving and delivery pressure.
2) The loading/unloading process time should be the shortest as possible. For this reason, high flow compressors have been preferred.
3) On board maintenance should be possibly done by not specialized workers; minimize the maintenance issues and simplify the ordinary maintained is a parameter that shall be as well taken into account in the choice of the compressor.
4) Lastly, the power need for compression should not be higher that the power available on board installed for propulsion. Indeed, compression system starts operating when the ship is at the deck, hence propulsion engines can be off. It would be no sense to install additional power strictly dedicated for loading and unloading process. This would strongly increase cost and reduce space on board of the ship.

Although the reciprocating technology appears to be more flexible to deal with a large variety of possible situations, based on preliminary evaluation of the possible scenarios of interest we decided to adopt centrifugal compression technology for the onboard compressors by restricting the possible range of receiving and delivery pressure. Practically speaking this choice means that the compressor size and the compressor working point shall need to be optimized in relation with the specific application of the specific GASVESSEL.

For the selected reference scenario (Table 1.3) two centrifugal cargo compressors of 5.9MW each are expected to be installed on board with relevant auxiliary services and cargo heat exchangers arranged forward above Deck at 27 500 ABL.

Selected compressors have been sized in order to be able to perform both loading and unloading process.

Dimensioning of the compressors has been performed considering a commercial gas volume of 12 millions Nm^3 with a loading time lower than 52 hours and an unloading time lower than 72 hours.

During the loading process each of the two compressors has to be able to displace 1.07 million Nm^3 in about 5 hours with a compression ratio of 1.40.

During the unloading each of the two compressors has to be able to displace 2.5 million Nm^3 in about process 53 hours with a compression ratio of 4.

Table 4.1 reports the main specification of the selected compressors.

Table 4.1 – Compressors specifications

COMPRESSORS		
Number		2
Type		Centrifugal
Gas		Methane
Rated power	kW	5 900
Max operative pressure	bar	335
LOADING		
Flow rate, average	Nm³/h	214 000
Compression ratio		1.40
Speed	RPM	7 600
UNLOADING		
Flow rate, average	Nm³/h	47 170
Compression ratio		4
Speed	RPM	12 000
DIMENSIONS		
Height	mm	3 400
Width	mm	2 220
Length	mm	8 000
Total compressor unit weight	kg	54 000
Lubrication system weight (wet)	kg	30 000

For example, the two stages compressors MAN RB28–7 could perform this task. Here below in Figure 4.1 are reported the characteristics curves of these compressors.

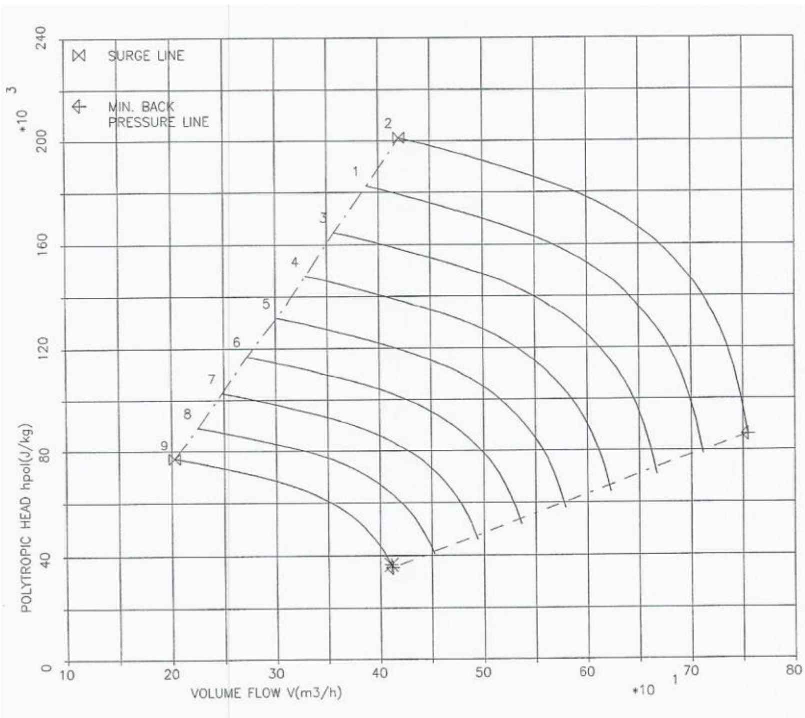


Figure 4.1 – MAN RB28–7 Performance curves

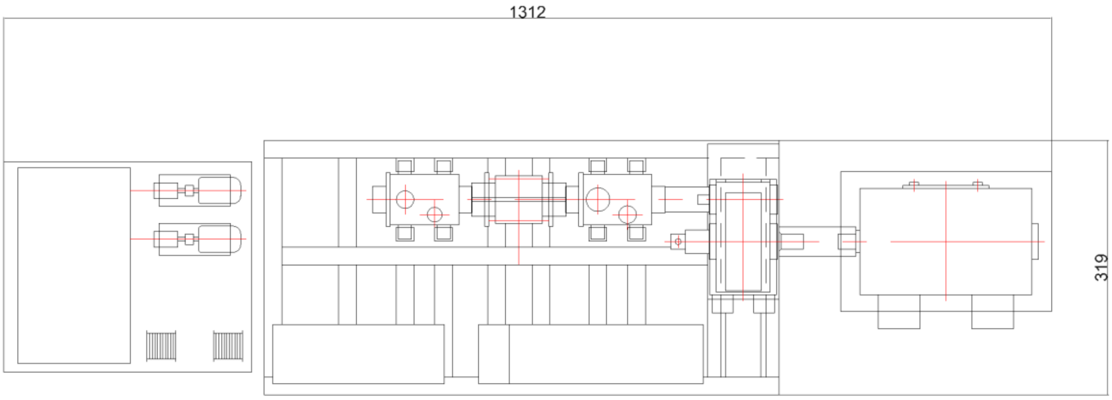


Figure 4.2 – Typical layout of a MAN RB28–7 – Plant view

The MAN RB28–7 has a total longitudinal length of 13 m a width of 3.2 m and an height of 3.4m. The compressor room has been set over deck 9 at 28 m above Base Line (B.L.), at 40 m from prow and centred with respect to the middle line of the ship, as shown in Figure 4.3 and Figure 4.4.

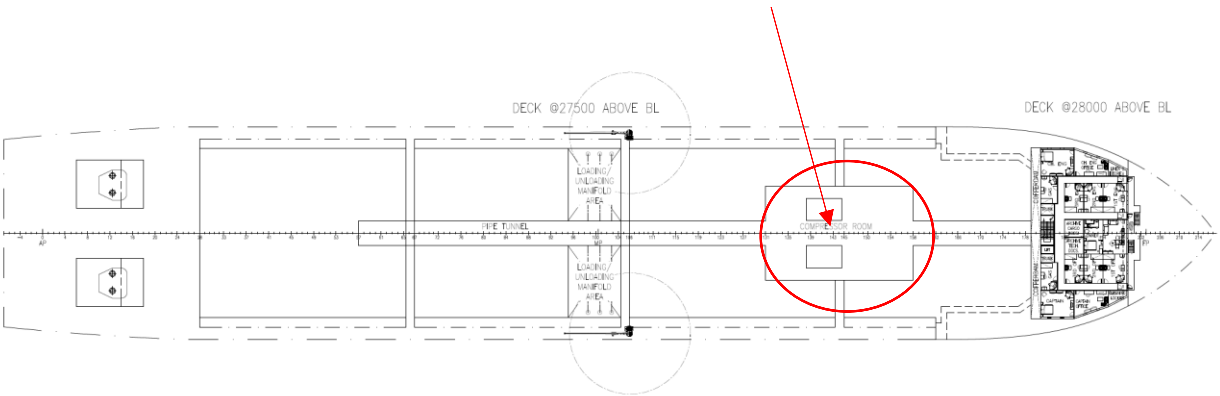


Figure 4.3 – General arrangement of GASVESSEL with highlighted the position of the compressor room – plant view

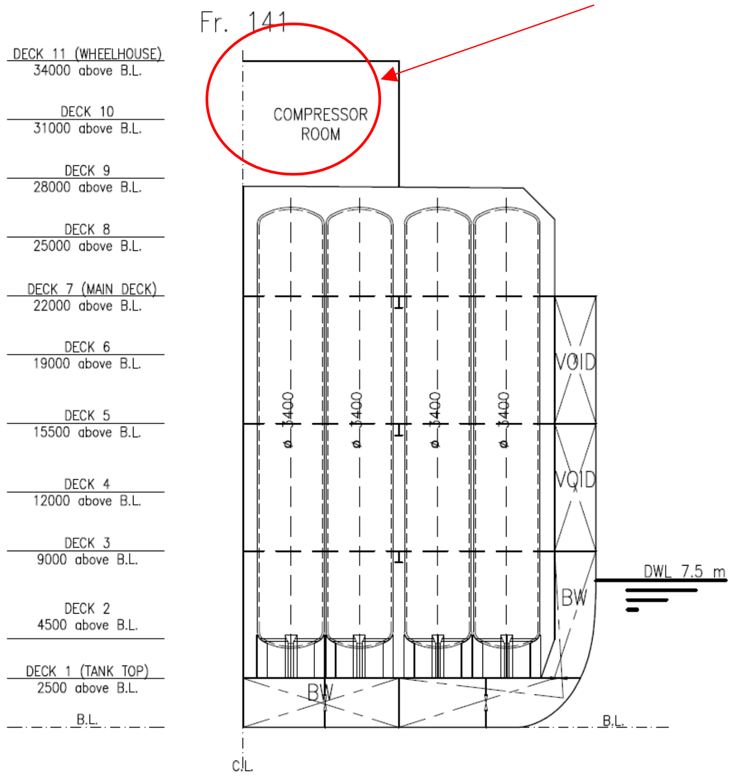


Figure 4.4 – General arrangement of GASVESSEL with highlighted the position of the compression room – section view

5 Compressors’ Accessories

5.1 Needs for Accessories

In addition to the compressor machine, various accessories are needed to allow the compression station to work. In particular three main accessories are crucial and strongly influence the choice of the compressor and its performance: the power system, the cooling system and the lubrification system.

Concerning the power system, two main option are available: electric motor or gas turbine, while concerning the cooling system, sea water cooling, air water cooling or both can be used.

Lubrification system can be optimize in order to reduce consumption and increase the performance of the compressor as well as its lifetime.

5.2 Power system

As mentioned before compressors can be powered by different engines. In particular two main options has been analysed: Electric motors and gas turbines. Installing a gas turbine on board of GASVESSEL would allow to switch off the propulsion engines when at port and to have a dedicated turbine for the loading and unloading process with no power limitation which could strongly reduce the process time. However, it would entail the installation on board of an additional machine that would take place, would increase cost and maintenance issues.

Today, on shore installations that use large centrifugal or axial compressors commonly have gas turbines as the prime mover, however, in spite of power, speed, and fuel advantages of turbines as prime movers, Adjustable Speed Drives (ASD) electric motor have begun replacing gas and steam turbines for driving large compressors also for on shore installations.

5.2.1 Gas Turbines

A typical gas turbine driven compressor train is shown in Figure 5.1. As can be seen Figure 5.1 an electric helper motors is needed, anyway, to start the turbine and to provide additional power when the turbine power declines to less than the process demands. The electric helper motor rotates the turbine up to speed creating pressure in the combustion chambers. The gas burners are ignited and the compressor is loaded up. Power and speed are adjusted by opening and closing the gas valves to regulate fuel. Once the gas turbine has reached rated power, the starter motor is not required. However, the electric motor can be brought online as a helper when the turbine power declines to less than demanded by the process. An ASD (Adjustable Speed Drive), not shown in the figure, is used to smoothly start the helper motor [27].

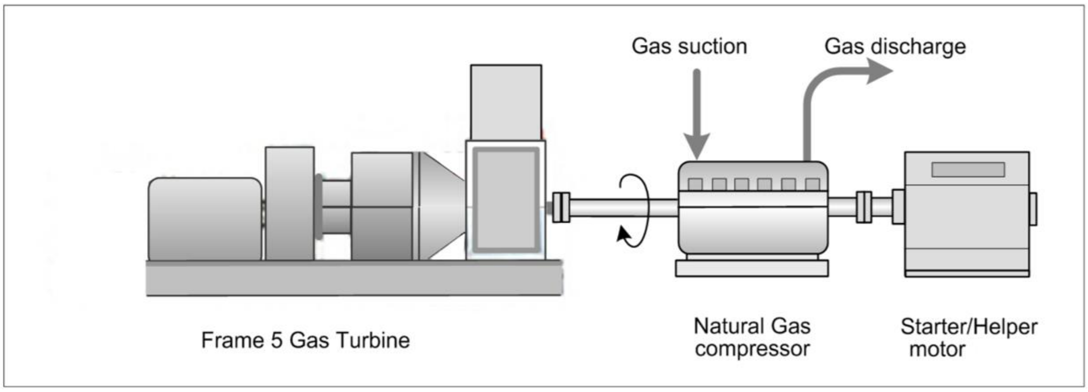


Figure 5.1 – Compressor Drive consisting of Gas Turbine and Electric Starter/Helper Motor [27]

Gas turbines have usually a lower investment cost and lower degradation of the components that allow the turbine depletion to remains flat for more than 20 years (with proper devices and maintenance), while for electric motors obsolescence or derating of operational parameters of electrical components happens faster.

5.2.2 Electric Motors

Figure 5.2 shows a typical ASD electric motor driven compressor train. In this typical on–shore configuration the electric motor is started and run by an adjustable speed drive. The starting current is controlled so that no large inrush occurs, which can result in overheating in the motor and a dip in the supply voltage. This capability of limiting inrush will save operations significant electrical charges. Generally, synchronous motors are employed for compressor power levels greater than 15 MW.

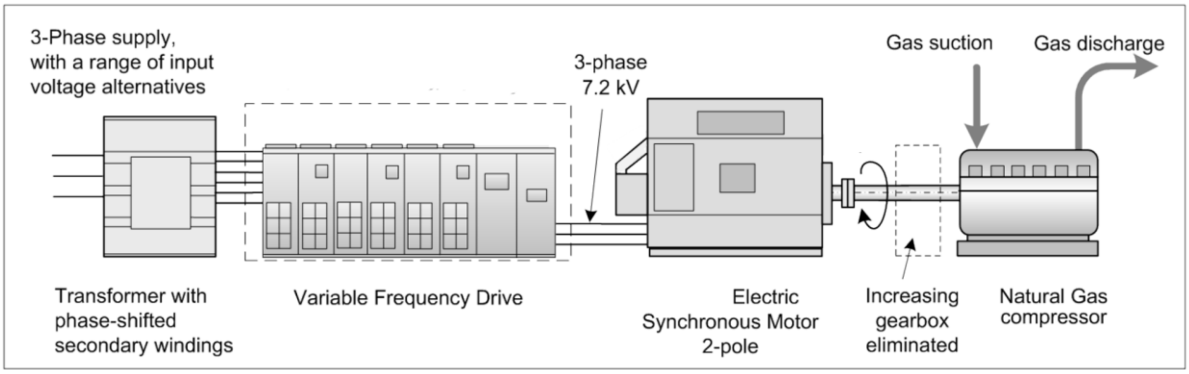


Figure 5.2 – Compressor Drive consisting of an Adjustable Speed Drive and Synchronous Motor *[27]*

Electric motors have the following advantages with respect to a gas turbine:

- Reduced downtime due to low maintenance
- Accurate speed control and hence optimum flow balance
- Higher efficiency especially at partial load
- Zero CO_2 and NO_X emissions
- Drastically reduced noise emissions
- Independence of power on air temperature

Moreover, in our case, since the propulsion of the ship is already performed by an electrical motor, seems very convenient to choose to use the same powering system also for the compression station, avoiding in this manner to install additional power system and reducing space encumbrance and maintenance issues.

5.3 Heat Exchangers (Cooling technology)

As mentioned before cooling system is crucial in compression system performance, it is hence indispensable to chose the most suitable technology allowing to fulfil the requirement of the compression system. Different technologies are available on market, but for offshore application the choice is focused on two mainly technologies: seawater cooling and air cooling.

5.3.1 Sea water cooling

Seawater cooling is generally more efficient and allow a considerable reduction of the size of the tube exchangers. This choice is hence often preferred when space is a major constraint.

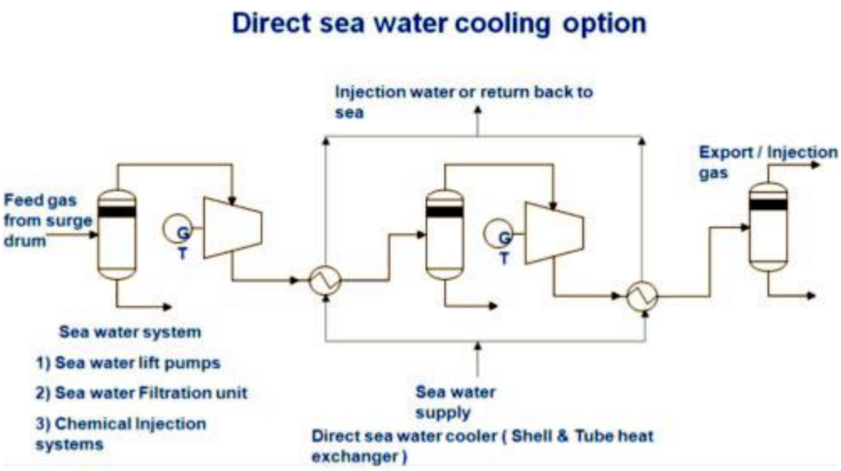


Figure 5.3 – Typical layout of a direct seawater cooling system

However some important drawback of this technology are:

- Need of dedicated sea water lift pumps, filtration units, chemical /corrosion inhibitor injection units and break tank are required for the service.
- Shell and tube exchanger with titanium tubes are highly expensive
- High tube temperature will accelerate fouling and corrosion severely at sea water side
- Less availability and reliability due to need of regular cleaning of sea water cooler

PCHE (Printed Circuit Heat Exchanger) is not suitable for direct sea water cooling, as small pores can be blocked by dirty sea water and scaling. Plate exchangers are limited by design pressures and it can also be blocked by solid particles. Thus only shell and tube exchangers are suitable for direct sea water gas cooling [28].

5.3.2 Air cooling

Air cooling system are almost maintenance free but they entail more space encumbrance which adds substantial structure weight and cost to the project together with are other small issues like hot air circulation and fan noise.

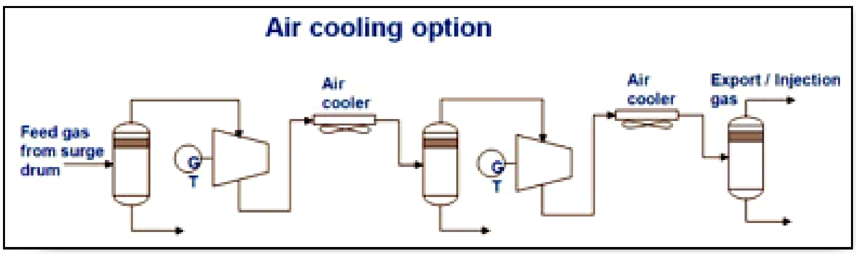


Figure 5.4 – Typical layout of air cooling system

5.4 Lubrification

Lubrification is a crucial issue to reach long term and safe operation of any compressor. Needs of lubrification strongly vary depending on the type of compressor and the nature of the gas to be compressed.

In general, lubricating issues are more complex in alternative compressors since more areas and moving components require lubrification and especially because lubricant get in contact with the gas. For centrifugal compressors, where oil and gas do not get in contact lubrication requirements are much simpler. Usually, for centrifugal compressors, a good rust and oxidation–inhibited oil will provide satisfactory lubrication of the bearings, gears and seals [29].

Lubrication of alternative compressors is needed for the following areas and components [30]:

- Compressor Frame
- Main bearings
- Connecting rod bearings
- Cross head bearings
- Motor bearings
- Cylinder Region
- Rider bands
- Compression rings
- Packing
- Valves

If the frame bearings and cylinder are using the same oil for lubrication, the oil is pumped from a reservoir where the oil is filtered and cooled. In many cases, two different lubricants are used. The frame bearings don't require synthetics because of the moderate conditions. High–pressure, high–temperature conditions may require synthetics or compounded oils in the cylinder. Also, higher pressures require higher viscosities. A separate oil system is used to supply oil to the injectors for the cylinder.

Hydrocarbon or wet gases can have a large dilution effect on an oil; as pressures are increased oil viscosity should increase. Polyalkylene glycols (PAG) and diester are a good choice when working with high pressures or temperature above 150°C. PAG are very resistant to dilution by hydrocarbons, and diesters have high thermal stability and excellent solvency that prevents exhaust–valve deposits (a major problem at high temperatures).

In centrifugal compressors few key components require a coolant/lubricant: gears, bearings and seals. To date, the majority of dynamic compressors use oil film–lubricated seals. Only labyrinth seals or gas–lubricated seals operate without a liquid film separating the faces. On the more conventional liquid–lubricated seals, the bearing and sealing lubricant are often the same [29].

The lube oil system supplies oil to the compressors and other components needing lubrification. The lube oil is pumped from a reservoir and fed under pressure through coolers and filters to the bearings and then circulated back to the reservoir. Pressure inside the lube oil tank should be by setting the reservoir at a different height with respect to the compressor, this allow to keep pressure in the tank also when the engine is off.

An oil temperature control system can be installed to provide preheating at cold–start and cooling at peak charge.

When in operation, the compressor lubricant oil is normally circulated by the main oil pump. An auxiliary pump serves as a standby. These Generally two pumps are installed, one main pump and one auxiliary pump in standby, usually powered by different types of power sources or connected to separate supply feeders.

On compressors with step–up gearboxes, the main oil pump may be driven mechanically from the gearbox, and the auxiliary pump operates during the start–up and run–down phases of the compressor train. Relief valves protect both pumps from the effects of excessively high pressures. Check–valves prevent reverse flow of oil through the stationary pump [29].

Heat generated in the compressor is transferred to the cooling medium in the oil coolers. Air–cooled oil coolers or water–cooled oil coolers can be used.

A oil pressure control system is needed to activate the auxiliary pump and/or switch of the compressor train if pressure drops down under a set limit.

6 Heat Exchangers

6.1 Generalities on Heat Exchangers

From the investigations on the dynamics of the loading and of the unloading process it appears that a carefully designed system of heat exchangers is of great importance to maximize the useful Gas payload and to minimize the timing for loading and unloading processes.

Figure 6.1 illustrates the schematics of the cooling system with reference to the starboard side of GASVESSEL. Identical configuration has to be considered for the Port side.

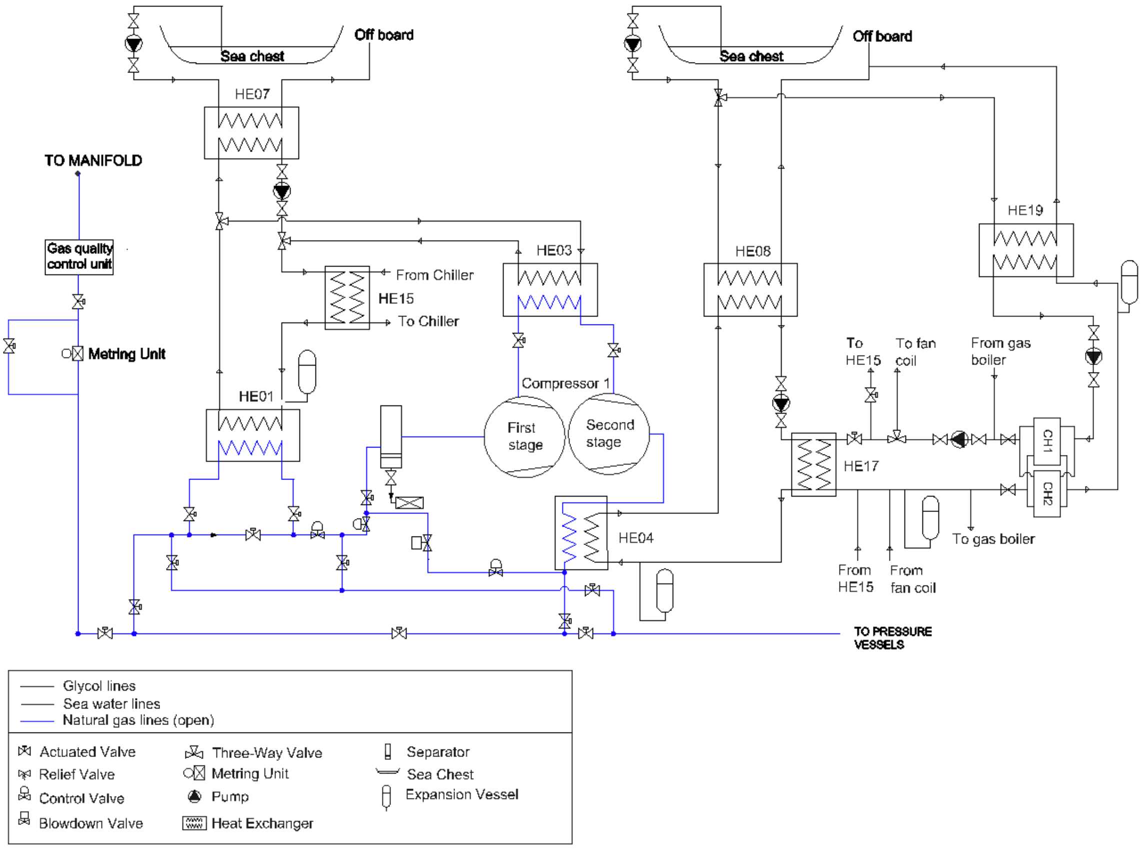


Figure 6.1 – Cooling system diagram – Starboard

Dimensioning of the heat exchangers has been performed considering average operating and ambient conditions. Dimensioning must be revised based on specific needs of minimum loading capacity at extreme ambient conditions.

As described in §7, during the free loading process, gas is cooled down with two water–glycol PCHE heat exchangers of 3.8 MW each (HE01, HE02). Technical characteristics of the selected heat exchangers are reported in Table 6.1. Figure 6.2 reports the main dimensions and layout of PCHE exchangers.

Table 6.1 – PCHE heat exchanger specification (HE01, HE02)*

HE01, HE02		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Methane		Glycol Water 60%	
Flow rate, total	kg/hr	82800		273600	
Flow rate, gas/vapour	kg/hr	82800	82800	–	–
Flow rate, liquid	kg/hr	–	–	273600	273600
Temperature	°C	–35	4	6	–10
Design temp: max/min	°C	150°C / –40°C		150°C / –40°C	
Pressure: inlet/design	bar	335 / 385 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	2		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	–	99	1095	–
Specific heat*	J/kg K	–	4236	3132	–
Viscosity*	cP	–	0,0128	1,362	–
Thermal conductivity	W/mK	–	0,0426	0,488	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 250	DN 250	DN 200	DN 200
THERMAL DESIGN					
Design heat load	MW	3,8			
LMTD	°C	9			
DIMENSIONS					
Height	mm	2160			
Width	mm	1420			
Length (**)	mm	1300			
Net Weight (**)	ton	2			
(*) these data are average values as they change during the process (affected by NG pressure)					
(**) Estimated data					

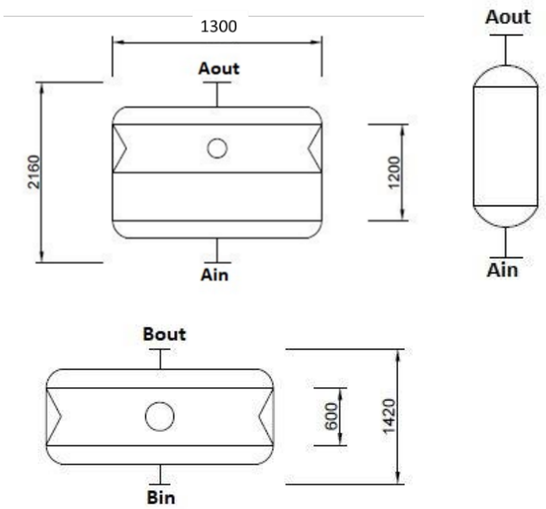


Figure 6.2 – Dimensions of PCHE exchangers used for heater

Each compressor is provided with a 3MW intercooler (Table 6.2– HE03, HE05) and a 3.8MW post cooler (Table 6.3– HE04, HE06). Intercooler cold side (side B) is cooled down thank to the 3.8MW seawater heat exchanger (Table 6.4– HE07, HE09), while the post cooler cold side (side B) is cooled thanks to a dedicated 3.8 MW seawater heat exchanger (Table 6.5– HE08, HE10) and by the chillers (Table 6.9) through other two plates exchangers (Table 6.6 – HE17, HE18).

Table 6.2 – Intercooler specification (HE03, HE05)

HE03, HE05		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Methane		Glycol Water 60%	
Flow rate, total	kg/hr	82800		223200	
Flow rate, gas/vapour	kg/hr	82800	82800	–	–
Flow rate, liquid	kg/hr	–	–	223200	223200
Temperature	°C	80	40	37	52
Design temp: max/min	°C	150°C / 10°C		150°C / 10°C	
Pressure: inlet/design	bar	335 / 385 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	–	165	1074	–
Specific heat*	J/kg K	–	3261	3132	–
Viscosity*	cP	–	0.0216	1.362	–
Thermal conductivity	W/mK	–	0.0713	0.488	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 250	DN 250	DN 200	DN 200
THERMAL DESIGN					
Design heat load	MW	3			
LMTD	°C	11			
DIMENSIONS					
Height	mm	2060			
Width	mm	1420			
Length (**)	mm	1000			
Net Weight (**)	ton	1.5			
(*) these data are average values as they change during the process (affected by NG pressure) (**) Estimated data					

Figure 6.3 reports the layout and main dimensions of the PCHE heat exchanger used for the intercooler and post cooler.

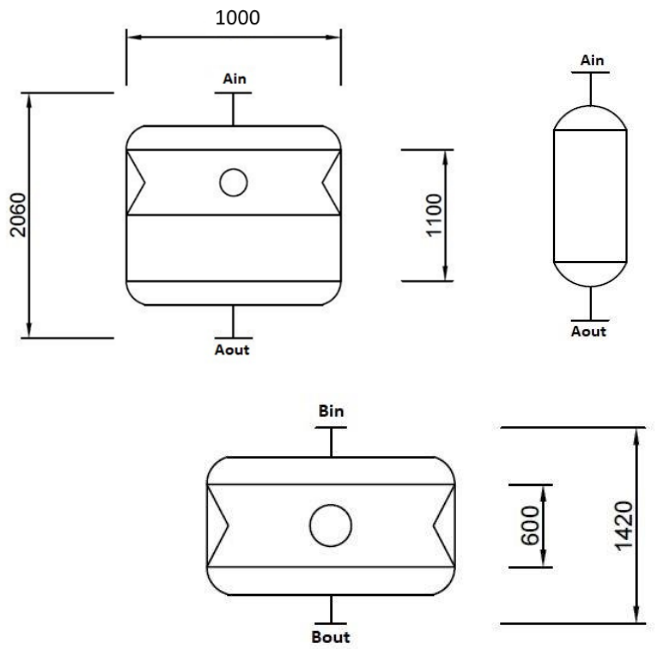


Figure 6.3 – Dimensions of PCHE exchangers used for the intercooler. The same HE could be used for the post cooler as the specifications are similar.

Table 6.3 – PCHE Post–cooler specification (HE04, HE06)

HE04, HE06		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Methane		Fresh Water	
Flow rate, total	kg/hr	82800		181818	
Flow rate, gas/vapour	kg/hr	82800	82800	–	–
Flow rate, liquid	kg/hr	–	–	181818	181818
Temperature	°C	90	40	37	55
Design temp: max/min	°C	150°C / 10°C		150°C / 10°C	
Pressure: inlet/design	bar	335 / 385 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	2		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	–	165	993	–
Specific heat*	J/kg K	–	3304	4180	–
Viscosity*	cP	–	0,0216	0,691	–
Thermal conductivity	W/mK	–	0,0713	0,624	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 250	DN 250	DN 200	DN 200
THERMAL DESIGN					
Design heat load	MW	3,8			
LMTD	°C	13			

HE04, HE06		SIDE A	SIDE B
DIMENSIONS			
Height	mm	2060	
Width	mm	1420	
Length (**)	mm	1000	
Net Weight (**)	ton	2.0	
(*) these data are average values as they change during the process (affected by NG pressure) (**) Estimated data			

Table 6.4 – Sea water plates heat exchangers HE07, HE09

HE07, HE09		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Glycol Water 60%		Sea Water	
Flow rate, total	kg/hr	273600		684000	
Flow rate, gas/vapour	kg/hr	273600	273600	–	–
Flow rate, liquid	kg/hr	–	–	684000	684000
Temperature	°C	–10	6	8	3
Design temp: max/min	°C	150°C / 0°C		60°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	1095	–	1025	–
Specific heat*	J/kg K	3132	–	4009	–
Viscosity*	cP	1,362	–	1,090	–
Thermal conductivity	W/mK	0,488	–	0,590	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 200	DN 200	DN 250	DN 250
THERMAL DESIGN					
Design heat load	MW	3,8			
LMTD	°C	5.9			
DIMENSIONS					
Height	mm	1435			
Width	mm	800			
Length (**)	mm	2715			
Net Weight (**)	ton	3.7			
(*) these data are average values as they change during the process (affected by NG pressure) (**) Estimated data					

In Figure 6.4 are reported layout and main dimensions of the plate heat exchangers used for the Intercooler and the Heater.

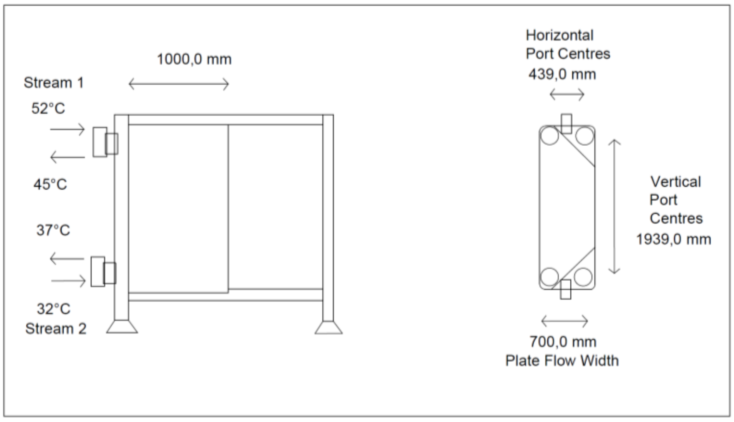


Figure 6.4 – Dimensions of the plate heat exchangers used for the Intercooler and the Post–cooler. In the figure the stream in the intercooler only operation are shown.

Table 6.5 – Sea water plates heat exchangers HE08, HE10

HE08, HE10		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Fresh Water		Sea Water	
Flow rate, total	kg/hr	181818		262000	
Flow rate, gas/vapour	kg/hr	–	–	–	–
Flow rate, liquid	kg/hr	181818	181818	262486	262486
Temperature	°C	55	37	32	45
Design temp: max/min	°C	150°C / 0°C		60°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	993	–	1025	–
Specific heat*	J/kg K	4180	–	4009	–
Viscosity*	cP	0,691	–	1,090	–
Thermal conductivity	W/mK	0,624	–	0,590	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 200	DN 200	DN 200	DN 200
THERMAL DESIGN					
Design heat load	MW	3,8			
LMTD	°C	7			
DIMENSIONS					
Height	mm	1435			
Width	mm	800			
Length (**)	mm	2715			
Net Weight (**)	ton	3.7			
(*) these data are average values as they change during the process (affected by NG pressure) (**) Estimated data					

In Figure 6.5 are reported layout and main dimensions of the plate heat exchangers used for the Intercooler and the Heater.

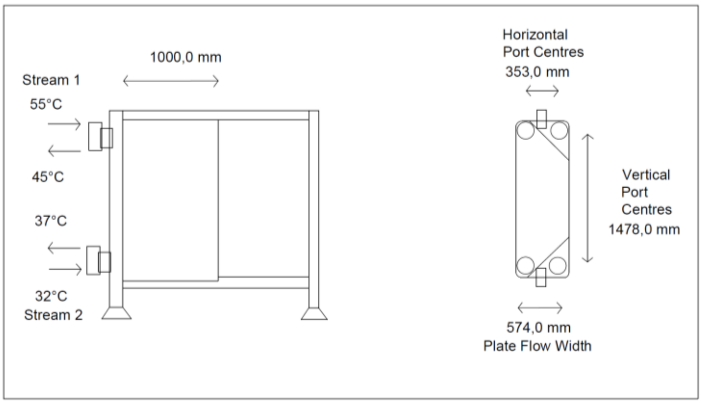


Figure 6.5 – Dimensions of the plate heat exchanger used for the Intercooler and the Heater

Table 6.6 – Glycol heat exchangers specifications (HE17, HE18)

HE17, HE18		SIDE A (**)		SIDE B (**)	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Fresh Water		Glycol water 60%	
Flow rate, total	kg/hr	181818		616000	
Flow rate, gas/vapour	kg/hr	–	–	–	–
Flow rate, liquid	kg/hr	181818	181818	616000	616000
Temperature	°C	32	18	7	12
Design temp: max/min	°C	150°C / 0°C		30°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	993	–	1074	–
Specific heat*	J/kg K	4180	–	3132	–
Viscosity*	cP	0,691	–	1.362	–
Thermal conductivity	W/mK	0,624	–	0.488	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 200	DN 200	DN 250	DN 250
THERMAL DESIGN					
Design heat load	MW	2.8			
LMTD	°C	15			
DIMENSIONS					
Height	mm	1435			
Width	mm	800			
Length (***)	mm	2000			
Net Weight (***)	ton	2.7			

(*) these data are average values as they change during the process (affected by NG pressure)
(**) side A: glycol water circuit connect to HE04 and HE08 (HE06 and HE010); side B: glycol water circuit connect to chiller.
(***) Estimated data

Warm side of the chillers is cooled down thanks to two glycol/sea water plates heat exchangers (Table 6.7–HE19, HE20).

Table 6.7 – Exchangers (HE19, HE20)

HE19, HE20		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Fresh Water		Sea Water	
Flow rate, total	kg/hr	566606		590772	
Flow rate, gas/vapour	kg/hr	–	–	–	–
Flow rate, liquid	kg/hr	566606	1566606	590772	590772
Temperature	°C	37	32	20(***)	25
Design temp: max/min	°C	60°C / 10°C		60°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	993	–	1025	–
Specific heat*	J/kg K	4180	–	4009	–
Viscosity*	cP	0,691	–	1,090	–
Thermal conductivity	W/mK	0,624	–	0,590	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 250	DN 250	DN 250	DN 250
THERMAL DESIGN					
Design heat load	MW	3,3			
LMTD	°C	12			
DIMENSIONS					
Height	mm	1435			
Width	mm	800			
Length (**)	mm	2360			
Net Weight (**)	ton	3.2			

(*) these data are average values as they change during the process (affected by NG pressure)
(**) Estimated data
(***) Average Mediterranean Sea Temperature

Oil coolers HE11 and HE12 are defined to be plate heat exchangers, with the characteristics in the following table. Cooling media has still to be defined, in the following table glycol water has been chosen.

Table 6.8 – Lube oil exchangers HE11, HE12

		SIDE A		SIDE B	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Oil		Fresh Water	
Flow rate, total	kg/hr	7560		34200	
Flow rate, gas/vapour	kg/hr	–	–	–	–
Flow rate, liquid	kg/hr	7560	7560	34200	34200
Temperature	°C	108	50	37	55
Design temp: max/min	°C	150°C / 0°C		60°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	t.b.d.	–	1025	–
Specific heat*	J/kg K	2052	–	4009	–
Viscosity*	cP	t.b.d.	–	1,090	–
Thermal conductivity	W/mK	t.b.d.	–	0,590	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 20	DN 20	DN 20	DN 20
THERMAL DESIGN					
Design heat load	kW	250			
LMTD	°C	28			
DIMENSIONS					
Height (**)	mm	737			
Width (**)	mm	245			
Length (**)	mm	115.5			
(*) these data are average values as they change during the process (affected by NG pressure) (**) Estimated data					

6.2 Compression Chiller choice

The chillers have been sized relying on the power required to cool down the hold of the ship during the loading phase. Dimensioning has been based on average need instead of peak needs since it has been considered to be possible to differ cooling and heating needs during the trip.

The use of the chiller is necessary to lower the temperature of the hold as much as possible during the journey with the empty ship before the loading phase.

The cooling of the hold can be continued during the free loading phase with reduced power. During the free loading phase the chiller adsorbs heat from the HE15 and HE16 (Table 6.10) circuit to lower the inlet gas temperature from the 25°C of the storage to 20 ° C.

During the forced loading phase the chiller supplies power to the cooler circuit to lower the temperature of the gas at the outlet of the compressor to 20 ° C before entering the tanks.

Table 6.9 reports the chiller specification according to (Carrier, Marine & Offshore).

Table 6.9 – Chillers specifications

Heat load	1407 kW
Electric Power(**)	278 kW
COP	5.05
Evaporator	
Water connection	DN 200
Water flow rate (*)	62.2 L/s
Condenser	
Water connection	DN 200
Flow rate	80.8 L/s
Length	4172 mm
Width	1707 mm
Height	2073 mm
Operating Weight	6.8 ton
(*) the flow rate should be related considering glycol water (**) the electric motor must be chose at 60 HZ	

Cold produced by the chillers is brought to the gas thanks to two plates heat exchangers (HE15, HE16). Main specifications of these exchangers are reported in Table 6.10.

Table 6.10 – Chiller/Heater exchangers specifications (HE15, HE16)

HE15, HE16		SIDE A (**)		SIDE B (**)	
FLUID CONDITIONS		IN	OUT	IN	OUT
Fluid		Glycol water 60%		Glycol water 60%	
Flow rate, total	kg/hr	273600		273600	
Flow rate, gas/vapour	kg/hr	–	–	–	–
Flow rate, liquid	kg/hr	273600	273600	273600	273600
Temperature	°C	18	13	7	12
Design temp: max/min	°C	150°C / 0°C		30°C / –5°C	
Pressure: inlet/design	bar	3 / 6 FV		3 / 6 FV	
Pressure drop: calc/allwd	bar	1		1	
FLUID PROPERTIES		Liq	Vap	Liq	Vap
Density*	kg/m³	1095	–	1095	–
Specific heat*	J/kg K	3132	–	3132	–
Viscosity*	cP	1.362	–	1.362	–
Thermal conductivity	W/mK	0.488	–	0.488	–
CONNECTIONS					
No. of nozzles		1	1	1	1
Nozzle size	mm NB	DN 200	DN 200	DN 200	DN 200
THERMAL DESIGN					
Design heat load	MW	1.2			
LMTD	°C	6			
DIMENSIONS					
Height	mm	1941			

HE15, HE16		SIDE A (**)	SIDE B (**)
Width	mm	610	
Length (***)	mm	1100	
Net Weight (***)	ton	2.2	
(*) these data are average values as they change during the process (affected by NG pressure) (**) side A: glycol water circuit connect to HE01, HE07 and HE03 (HE02, HE09 and HE05); side B: glycol water circuit connect to chiller. (***) Estimated data			

Figure 6.6 – Dimensions of the plates heat exchangers used for the HE15, HE16 reports layout and main dimensions of the plates heat exchanger used for HE15 and HE16.

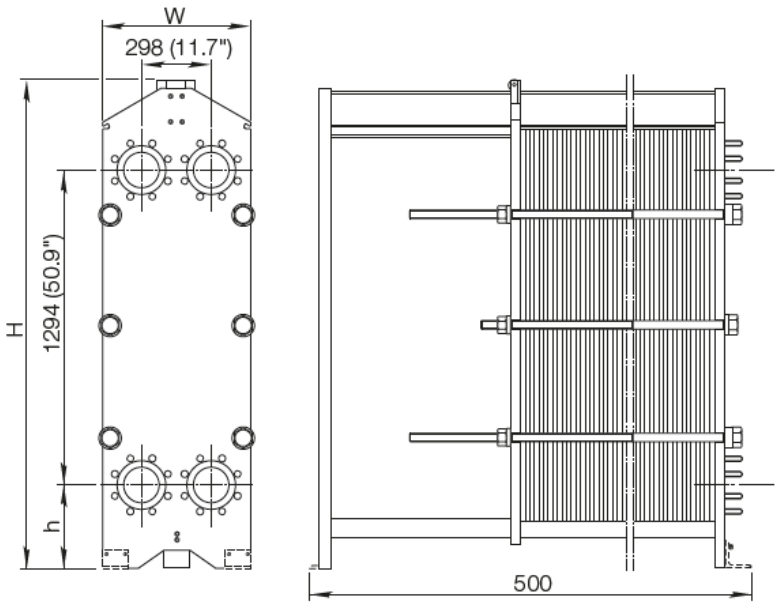


Figure 6.6 – Dimensions of the plates heat exchangers used for the HE15, HE16

The heat exchangers are also connected to two seawater heat exchangers of 3.8MW each (Table 6.4).

6.3 Fan coil selection for the holds

In order to increase the total loading capacity of the ship, it is important to decrease as much as possible both the gas temperature and the hold temperature. For this reason 224 fan coils of 25kW each (Table 6.11) has been installed on the dome of the holds as, for example, shown in Figure 6.7

Table 6.11 – Fan coils specifications

Fan coil(*) Specification	Total Values	Single Unit
Cooling Heat load	5.6 MW	25 kW
Number of fan coil	224	1
Electric Power	246.4 kW	1.1 kW
Water flow rate	345.6 kg/s	1.5 kg/s
length	–	1536 mm
width	–	525 mm
height	–	780 mm

The internal piping diameter of the fan coils is DN25, while glycol water piping distribution lines diameters are reported Figure 6.7.

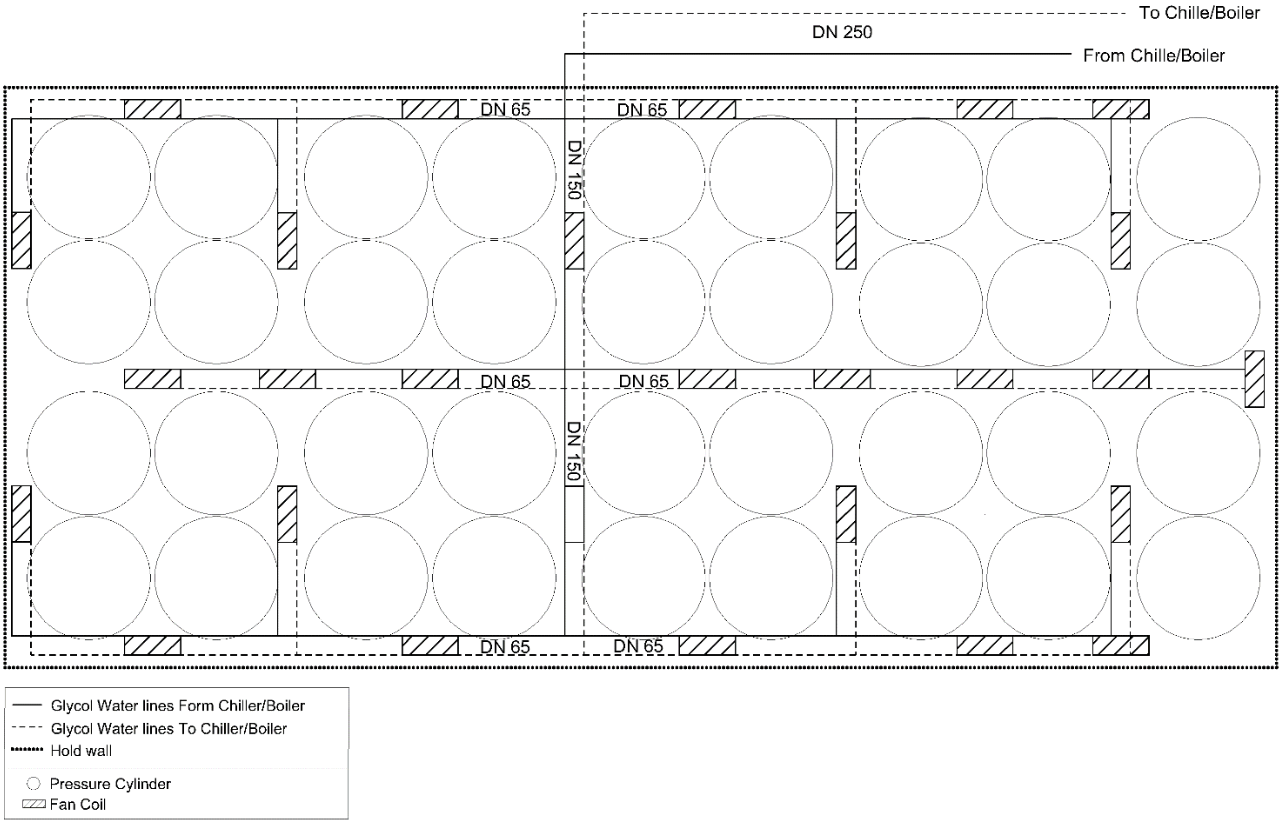


Figure 6.7 – Fan coils layout in hold 3S (Typical)

Fan coils thermal power has been estimated considering dry nitrogen with 0% of RH.

6.4 Auxiliaries and Dimensioning of Auxiliaries

Each cooling circuit is provided with expansion vessels whose specifications are reported in Table 6.12.

Table 6.12 – Expansion vessels specifications

		EX1/EX3	EX2/EX4	EX5/EX6	EX9/EX10
MATERIALS					
Body	–	Stainless Steel			
Membrane	–	SBR (Styrene Butadiene Rubber)			
Piping plug	–	Galvanized Steel			
PERFORMANCES					
Fluid	–	Fresh Water	Glycol Water	Glycol Water	Fresh Water
Max percentage of Glycol	*%*	0%	60%	60%	0%
Max operating pressure	*bar*	6	6	6	6
Pre–charge pressure	*Bar*	1.3	1.3	1.3	1.3
System temperature range	*°C*	10 / 150	–40 / 150	–5 / 30	–5 / 60
Membrane temperature range	*°C*	10 / 150	–40 / 150	–5 / 30	–5 / 60
Piping plug DN	*mm*	254	254	190	250
DIMENSIONS					
Volume	litres	750	1800	50	200
Weight	kg	120	290	8	32

The heat duties of the heat exchangers and therefore the pump power have been calculated assuming the peak heat dissipation need. In a design review phase the heat duty can be reduced according to the specific load/unload profile considered.

Table 6.13, Table 6.14, Table 6.15, Table 6.16 report the dimensioning of the pumps needed for the circulation of cooling mediums.

Table 6.13 – Glycol/Fresh water pumps specifications

Name	Flowrate (ton/h)	Flowrate (m3/h)	DN	Head (m)	Power mech. (kW)	Power el. (kW)	Weight (kg)
EP01	273	254	125	40	30	60	180
EP04	230.4	215	125	40	25	50	180
EP05	273.6	255	125	40	30	60	180
EP06	230.4	215	125	40	25	50	180

Table 6.14 – Sea water pumps specifications

Name	Flowrate (ton/h)	Flowrate (m3/h)	DN	Head (m)	Power mech. (kW)	Power el. (kW)	Weight (kg)
EP07	684	667	200	20	37	75	250
EP08	829	835	250	20	45	90	450
EP02	684	667	200	20	37	75	450
EP03	829	835	250	20	45	90	250

Table 6.15 – Chillers water pumps specifications

Name	Flowrate (ton/h)	Flowrate (m3/h)	DN	Head (m)	Power mech. (kW)	Power el. (kW)	Weight (kg)
EP09	616	574	200	40	67	134	330
EP10	616	574	200	40	67	134	330

Table 6.16 – Chiller warm–side pumps specifications

Name	Flowrate (ton/h)	Flowrate (m3/h)	DN	Head (m)	Power mech. (kW)	Power el. (kW)	Weight (kg)
EP11	566	570	200	40	62	123	330
EP12	566	570	200	40	62	123	330

A solution to increase gas loading capacity could be to store cold and heat in the ballast water. To define the plant layout further date are necessary. Table 6.17 reports the potential heat capacity of ballast water.

Table 6.17 – Ballast water heat capacity

Ballast capacity	3000	tons
Sea water temperature	16	°C
Minimum temperature	5	°C
Heat	38.32	MWh

7 Loading and Unloading Process Description

7.1 Introduction to the Loading Process

Gas will be taken on board via the loading facilities and transferred via the deck piping to the cargo containment system. Loading process will start spontaneously from the delivery pressure of about 240 bar (free loading phase), then, when pressure inside the on–board pressure cylinders reaches about 240 bars, the on–board compressors start up to increase the gas pressure from the site delivery pressure of 240 bar to the storage pressure cylinders of 335 bar (forced loading phase). This process is expected to take about 52 hours considering a commercial gas volume of 12 millions Nm^3.

All dimensioning of the loading and unloading system has been performed considering pure methane.

Figure 7.1 reports the loading process phases main parameters and the evolution of the mass flow during free loading and forced loading phases.

- Suspion pressure: 240 bar
- Discharge pressure: 335 bar
- Initial pressure in tanks: 20 bar

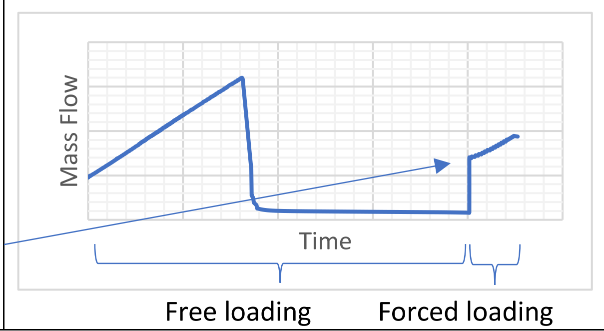


Figure 7.1 – Loading process phases

The manifold of the ship is connected to the onshore manifold through two flexible hoses (see §3.3). (The ship is provided with two identical connections systems, one at starboard and one at port, in Figure 7.2 it is reported the starboard connection system as an example).

For the on shore connection system, please refers to VTG report "Design Parameters and Cost of Onshore and Off–shore Loading/Unlading Systems".

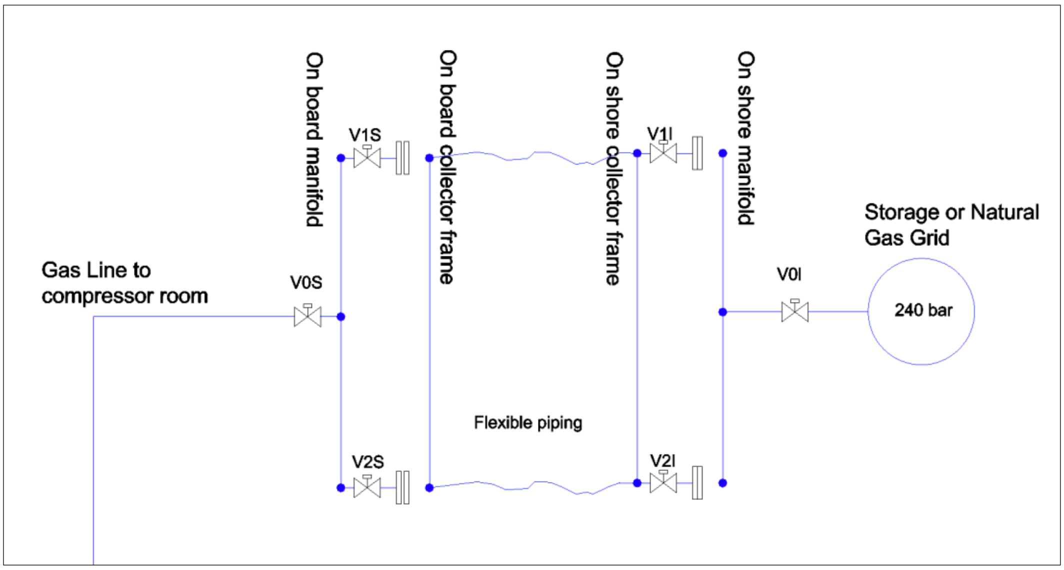


Figure 7.2 – Ship–Grid Connection via Flexible Hoses

7.2 Free loading phase

Free loading phase schematics is reported in Figure 7.3, and will take place following the process steps indicated in Table 7.1 – Free loading phase process steps.

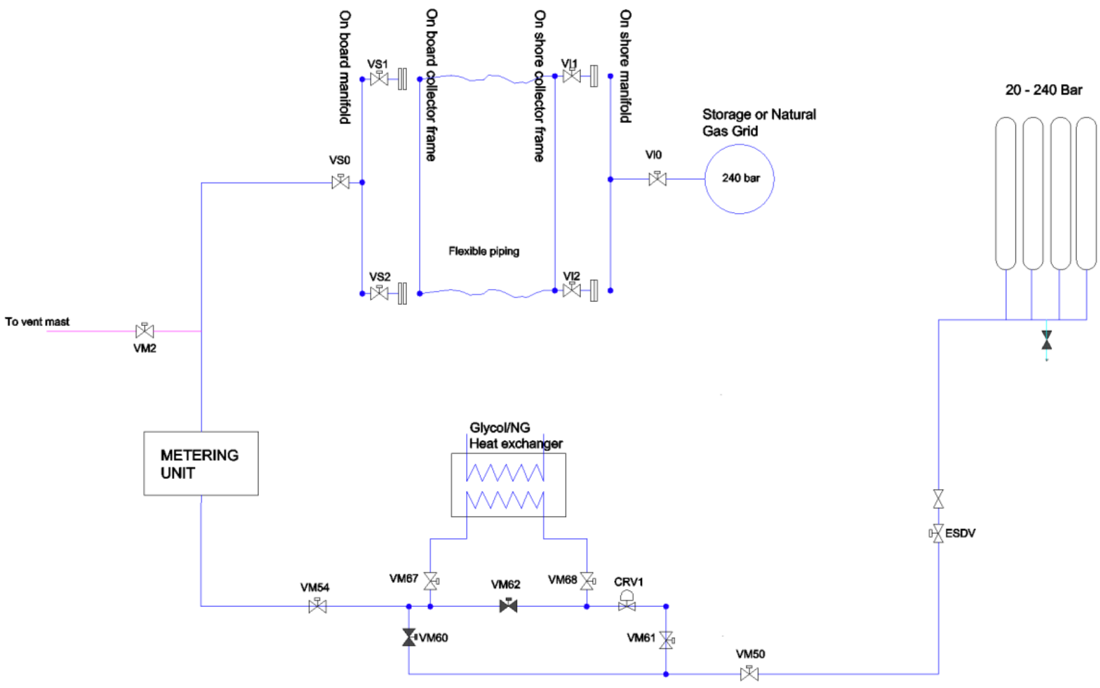


Figure 7.3 – Free loading phase schematics

Table 7.1 – Free loading phase process steps

Step #	Action Performed
FreeL.1	Valves VS1, VS2 are closed. Valves VI1, VI2 are closed. VS0 and VI0 are closed.
FreeL.2	The flexible hoses will be connected to the connector frame
FreeL.3	Valves VS1, VS2 are opened. Valves VI1, VI1 are open.
FreeL.4	Valves Vl0, will open and put the connector frame under 240 bar of pressure
FreeL.5	The ESDV of each cargo tank will open. In this way all the piping system and the tanks are considered to be at uniform pressure of 20 bars.
FreeL.6	Valves V0S will open.
FreeL.7	The first part of the gas with presence of air can be evacuated through valve VM2 to the vent must. Then VM2 is closed.
FreeL.8	Valve VM54 and VM62, VM61 and VM50 are open
FreeL.9	Control Valve CRV1 (CRV2) will gradually open and gas will start flowing on the gas piping system and the cargo tanks.
FreeL.10	To maximise the amount of loaded gas, the flow could need a cooling process. In this case, VM62 would close and VM67 and VM68 would open.

During the free loading process, gas is cooled down with two water–glycol PCHE heat exchangers of 3.8 MW each (HE01, HE02 – see §6).

In order to increase the total loading capacity of the ship, it is important to decrease as much as possible both the gas temperature and the hold temperature. For this reason 224 fan coils of 25kW each has been installed on the dome of the holds (see § 6.3).

The cold side of the heat exchangers and fan coils is cooled thanks to four chillers of minimum 1.4 MW each (CH1, CH2, CH3, CH4). Cold produced by the chillers is brought to the gas thanks to two plates heat exchangers (HE15, HE16). The heat exchangers are also connected to two seawater heat exchangers of 3.8MW each (HE07, HE09)

7.3 Forced loading phase

Once pressure inside the cylinders reaches about 240 bar, the on–board compressors start up to increase the gas pressure from the site delivery pressure of 240 bar to the storage pressure cylinders of 335 bar.

Forced loading phase schematics is reported in Figure 7.4, and will take place following the process steps indicated in Table 7.2

Figure 7.4 – Forced loading phase schematics

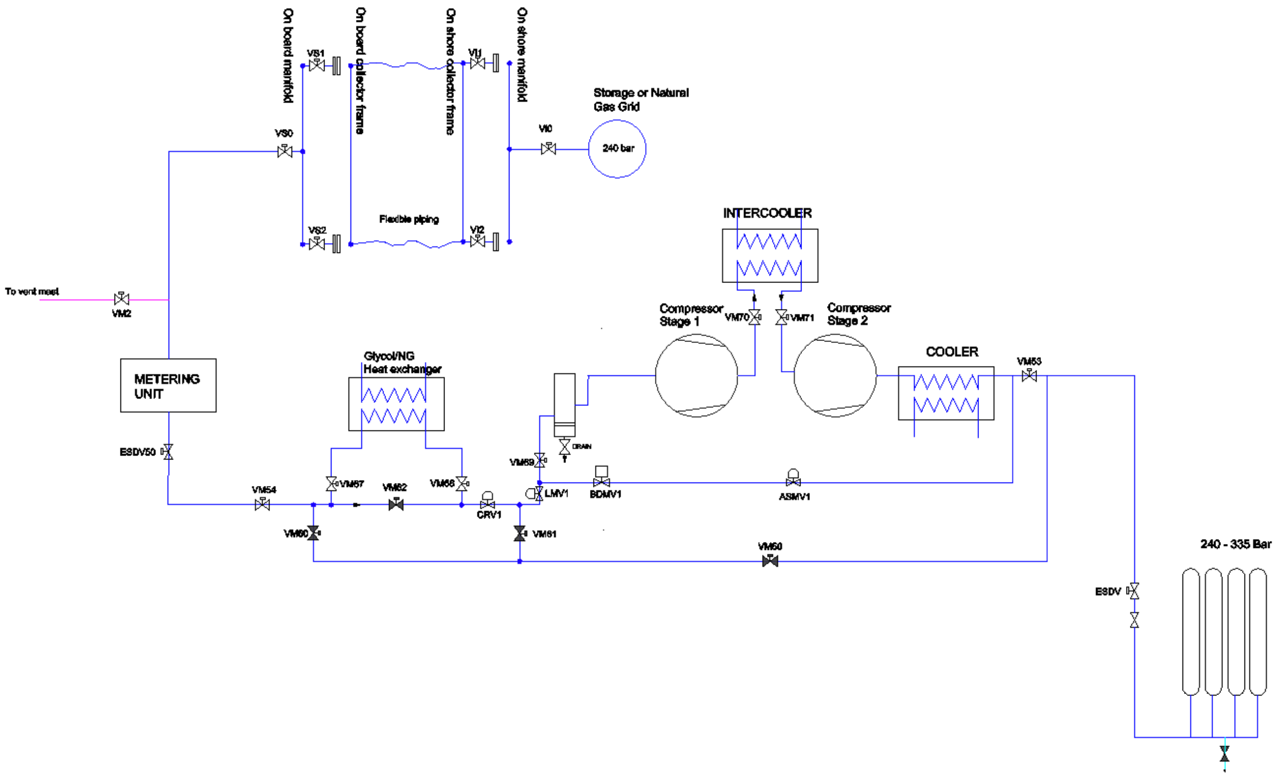


Table 7.2 – Forced loading phase process steps

Step #	Action Performed
FcdL.1	When pressure inside the tanks reaches a threshold pressure (240 bars), bypass valve VM61 is closed, inlet valves VM69 at the compressor line will open and compressor will start. LMV1 will guaranty correct overpressure across the compressor.
FcdL.2	If gas temperature and water temperature are compatible, heat exchanger can be used to reduce temperature of the inlet gas and optimize compressor efficiency by closing VM62 and opening valve VM67 and VM68.
FcdL.3	Valve VM53 will open and flow reaches the vessels up to 335 bars, then compressors will stop and vessel valves (ESDV) will be closed.
FcdL.4	Valve ESDV50 will close. Valve V0I will close.
FcdL.5	VM2 will open and pressure in the connector frame will be evacuated through the vent mast.
FcdL.6	Valve VS0 will close. ESDV50 Will open.
FcdL.7	Valve VS1, VS2 and valves VI1, VI2 are then closed and hoses can be disconnected from the connector frame

The compression is performed by two two–stages centrifugal compressors. Each compressor is provided with a 3MW intercooler (Table 6.2 – HE03, HE05) and a 3.8MW post cooler (Table 6.3 – HE04, HE06). Intercooler cold side (side B) is cooled down thank to the 3.8MW seawater heat exchanger (Table 6.4 – HE07, HE09) and by the chillers (Table 6.9).

If, during the force loading phase, additional power is available on the chillers, this is used by the fan coils to cool down the holds.

Once loading is complete, all the remote controlled stop valves between deck piping and cargo containment systems will be closed in order to segregate the cargo tanks each other. The deck piping will remain pressurized.

During the trip, the hold temperature is kept constant at about 40°C with the fan coils.

7.4 Introduction to the Unloading Process

Unloading is the reverse of the above operations. The process will start spontaneously at the valves opening. It has been considered to perform unloading, injecting the gas in a pipeline at a constant pressure of 80 bars. In this case, during the free unloading phase, the delivery pressure is kept constant at 80 bar thanks to two control valves (CRV1, CRV2) installed on board, on the two main DN250 lines. After the control valves the flow can be heated up thanks two heat exchangers of 3.8MW each (Table 6.1 – HE01, HE02).

Figure 7.5 reports the unloading process phases main parameters and the evolution of the mass flow during free unloading and forced unloading phases.

- Suction pressure: 335 to 20 bar
- Discharge pressure: 80 bar
- Residual pressure in tanks: 20 bar

Compressor starts

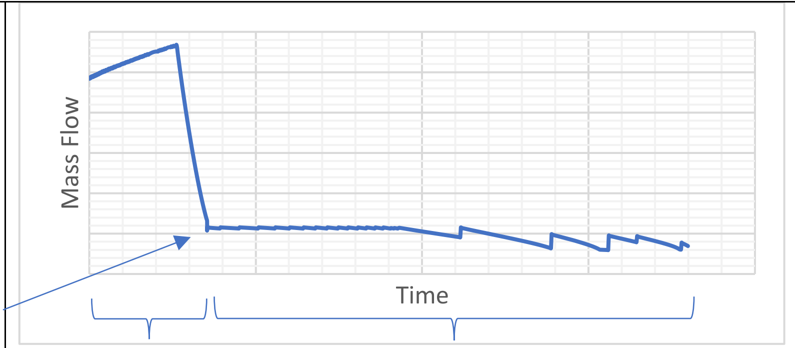


Figure 7.5 – Unloading process phases

When pressure inside the cylinders reaches about 80 bars, compressors will start to finish the emptying process. During the forced unloading process the gas can be pre–heated in the heat exchanger upstream of the compressor, and then cooled in the intercooler and post–cooler. To increase the quantity of gas that can be discharged, holds are heated up with the fan coils. Power to the fan coils is supplied thank to two gas boilers of 3MW each installed onboard. A residual gas pressure inside of cylinders at the end of the unloading is expected to be about 20 bar. The complete unloading process is expected to last about 72 hours for a commercial gas volume of 12 millions of Nm^3.

7.5 Free unloading phase

Free unloading phase schematics is reported in Figure 7.6, and will take place following the process steps indicated in Table 7.3.

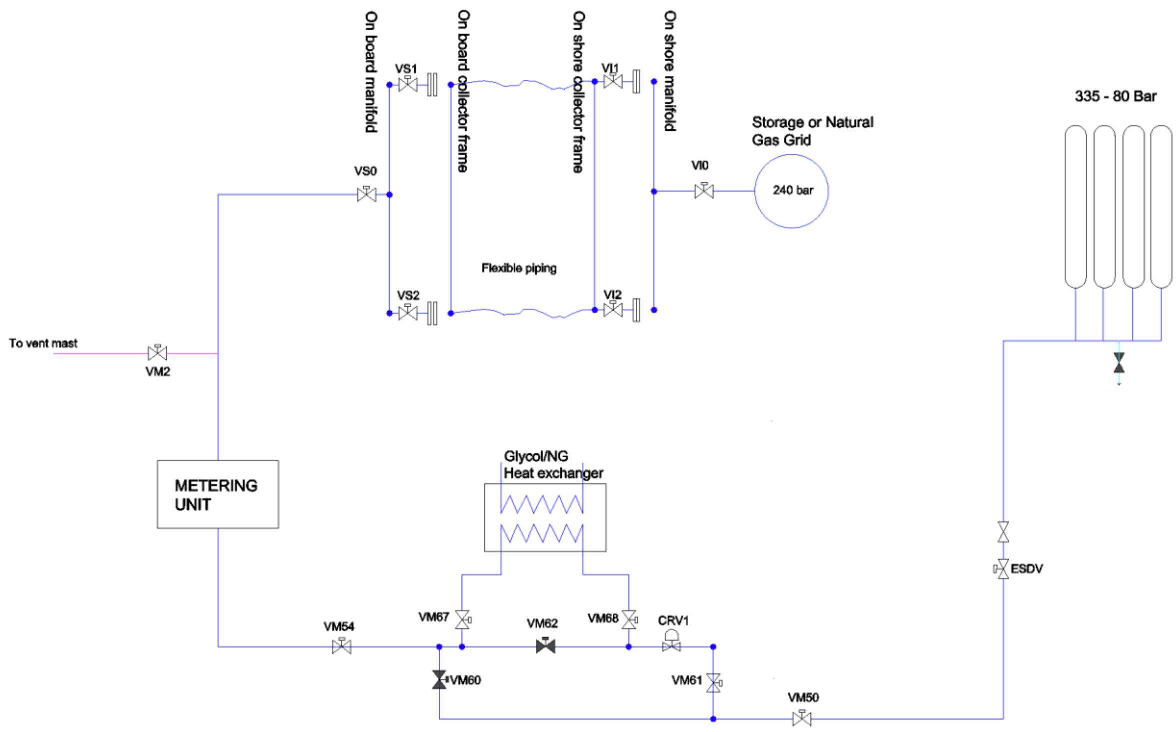


Figure 7.6 – Free unloading phase schematics

Table 7.3 – Free unloading phase process steps

Step #	Action Performed
FreeU.1	Valves VS1, VS2 are closed. Vl1, Vl2 are closed. Valves VS0 and Valve Vl0 are closed.
FreeU.2	Flexible hoses are connected to the connector frame
FreeU.3	ESDV of all cargo tanks are opened. In this way all the piping system and tanks will be at uniform pressure of 335 bars.
FreeU.4	Valves VS1, VS2 are open. Vl1, Vl2 are open.
FreeU.5	The compressor inlet valves are closed. VM60 and VM62 are closed while valves VM67 and VM68 are opened. Flow will pass through heater to guaranty minimum output temperature of 7°C. (if temperature of the gas is higher, valves VM68 and VM67 will close and valve VM62 will open).
FreeU.6	Valve CRV1 will guaranty delivery pressure at 80bars.
FreeU.7	Valve Vl0 will open.

7.6 Forced Unloading

Forced unloading phase schematics is reported in Figure 7.7, and will take place following the process steps indicated in Table 7.4.

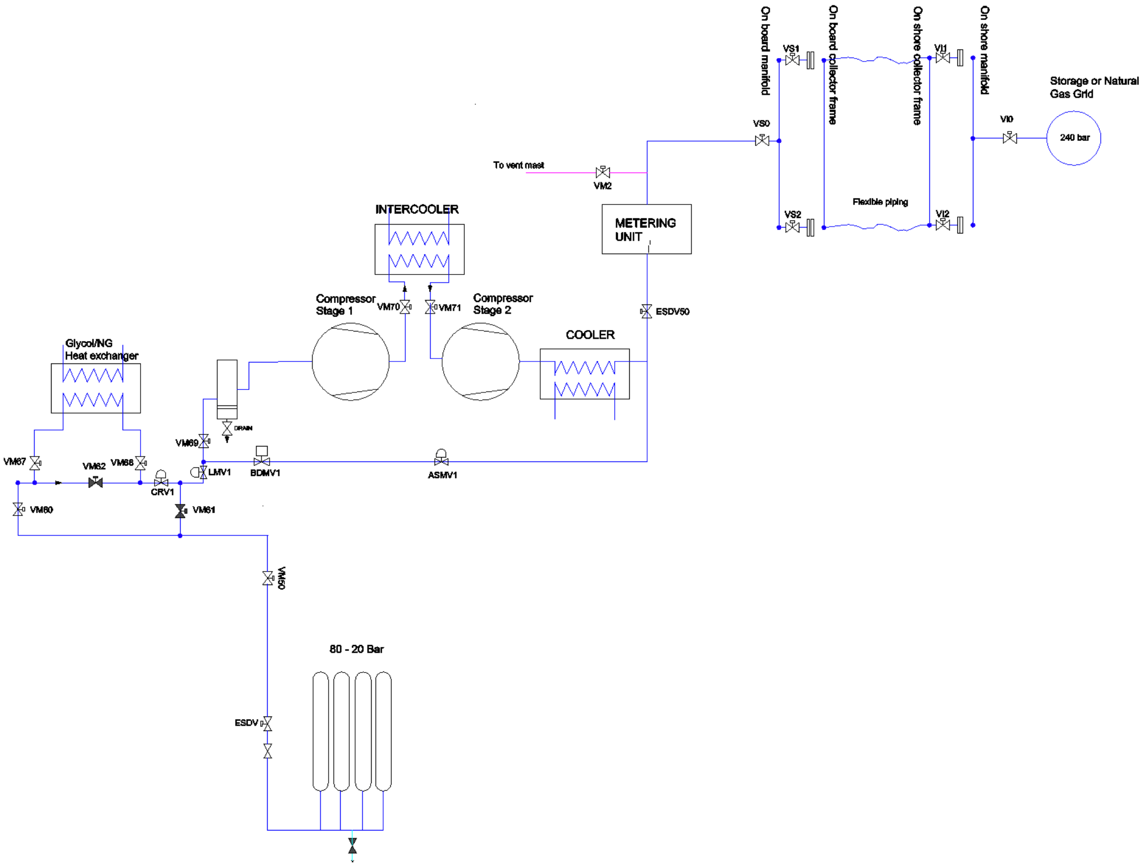


Figure 7.7 – Forced unloading phase schematics

Table 7.4 – Forced unloading phase process steps

Step #	Action Performed
FcdU.1	When the pressure in the vessels reaches a threshold pressure (about 80 bar), valves VM61 and VM62 will close and inlet compressor valves V69 will gradually open and compressor will start (valve LMV1 will guaranty the correct overpressure across the compressor)
FcdU.2	when pressure in the vessels reaches 20 bars, compressor will stop and valves ESDV50 will close and VI0 will close.
FcdU.3	Pressure in the connector frame is evacuated through valve VM2 to the vent must
FcdU.4	Valve VS0 will close. ESDV50 Will open.
FcdU.5	Valve VS1, VS2 and valves VI1, VI2 are then closed and hoses can be disconnected from the connector frame

8 References

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[15] ASME. Gas Transmission and Distribution Piping Systems n.d.

[16] API. Standard 5L – Specification for Line Pipe n.d.

[17] ASME. Standard B318s – Managing System Integrity of Gas Pipelines n.d.

[18] API. Standart 1104 – Standard for Welding Pipelines and Related Facilities n.d.

[19] API. Standard 521 – Pressure–relieving and Depressuring Systems 2014.

[20] ISO. Standard 13707 – Petroleum and natural gas industries–Reciprocating compressors 2000;2000.

[21] ISO. Standard 13631 – Petroleum and natural gas industries – Packaged reciprocating gas compressors 2003.

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[23] API. Standard 617 – Axial and Centrifugal Compressors and Expander– compressors 2014;7056:0–4.

[24] API. Standard 619 – Rotary–Type Positive– Displacement Compressors for Petroleum , Petrochemical , and Natural Gas Industries 2005.

[25] API. Standard 672 – Packaged , Integrally Geared Centrifugal Air Compressors for Petroleum , Chemical , and Gas Industry Services 2010.

[26] API. Standard 673 – Centrifugal Fans for Petroleum , Chemical , and Gas Industry Services 2014.

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Appendix A. Applicable Standards and Regulations

This chapter includes a summary and a review of Standards and Regulations that might be relevant to the design, installation, operation, and maintenance of the GASVESSEL loading and unloading and compression systems. Three macro areas are considered:

- the general design of CNG carriers;
- the loading/unloading piping system, connecting the on–board facilities with the off board facilities; and the onboard distribution system, including in particular all the piping to distribute/collect gas from/to the vessels.
- the compression system, eventually including the pressure regulation subsystem, the cooling subsystem, and all auxiliary subsystems;

Summary of Standards and Regulations for General Design of CNG carriers

Document	Topic	Excerpt
IMO IGC – IA104E Current version: 2nd Published: January 2016 [3]	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk	This code prescribes the design and construction standards of ships and the equipment necessary to minimize the risk. Hazard properties analysis including flammability, toxicity, corrosivity and reactivity. Cryogenic or pressure conditions are also considered. Severe collisions or stranding could lead to cargo tank damage and consequent uncontrolled release of the product. The requirements in the Code are intended to minimize this risk as far as is practicable, based upon present knowledge and technology.
IMO – MSC/Circ. 1023, MEPC/Circ. Current version: 1nst Published: 05/04/2002 AMENDEMENT: 2006 [4]	Guidelines for Formal Safety Assessment for use in the IMO rule–making process	This guide is a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO’s options for reducing these risks. In this guide are reported: - The methodology of assessing the risks - The identification of the hazards - Risk analysis and risk control options - Cost benefit assessment - Recommendation for decision making
DNV Part 5 – Chp.15 Current version: 1st Published: July 2011	Compressed Natural Gas Carriers	In this document the minimum acceptable safety level for a CNG vessel are reported. In particular: - Individual risk for crew members (due to major accidents) - Total loss due to collision - Total loss due to cargo hazards (fires and explosions)

Document	Topic	Excerpt
[5]		- Individual risk from cargo cylinder failure - Individual risks for public ashore
ABS Part 5C, Chapter 8 Current version: 11th Published: January 2018 ERRATA 1: May 2018 [2]	Rule Requirements for Vessels Intended to Carry Liquefied Gases in Bulk	ABS defines the minimum safety requirements to obtain ABS classification for vessels intended to carry Liquified gases in bulk. Technical standards are defined for: - Ship arrangement - Cargo containment - Process pressure vessels and piping system - Construction materials - Pressure/temperature controls - Vent systems - Fire protections - Electrical installations - Required instrumentation - Operating requirements
ABS Guide Current version: 8th Published: March 2018 [1]	Vessels intended to carry compressed natural gases in bulk	Based on the rule requirements for vessels intended to transport liquified gases in bulk, ABS defines the minimum safety requirements to obtain ABS classification of new concepts of CNG carriers. Specific qualitative and quantitative risk assessments of different hazards are required. Technical best practices to improve safety on board are reported for: - Ship arrangement - Cargo containment - Process pressure vessels and piping system - Construction materials - Pressure/temperature controls - Vent systems - Fire protections - Electrical installations - Required instrumentation - Operating requirements
MSC – SOLAS Amendments 1983 Current version: 48th	1983 Amendments to International Convention for the Safety of Life at Sea, 1974 (MSC.6(48)) Volume 1	These amendments report technical specifications for: - Machinery and electrical installations - Fire protections, fire detection and extinction

Document	Topic	Excerpt
Published: June 1983 [6]		- Life–saving appliances and arrangements - Radiotelegraphy and radiotelephony - Carriage of dangerous goods
ASME – Boiler and Pressure Vessel Code Section VIII Div. 3 Current version: 13th Published: 01/07/2017 [8]	Rules for Construction of Pressure Vessels Division 3–Alternative Rules for Construction of High Pressure Vessels	This Division of Section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures generally above 10,000 psi. Specific requirements apply to several classes of material used in pressure vessel construction and to fabrication methods such as welding, forging and brazing. It contains mandatory and non–mandatory appendices detailing supplementary design criteria, non–destructive examination and inspection acceptance standards.
ABS Guide Current version: 9th Published: January 2018 [7]	Rules for Building and Classing Facilities on Offshore Installations	This guide gives the conditions for the classification of offshores installations and defines technical guidelines for: - Materials and welding - General Design and structural design - Extension of use and reuse beyond the design life of existing installations - Testing and survey during construction and after construction

Summary of Standards and Regulations for Piping and Loading/Unloading System

Document	Topic	Excerpt
ASME B16.5 Current version: 5th Published: 31/10/2017 [9]	Pipe Flanges and Flanged Fittings	This standard covers pressure–temperature ratings, materials, dimensions, tolerances, marking, testing, and methods of designating openings for pipe flanges and flanged fittings. This Standard is limited to: - flanges and flanged fittings made from cast or forged materials - blind flanges and certain reducing flanges made from cast, forged, or plate materials

Document	Topic	Excerpt
		- rating class designation from 150 to 2500 - NPS ½ to 24 inches
ASME B16.34 Current version: 5th Published: 23/08/2017 [13]	Valves – Flanged, Threaded and Welding End	This Standard covers pressure–temperature ratings, dimensions, tolerances, materials, non–destructive examination requirements, testing, and marking for cast, forged, and fabricated flanged, threaded, and welding end and wafer or flangeless valves of steel, nickel–base alloys, and other alloys. This standard is limited to: - rating class designation from 150 to 2500 - NPS ½ to 30 inches
Norsok P–002 Current version: 1st Published: 29/08/2014 [12]	Process system design	This standard supersedes Norsok P–001 and Norsok P–100 provides requirements for the following aspects of topside process piping and equipment design on offshore production facilities: - Design Pressure and Temperature - Line Sizing - System and Equipment Isolation. - Insulation and Heat Tracing
API 6D Current version: 24th Published: 01/08/2014 ERRATA 1: 2014 ERRATA 2, 3, 4, 5, ADDENDUM 1, ERRATA 6: 2015 ERRATA 7, 8, ADDENDUM 2: 2016 ERRATA 9: 2017 [14]	Specification for Pipeline Valves	This International Standard specifies requirements and provides recommendations for the design, manufacturing, testing and documentation of ball, check, gate and plug valves for application in pipeline systems meeting the requirements of ISO 13623 for the petroleum and natural gas industries. This International Standard is **not** applicable to subsea pipeline valves, as they are covered by a separate International Standard (ISO 14723). This International Standard is limited to: - rating class designation from 150 to 2500 - NPS ½ to 60 inches

Document	Topic	Excerpt
ASME/ANSI B31.8 Current version: 8th Published: October 2016 [15]	Gas Transmission and Distribution Piping Systems	The Code ASME B31 sets engineering requirements deemed necessary for safe design and construction of pressure piping. In particular section B31.8 defines requirements for piping transporting products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations; gas gathering pipelines
ASME/ANSI B31.8s Current version: 6th Published: 31/10/2016 [17]	Managing Systems Integrity of Gas Pipelines	This standard covers on–shore, gas pipeline systems constructed with ferrous materials, including pipe, valves, appurtenances attached to pipe, compressor units, metering stations, regulator stations, delivery stations, holders and fabricated assemblies. Its principles, processes and approaches apply to the entire system for all pipeline systems. B31.8s provides the operator with the information necessary to develop and implement an effective integrity management program using proven industry practices and processes.
API 5L Current version: 46th Published: 01/04/2016 [16]	Specification for Line Pipe	This Code applies to onshore pipeline systems constructed with ferrous materials and that transport gas. The principles and processes embodied in integrity management are applicable to all pipeline systems. Requirements for the manufacture are limited to two product specification levels (PSL 1 and PSL 2) of seamless and welded steel pipe for use in pipeline transportation systems in the petroleum and natural gas industries. This standard is **not** applicable to cast pipes.
API 1104 Current version: 21st Published: 01/09/2013 [18]	Welding of Pipelines and Related Facilities	This standard presents methods for the production of high–quality welds through the use of qualified welders using approved welding procedures, materials, and equipment. This standard covers the gas and arc welding of butt, fillet, and socket welds in carbon and low–alloy steel piping used in the compression, pumping, and transmission of crude petroleum, petroleum products, fuel gases, carbon dioxide, nitrogen, and where applicable, covers welding on distribution systems. This standard also presents inspection methods to ensure the

Document	Topic	Excerpt
		proper analysis of welding quality through the use of qualified technicians and approved methods and equipment
Norsok L–CR–002 Current version: 1st Published: January 1996 [11]	Piping Design, layout and stress analysis	This standard covers the basis for design and layout of process, drilling and utility piping for offshore oil and/or gas production facilities. Relevant parts of this specification may also be used for control room, laboratory, helideck and other facilities around the platform. This standard is **not** applicable to: - All instrument control piping downstream of the last piping block valve - Risers and sub–sea pipework - Flexible hoses - Sanitary piping systems - GRP piping
API 521 Current version: 6th Published: 01/01/2014 [19]	Guide for Pressure–Relieving and Depressuring Systems	This standard specifies requirements and gives guidelines for the following: - examining the principal causes of overpressure - determining individual relieving rates - selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks This standard is **not** applicable to direct–fired steam boilers.
API 14E RP Current version: 5th Published: 01/10/1991 Reaffirmed: January 2013 [10]	Recommended Practice for Design and installation of Offshore Production Platform Piping Systems	This standard states minimum requirements and guidelines for the design and installation of carbon steel piping systems on production platforms located offshore. This standard is limited to: - maximum design pressure 10,000 psig - temperature range –20ºF to 650ºF

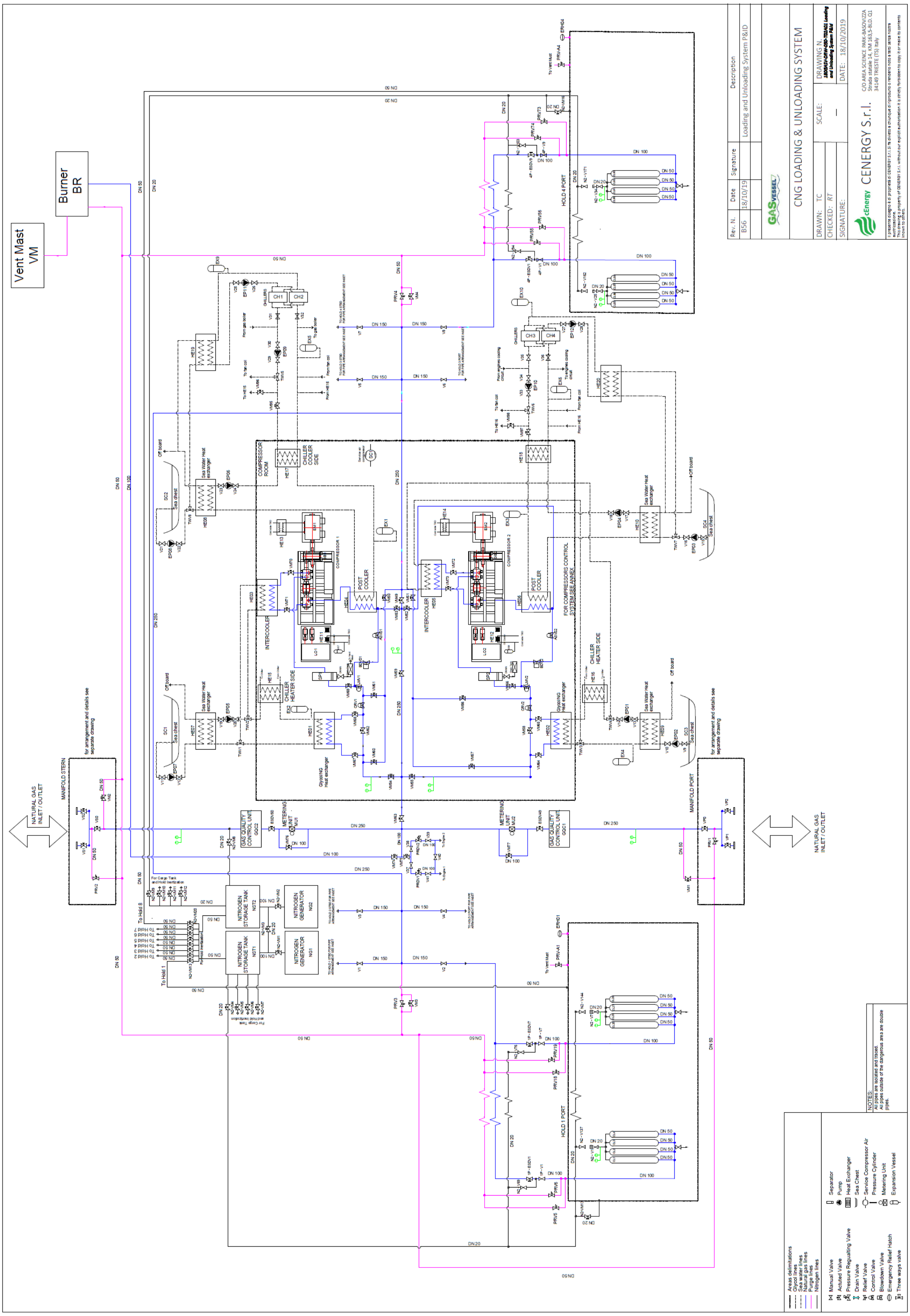
Summary of Standards and Regulation for the Compression System

Document	Topic	Excerpt
ISO 13707 Current version: 1st Published: 01/12/2000 [20]	Petroleum and Natural Gas Industries – Reciprocating Compressors	This International Standard covers the minimum requirements for reciprocating compressors and their drivers used in the petroleum and natural gas industries with either lubricated or nonlubricated cylinders. Compressors covered by this International Standard are moderate to low–speed and in critical services. This standard is **not** applicable to: - integral gas–engine driven compressors - packaged high–speed separable engine–driven reciprocating gas compressors - compressors having trunk–type (automotive–type) pistons that also serve as crossheads utility or instrument air compressors with a discharge gauge pressure of 0,9 MPa (9 bar) or less - gas engine and steam engine drivers
ISO 13631 Current version: 1st Published: 22/08/2002 [21]	Petroleum and natural gas industries – Packaged reciprocating gas compressors	This standard supersedes API 11p and gives requirements and recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of packaged skid–mounted, reciprocating, separable or integral compressors with lubricated cylinders and their prime movers, for use in the petroleum and natural gas industries for the compression of hydrocarbon gas This standard is **not** applicable to: - Reciprocating compressors covered by ISO 13707 - column–mounted compressors - non–lubricated compressors - compressors having trunk–type (automotive–type) pistons that also serve as crossheads utility or instrument air compressors with a discharge gauge pressure of 0,9 MPa (9 bar) or less - compressors driven by diesel engine, gas turbine and steam turbine prime mover
API 617 Current version: 8th	Axial and Centrifugal Compressors and Expander compressors	This standard covers the minimum requirements for axial compressors, single–shaft and integrally geared process centrifugal compressors, and

Document	Topic	Excerpt
Published: August 2016 [23]		expander–compressors for use in the petroleum, chemical, and gas industries services that handle air or gas. This standard is **not** applicable to: - fans, blowers that develop less than 34 kPa - packaged, integrally geared centrifugal plant - instrument air compressor - hot gas expanders
API 618 Current version: 5th Published: 01/12/2007 ERRATA 1: 2009 ERRATA 2: 2010 [22]	Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services	This standard covers the minimum requirements for reciprocating compressors and their drivers for use in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or non–lubricated cylinders. Compressors covered by this standard are moderate to low speed machines. Also included are related lubricating systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment. This standard is **not** applicable to: - integral gas–engine–driven compressors - compressors having trunk–type (automotive–type) pistons that also serve as crossheads utility or instrument air compressors with a discharge gauge pressure of 0,9 MPa (9 bar) or less
API 619 Current version: 5th Published: 01/12/2010 Identical to ISO 10440–1:2007 [24]	Rotary–Type Positive Displacement Compressors for Petroleum, Petrochemical, and Natural Gas Industries	This standard covers specifies requirements for dry and oil–flooded, helical–lobe rotary compressors used for vacuum or pressure or both in petroleum, petrochemical, and gas industry services. It is intended for compressors that are in special–purpose. This standard is **not** applicable to general–purpose air compressors, liquid–ring compressors, or vane–type compressors applications.
API 672 Current version: 4th Published: 01/03/2004 ERRATA 1: 2007	Packaged, Integrally Geared Centrifugal Air Compressors for Petroleum, Chemical, and Gas Industry Services	This standard covers the minimum requirements for constant–speed, packaged, general purpose integrally geared centrifugal air compressors, including their accessories.

Document	Topic	Excerpt
ERRATA 2: 2010 [25]		This standard is **not** applicable to machines that develop a pressure rise of less than 0.35 bar.
API 673 Current version: 3rd Published: 01/12/2014 [26]	Centrifugal Fans for Petroleum, Chemical and Gas Industry Services	This standard covers the minimum requirements for centrifugal fans for use in petroleum, chemical, and gas industry services. This standard is **not** applicable to axial flow, aerial cooler, cooling tower, and ventilation fans and positive displacement blowers.

Appendix B. P&ID – (see joint document “180GASV–DRW–050–T02A01 Loading and Unloading System P&Id”)



Appendix C. Metering Unit Datasheet

Measured values	Volumetric flow, a. c., volume a. c., gas velocity, sound velocity
Number of measuring paths	2, 4, 4+1, 4+4
Measurement principle	Ultrasonic transit time difference measurement
Measuring medium	Natural gas, N_2, O_2, air, C_2H_4, steam, process gases
Measuring ranges	
Volumetric flow, a. c.	4 ... + 400 m³/h / 1,600 ... 100,000 m³/h Measuring ranges depend on nominal pipe size
Repeatability	< 0.1 % of the measured value
Accuracy	Error limits
2-path version [1]:	≤ ± 1 %
4-path version [2]:	≤ ± 0.5 % Dry calibrated
4-path version [2]:	≤ ± 0.2 % After flow calibration and adjustment with constant factor
4-path version [2]:	≤ ± 0.1 % After flow calibration and adjustment with polynomial or piecewise correction
	[1] In the range Q_t ... Q_{max} with straight 20D/3D inlet/outlet section or with 10D/3D flow conditioner [2] In the range Q_t ... Q_{max} with undisturbed 10D/3D inlet/outlet section or with 5D/3D flow Conditioner
Diagnostics functions	Integrated device diagnosis and extended diagnosis via MEPAFLOW600 CBM software
Gas temperature	–40 °C ... +180 °C
On request:	–194 °C ... +280 °C
Operating pressure	0 bar (g) ... 250 bar (g) On request: 450 bar (g)
Nominal pipe size	2 ″ ... 48 ″ (DN 50 ... DN 1200)
Ambient temperature	
ATEX, CSA:	–40 °C ... +60 °C
IECEx:	–40 °C ... +70 °C Optional
IECEx:	–50 °C ... +70 °C

Storage temperature	-40 °C ... +70 °C
Ambient humidity	≤ 95 % Relative humidity
Conformities	AGA-Report No. 9 API 21.1 OIML D 11:2013 OIML R 137-1:2006 ISO 17089-1 BS 7965 Pattern approval: MID, PTB, NMi, Measurement Canada, GOST ...
Ex-approvals	
IECEx	Gb/Ga Ex d e ib [ia Ga] IIA T4 Gb/Ga Ex d e ib [ia Ga] IIC T4 Ultrasonic transducers intrinsically safe
ATEX	II 1/2G Ex de ib [ia] IIA T4 II 1/2G Ex de ib [ia] IIC T4 Ultrasonic transducers intrinsically safe
NEC/CEC (US/CA)	Class I, Division 1, Groups B, C, D T4 Class I, Division 2, Groups A, B, C, D T4 Class I, Division 1, Group D T4 Class I, Division 2, Group D T4 Ultrasonic transducers intrinsically safe
Electrical safety	CE
Enclosure rating	IP65 / IP66 / IP67
Analog outputs	1 output: 4 ... 20 mA, 200 Ω Active/passive, electrically isolated
Digital outputs	3 outputs: + 30 V, 10 mA Passive, electrically isolated, Open Collector or according to NAMUR (EN 50227), f_{max} = 6 kHz (scalable)
Modbus	✓
Type of fieldbus integration	ASCII RS-485 (2x) RTU RS-485 (2x)
HART	✓
Operation	Via meter display and software MEPAFLOW600
Dimensions (W x H x D)	See dimensional drawings
Weight	Depending on device version
Material in contact with media	Low temperature carbon steel, stainless steel, duplex steel
Electrical connection	
Voltage	12 ... 28.8 V DC With active current output: 15 ... 28.8 V DC
Power consumption	≤ 1 W

Appendix D. Control Valves Datasheet

FLOWSERVE

Mark 200 Control Valve FCD VLENTB0200 12/12

Table 5.6:
ASME Mark 200: Angle Cv, Class 2500, Standard Retainer

Valve Size	Trim No.	Stroke	Characteristic	Flow Direction	Cv at Percent Open										
					5	10	20	30	40	50	60	70	80	90	100
2 in. (50 mm)	1.5	1.5 in. (38 mm)	=%	Flow Under	0.6	1.1	2.9	5.1	7.6	12.5	21.0	32.4	40.3	45.1	47.6
				Flow Over	0.7	1.1	2.7	4.7	6.8	12.1	22.3	31.5	37.7	41.1	42.5
			Linear	Flow Under	1.5	3.3	9.0	16.0	22.9	29.6	35.9	40.5	44.0	46.0	47.6
				Flow Over	1.5	3.1	8.1	13.5	19.6	25.9	31.7	35.8	39.1	41.1	42.5
3 in. (80 mm)	2.25	2 in. (50 mm)	=%	Flow Under	1.3	2.4	6.2	10.8	16.1	26.7	44.7	69.0	85.8	96.0	101.4
				Flow Over	1.6	2.8	6.7	11.8	17.0	30.2	55.7	78.8	94.2	102.7	106.2
			Linear	Flow Under	3.3	7.1	19.1	34.1	48.9	63.0	76.5	86.3	93.8	97.9	101.4
				Flow Over	3.6	7.9	20.3	33.9	49.0	64.8	79.2	89.6	97.7	102.7	106.2
4 in. (100 mm)	2.875	3 in. (76 mm)	=%	Flow Under	2.3	4.3	11.1	19.2	28.8	47.7	79.9	123.3	153.3	171.5	181.1
				Flow Over	3.1	5.2	12.5	22.0	31.7	56.2	103.8	146.9	175.5	191.4	197.8
			Linear	Flow Under	5.8	12.6	34.2	60.9	87.2	112.6	136.6	154.1	167.4	174.9	181.1
				Flow Over	6.8	14.6	37.8	63.1	91.4	120.7	147.6	166.9	182.1	191.4	197.8
6 in. (150 mm)	4.375	4 in. (101 mm)	=%	Flow Under	4.6	8.7	22.5	38.9	58.2	96.4	161.6	249.3	310.1	346.9	366.4
				Flow Over	6.4	10.8	25.9	45.7	65.7	116.6	215.2	304.5	363.8	396.9	410.1
			Linear	Flow Under	11.8	25.5	69.1	123.3	176.5	227.7	276.3	311.7	338.7	353.8	366.4
				Flow Over	14.1	30.3	78.4	130.8	189.4	250.3	306.1	346.1	377.5	396.8	410.1
8 in. (200 mm)	5.75	4 in. (101 mm)	=%	Flow Under	8.3	15.8	40.8	70.6	105.8	175.1	293.5	452.9	563.3	630.1	665.5
				Flow Over	12.1	20.6	49.2	87.0	125.0	222.0	409.6	579.6	692.5	755.5	780.7
			Linear	Flow Under	21.5	46.3	125.5	223.9	320.5	413.6	501.9	566.2	615.1	642.6	665.5
				Flow Over	26.8	57.7	149.2	249.0	360.5	476.4	582.6	658.8	718.5	755.3	780.7
10 in. (250 mm)	7.25	6 in. (152 mm)	=%	Flow Under	12.1	23.2	59.6	103.3	154.7	256.0	429.1	662.1	823.4	921.1	972.9
				Flow Over	15.5	26.2	62.7	110.9	159.3	282.9	522.0	738.6	882.5	962.8	994.9
			Linear	Flow Under	31.4	67.7	183.5	327.3	468.6	604.6	733.7	827.7	899.2	939.5	972.9
				Flow Over	34.2	73.6	190.2	317.3	459.5	607.2	742.5	839.5	915.7	962.6	994.9
12 in. (300 mm)	8.625	6 in. (152 mm)	=%	Flow Under	19.7	37.6	96.7	167.5	250.9	415.3	696.1	1074.1	1335.9	1494.4	1578.4
				Flow Over	25.1	42.5	101.8	179.9	258.6	459.0	847.0	1198.5	1432.0	1562.4	1614.4
			Linear	Flow Under	50.9	109.8	297.7	531.1	760.2	980.9	1190.4	1342.8	1458.9	1524.2	1578.4
				Flow Over	55.4	119.4	308.6	515.0	745.6	985.2	1204.8	1362.3	1485.9	1562.0	1614.4
14 in. (350 mm)	9.5	8 in. (203 mm)	=%	Flow Under	24.0	45.9	118.0	204.5	306.2	506.8	849.5	1310.8	1630.2	1823.6	1926.1
				Flow Over	31.5	53.4	127.6	225.6	324.3	575.6	1062.2	1503.0	1795.8	1959.3	2024.6
			Linear	Flow Under	62.1	134.0	363.3	648.1	927.7	1197.0	1452.7	1638.6	1780.3	1860.0	1926.1
				Flow Over	69.5	149.7	387.0	645.8	935.0	1235.5	1510.9	1708.4	1863.4	1958.8	2024.6

Appendix E. Emergency Relief Hatches Datasheet

Enardo 2000 Series

Emergency Relief Vent

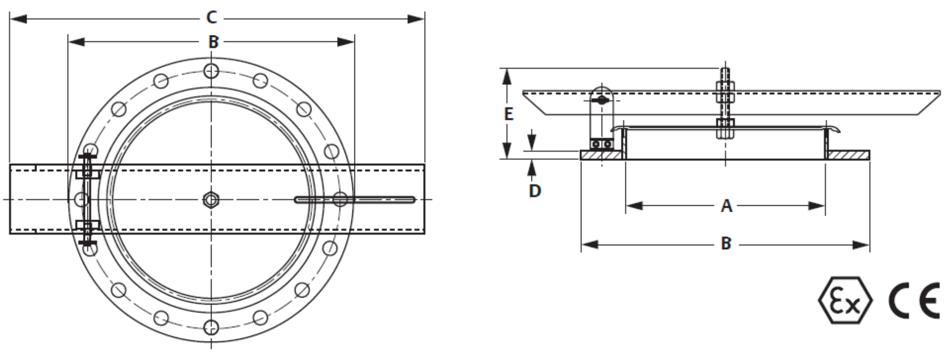


Figure 2. Enardo™ 2000 Series Dimensions

Table 1. Enardo 2000 Series Dimensions

MODEL	A (SIZE)		B1 (ANSI FLANGE O.D.)		B2 (API FLANGE O.D.)		C (OVERALL LENGTH)		D (FLANGE THICKNESS)		E (HEIGHT)		WEIGHT (CARBON STEEL)(1)		WEIGHT (STAINLESS STEEL)(1)	
	In.	mm	In.	mm	In.	mm	In.	mm	In.	mm	In.	mm	Lbs	kg	Lbs	kg
Enardo 2004	4	100	9	229	----	----	14	356	1/2	13	4-3/4	121	14	6	14	6
Enardo 2008	8	200	13-1/2	343	13-1/2	343	21	533	1/2	13	6-1/2	165	28	13	29	13
Enardo 2012	12-1/4	310	19	483	----	----	22	559	1/2	13	6-1/2	165	42	19	43	20
Enardo 2016	15-1/4	390	23-1/2	597	----	----	29	737	1/2	13	6-1/2	165	94	43	97	44
Enardo 2018	17-1/2	445	25	635	----	----	36	914	3/4	19	6-3/4	171	110	50	118	54
Enardo 2020	19-1/4	490	27-1/2	699	26	660	38-1/4	972	3/4	19	6-3/4	171	119	54	127	58
Enardo 2024	23-1/4	590	32	813	30	762	41	1041	3/4	19	6-3/4	171	176	80	186	84

1. Unit weights indicate Net Weight of valve at standard set pressure (2.0 oz./sq.in. pressure), does not include shipping crate or box. Add 20% for gross shipping weight (Domestic Only). Pressure settings above the standard will increase total unit weight - consult factory for more information.

Selection Guide to Enardo 2000 Series

ENARDO [2][0] [ ][ ] – [ ] [ ] [ ] – [ ] – [ ][ ] – [ ]

Series (2 0)

Connection Size (2 digits)

Base and Arm
2 = Carbon Steel
3 = 304 Stainless steel
4 = 316 Stainless steel
5 = Exotic

Disk Cover
1 = Aluminum
3 = 304 Stainless steel
4 = 316 Stainelss steel
5 = Exotic

Gasket
T = Teflon®
N = Buna-N
V = Viton®
X = Special

Bolt Pattern
1 = ANSI
2 = API

Pressure Settings
n = in. w.c.
z = oz./sq. in.
2.0. to 32.0 oz./sq. in. (0.5 oz./sq. in. increments)
3.5 to 55.0 in. w.c. (1.0 in. w.c. increments)
8.6 to 138 mbar (2.2 mbar increments)

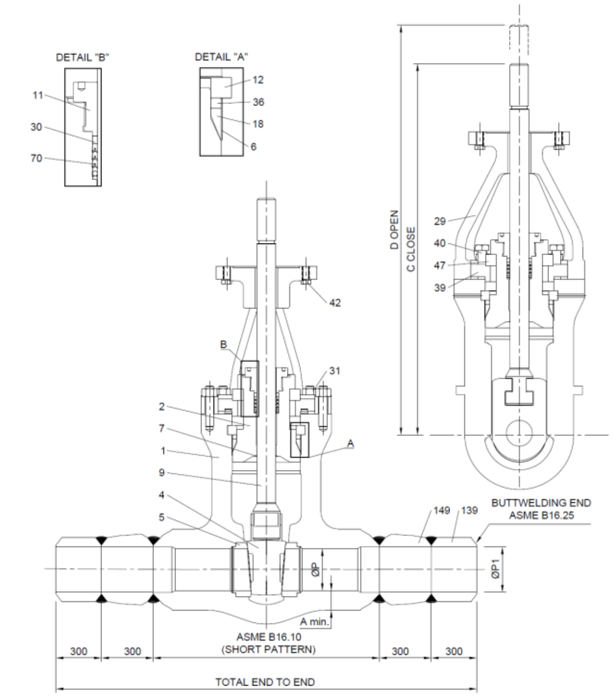
Options
1 = Special Coating
2 = Optional Hardware
3 = Other
4 = Smart Wireless Monitoring

Example:

ENARDO [2][0] [1][2] – [2] [1] [N] – [1] – [Z][2] – [4]

Indicates a 12 in. Emergency Pressure Relief Vent with a Carbon steel base, an aluminum lid with a Buna-N gasket, a ANSI 150 lb. bolting pattern, with relief pressure of 24 oz./sq.in. and Smart Wireless Monitoring.

Appendix F. Gate Valves Datasheet



N°	DESCRIPTION	MATERIALS
1	BODY	ASTM A 351 GR CF8
2	BONNET	ASTM A 182 GR F 304
4	WEDGE (FLEXIBLE)	ASTM A 351 GR CF8 + AWS A5.21 ERCoCr-A
5	SEAT (WELDED IN)	AISI 304 + AWS A5.21 ERCoCr-A
6	SEATING SURFACE	AWS A5.14 ERNiCrMo-3
7	BACKSEATING SURFACE	AWS A5.21 ERCoCr-A
9	STEM	ASTM A 276 TYPE XM-19
11	GLAND	ASTM A 276 TYPE 316
12	FOUR PIECES RING	ASTM A 276 TYPE XM-19
18	P.S. GASKET	AISI 316 L
29	YOKE	ASTM A 351 GR CF8
30	FIRE SAFE GASKET	GRAPHITE
31	YOKE BOLT + NUT	ASTM A 193 GR B8 cl.2 / ASTM A 194 GR 8
36	SPACER RING	AISI 316
39	LOCKING FLANGE	ASTM A 276 TYPE 316
40	SCREW	BS EN ISO 3506 A4-80
42	HEXAGONAL HEAD SET SCREW	BS EN ISO 3506 A4-80
47	BONNET HALF RING	ASTM A 276 TYPE XM-19
70	LIP SEAL + CHEVRON PACKING	PTFE + PEEK +ELGILOY
139	PUPS	AISI 304
149	TRANSITION PIECES	AISI 304

cENERGY - GAS VESSEL
INQUIRY N°: H2020 - 723030 Gasvessel
ORION REF.: 2018 NOV/2XX1

PRELIMINARY DRAWING

THIS DOCUMENT IS ISSUED WITH REFERENCE PURPOSES ONLY AND SHOULD NOT TO BE CONSIDERED AS FINAL UNLESS AGREED OTHERWISE. SOME OF ITS DETAILS MAY VARY. IN CASE OF PURCHASE ORDER, THIS DOCUMENT SHALL BE RE-ISSUED IN ACCORDANCE WITH THE PO REQUIREMENTS AND IN COMPLIANCE WITH THE APPLICABLE SPECIFICATIONS.

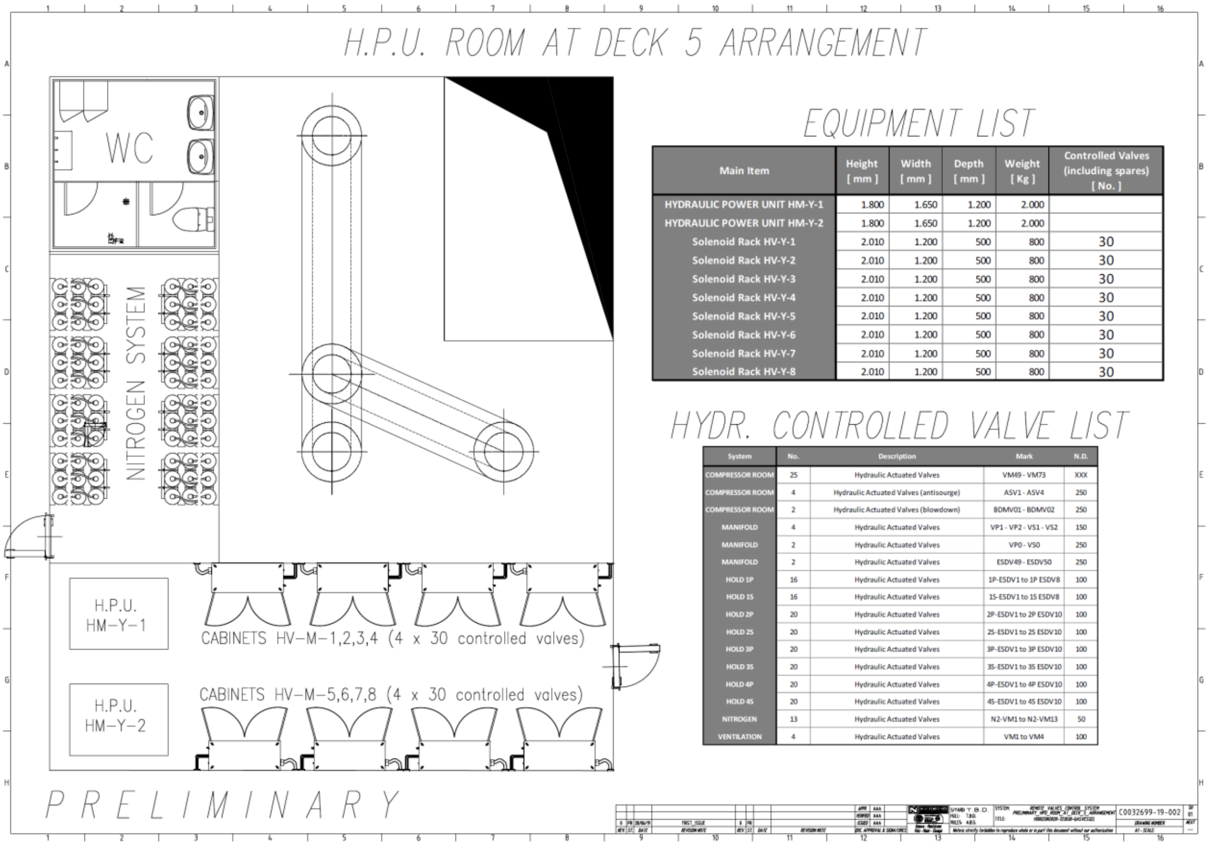
DESIGN ASME B 16.34

SIZE		TOTAL END TO END (mm)	DIMENSIONS ARE IN mm						PIPE SCHEDULE	VALVE WEIGHT * (kg)	ORION ITEM
inch	DN		A	B*	C*	D*	P	P1			
10"	250	2114	67.6	1286	1453	1666	184.2	T.B.A.	T.B.A.	2222	4

* GENERAL DIMENSIONS TOLERANCE ±5%

DRW.: SAMUELI	VER.: GEROLIN	APP.: RIGHINI		ORION	
DATE: 01/12/18	DATE: 01/12/18	DATE: 01/12/18		TRIESTE-ITALY	
TITLE: CLASS 2500 GATE VALVE PRESSURE SEAL				DRW. n.°	18.2XX1.004
REV. 0	APPR. RIGHINI	DATE 01/12/18		SCALE	NOT TO SCALE

Appendix G. Valves Remote Control System Datasheet

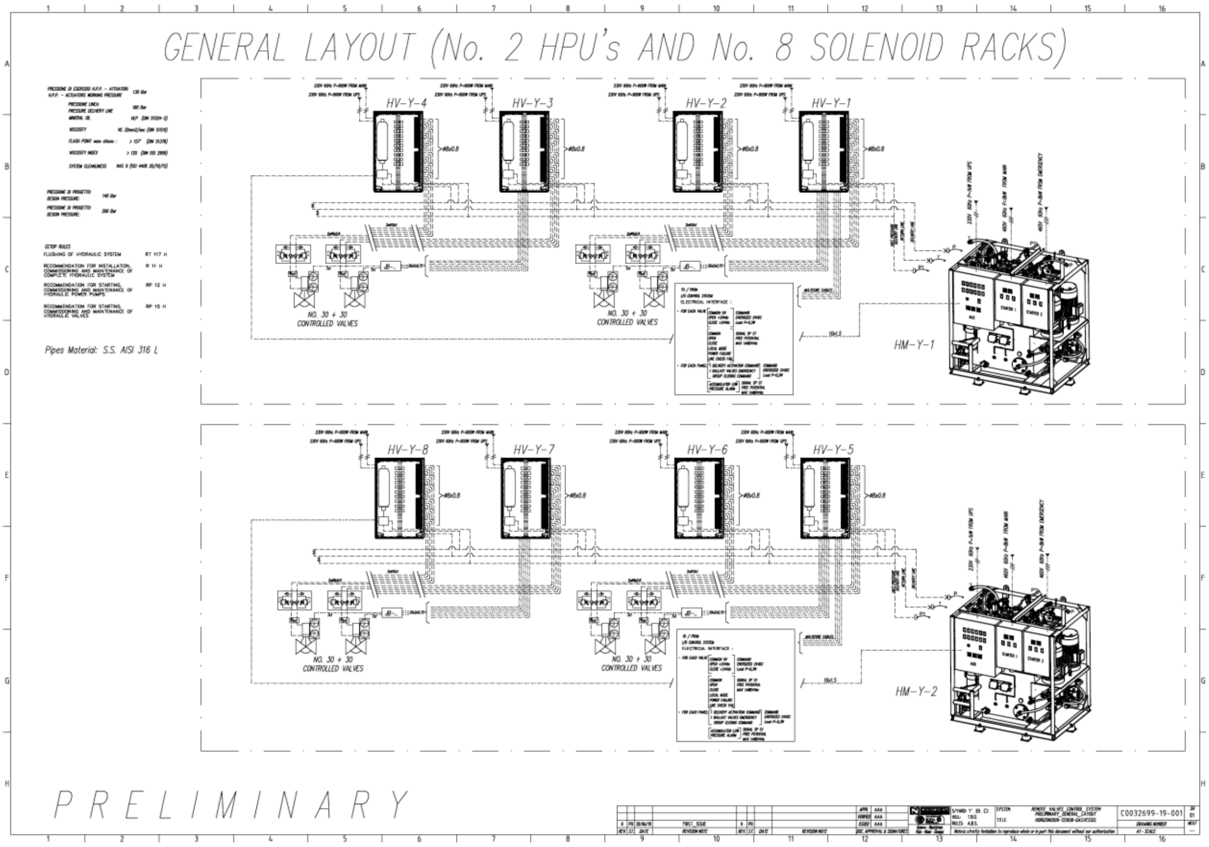


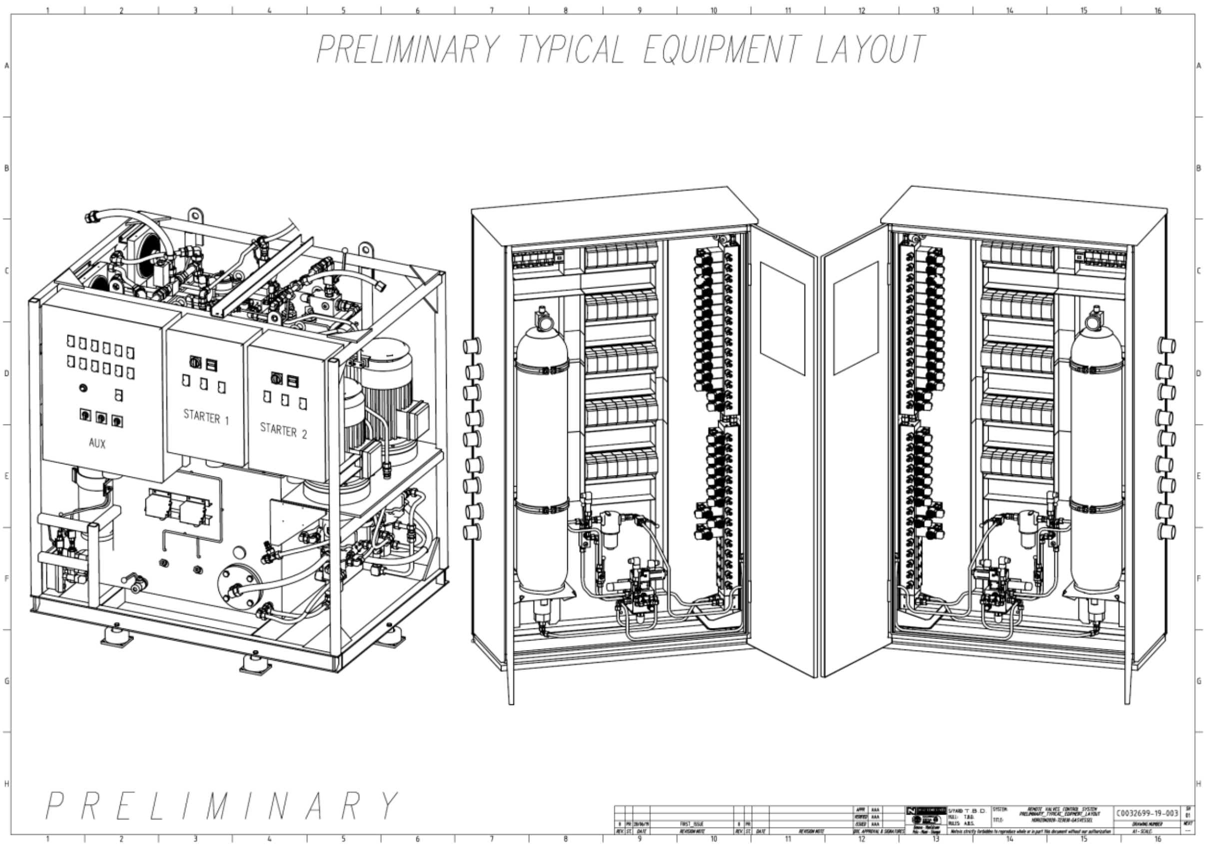
EQUIPMENT LIST

Main Item	Height [mm]	Width [mm]	Depth [mm]	Weight [Kg]	Controlled Valves (including spares) [No.]
HYDRAULIC POWER UNIT HM-Y-1	1.800	1.650	1.200	2.000	
HYDRAULIC POWER UNIT HM-Y-2	1.800	1.650	1.200	2.000	
Solenoid Rack HV-Y-1	2.010	1.200	500	800	30
Solenoid Rack HV-Y-2	2.010	1.200	500	800	30
Solenoid Rack HV-Y-3	2.010	1.200	500	800	30
Solenoid Rack HV-Y-4	2.010	1.200	500	800	30
Solenoid Rack HV-Y-5	2.010	1.200	500	800	30
Solenoid Rack HV-Y-6	2.010	1.200	500	800	30
Solenoid Rack HV-Y-7	2.010	1.200	500	800	30
Solenoid Rack HV-Y-8	2.010	1.200	500	800	30

HYDR. CONTROLLED VALVE LIST

System	No.	Description	Mark	N.D.
COMPRESSOR ROOM	25	Hydraulic Actuated Valves	VM49 - VM73	XXX
COMPRESSOR ROOM	4	Hydraulic Actuated Valves (antisourge)	ASV1 - ASV4	250
COMPRESSOR ROOM	2	Hydraulic Actuated Valves (blowdown)	BDMV01 - BDMV02	250
MANIFOLD	4	Hydraulic Actuated Valves	VP1 - VP2 - VS1 - VS2	150
MANIFOLD	2	Hydraulic Actuated Valves	VP0 - VS0	250
MANIFOLD	2	Hydraulic Actuated Valves	ESDV49 - ESDV50	250
HOLD 1P	16	Hydraulic Actuated Valves	1P-ESDV1 to 1P ESDV8	100
HOLD 1S	16	Hydraulic Actuated Valves	1S-ESDV1 to 1S ESDV8	100
HOLD 2P	20	Hydraulic Actuated Valves	2P-ESDV1 to 2P ESDV10	100
HOLD 2S	20	Hydraulic Actuated Valves	2S-ESDV1 to 2S ESDV10	100
HOLD 3P	20	Hydraulic Actuated Valves	3P-ESDV1 to 3P ESDV10	100
HOLD 3S	20	Hydraulic Actuated Valves	3S-ESDV1 to 3S ESDV10	100
HOLD 4P	20	Hydraulic Actuated Valves	4P-ESDV1 to 4P ESDV10	100
HOLD 4S	20	Hydraulic Actuated Valves	4S-ESDV1 to 4S ESDV10	100
NITROGEN	13	Hydraulic Actuated Valves	N2-VM1 to N2-VM13	50
VENTILATION	4	Hydraulic Actuated Valves	VM1 to VM4	100


GENERAL LAYOUT (No. 2 HPU's AND No. 8 SOLENOID RACKS)
HV-Y-4
HV-Y-3
HV-Y-2
HV-Y-1
HV-Y-8
HV-Y-7
HV-Y-6
HV-Y-5
HM-Y-1
HM-Y-2
NO. 30 + 30 CONTROLLED VALVES
Pipes Material: S.S. AISI 316 L
PRELIMINARY
C0032699-19-001


PRELIMINARY TYPICAL EQUIPMENT LAYOUT
AUX
STARTER 1
STARTER 2
PRELIMINARY
C0032699-19-003

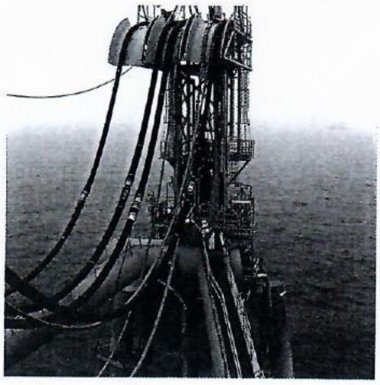
Appendix H. Flexible Hoses Data Sheets

Standard

API Spec. 17K

Construction

Bore type	full flow, rough bore
Liner type	H_2S resistant HNBR or PA
Operating temperature	-30°C to +90°C (-22°F to 194°F)
Max. available length	60m (200ft) up to 8" 30m (100ft) up to 16"



Features & Comments

- Cathodic protection is available upon request
- Lengths over 60m (200ft) are available in some sizes with splicing technology
- Coupling materials meet NACE MR 01-75 / ISO 15156 latest edition
- Material of the end fittings is either carbon steel or duplex
- Material of the internal carcass is either 316L or 254 SMO
- Handling instructions: ContiTech TKO ASO and AS4 latest edition

Technical Data

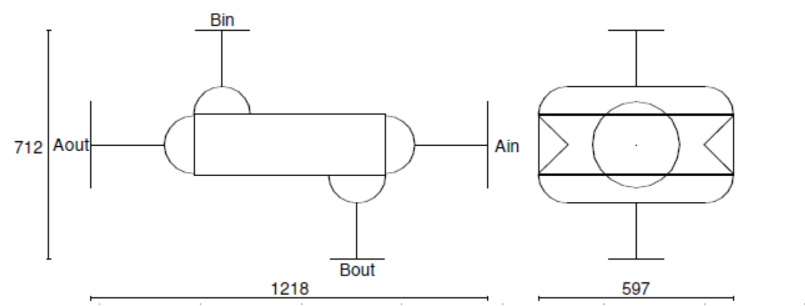
Inside Diameter		Type	Rated Working Pressure		Test Pressure		Safety Factor	Outer Diameter		MBR (static)		MBR (dynamic)		Weight	
mm	in		bar	psi	bar	psi	(WP)	mm	in	m	ft	m	ft	kg/m	lb/ft
53	2.0	Fire rated	345	5,000	517	7,500	2.25	168	6.6	1.0	3.3	1.4	4.6	49	33
		Fire rated c/w st. st. wrap						174	6.9	1.0	3.3	1.4	4.6	55	37
		Fire rated	517	7,500	776	11,250	2.25	163	6.4	1.3	4.3	1.8	5.9	47	32
		Fire rated c/w st. st. wrap						174	6.9	1.3	4.3	1.8	5.9	53	36
65	2.5	Fire rated	345	5,000	517	7,500	2.25	180	7.1	1.0	3.2	1.4	4.6	54	36
		Fire rated c/w st. st. wrap						191	7.5	1.0	3.3	1.4	4.6	62	42
		Fire rated	517	7,500	776	11,250	2.25	176	6.9	1.4	4.6	1.8	5.9	52	35
		Fire rated c/w st. st. wrap						187	7.4	1.4	4.6	1.8	5.9	60	40
78	3.0	Fire rated	345	5,000	517	7,500	2.25	197	7.8	1.2	3.9	1.7	5.6	65	44
		Fire rated c/w st. st. wrap						208	8.2	1.2	3.9	1.7	5.6	73	49
		Fire rated	517	7,500	776	11,250	2.25	190	7.5	1.5	4.9	2.0	6.6	61	41
		Fire rated c/w st. st. wrap						202	8.0	1.5	4.9	2.0	6.6	69	46
92	3.5	Fire rated	345	5,000	517	7,500	2.25	211	8.3	1.4	4.6	1.8	5.9	72	48
		Fire rated c/w st. st. wrap						222	8.7	1.4	4.6	1.8	5.9	81	54
		Fire rated	517	7,500	776	11,250	2.25	204	8.0	1.7	5.6	2.2	7.2	68	46
		Fire rated c/w st. st. wrap						216	8.5	1.7	5.6	2.2	7.2	78	52
104	4.0	Fire rated	345	5,000	517	7,500	2.25	223	8.8	1.5	4.9	2.0	6.6	79	53
		Fire rated c/w st. st. wrap						239	9.4	1.5	4.9	2.0	6.6	91	61
		Fire rated	517	7,500	776	11,250	2.25	214	8.4	1.8	5.9	2.3	7.5	73	49
		Fire rated c/w st. st. wrap						226	8.9	1.8	5.9	2.3	7.5	82	55
130	5.0	Fire rated	345	5,000	517	7,500	2.25	252	9.9	1.6	5.3	2.1	6.9	97	65
		Fire rated c/w st. st. wrap						269	10.6	1.6	5.3	2.1	6.9	107	72
152	6.0	Fire rated	345	5,000	518	7,500	2.25	278	10.9	1.9	6.2	2.6	8.5	112	75
		Fire rated c/w st. st. wrap						291	11.5	1.9	6.2	2.6	8.5	124	83
178	7.0	Fire rated	293	4,250	440	6,375	2.25	299	11.8	2.2	7.2	2.9	9.5	117	79
		Fire rated c/w st. st. wrap						312	12.3	2.2	7.2	2.9	9.5	135	91
207	8.0	Fire rated	259	3,750	389	5,625	2.25	331	13.0	2.4	7.9	3.2	10.5	139	93
		Fire rated c/w st. st. wrap						346	13.6	2.4	7.9	3.2	10.5	156	105
255	10.0	Fire rated	155	2,250	233	3,375	2.25	383	15.1	2.6	8.5	3.5	11.5	168	113
		Fire rated c/w st. st. wrap						394	15.5	2.6	8.5	3.5	11.5	184	124
303	12.0	Fire rated	155	2,250	233	3,375	2.25	430	16.9	2.8	9.2	3.8	12.5	194	130
		Fire rated c/w st. st. wrap						442	17.4	2.8	9.2	3.8	12.5	212	143
327	13.0	Fire rated	103	1,500	155	2,250	2.25	454	17.9	3.0	9.8	4.1	13.5	207	139
		Fire rated c/w st. st. wrap						466	18.4	3.0	9.8	4.1	13.5	226	152
352	14.0	Fire rated	86	1,250	129	1,875	2.25	477	18.8	3.2	10.5	4.4	14.4	215	145
		Fire rated c/w st. st. wrap						489	19.3	3.2	10.5	4.4	14.4	224	151

Appendix I. PCHE Datasheet

DS-E7946--	PCHE DATA SHEET	Sheet 1 of 2

Operator	Statoil	**Project**	Nat gas coolers - Comp systems
Contractor	BHGE Thermodyn	**Project No**	-
Enquiry/Order No	-	**Item No(s)**	-
Equipment	Gas cooler HEIDRUN	**No. of items required**	1
Case	NORMAL (Design) - Hydraulically & Thermally Controlling	**Parallel sections per item**	N/A

	SERVICE PER ITEM		SIDE A				SIDE B				Rev
1	**FLUID CONDITIONS**		In		Out		In		Out		
2	**Fluid**		Hydrocarbon Gas				Cooling Medium 30% TEG				
3	**Flow rate, total**	kg/hr	21600				32468				
4	**Flow rate, gas/vapour**	kg/hr	21600		21600		0		0		
5	**Flow rate, liquid**	kg/hr	0		0		32468		32468		
6	**Temperature**	℃	90.0		25.0		14.0		49.0		
7	**Design temp: max/min**	℃	170 / -28				170 / -28				
8	**Pressure: inlet/design**	barg	140.0 / 200.0 FV				6.6 / 15.7 FV				
9	**Pressure drop: calc/allwd**	bar	0.99 / 1.00				1.00 / 1.00				
10	**FLUID PROPERTIES**		Liq	Vap	Liq	Vap	Liq	Vap	Liq	Vap	
11	**Density**	kg/m³	-	99.4	-	143.6	1053	-	1033	-	
12	**Specific heat**	J/kg K	-	2874	-	3360	3711	-	3790	-	
13	**Viscosity**	cP	-	0.0173	-	0.0179	3.669	-	1.362	-	
14	**Thermal conductivity**	W/mK	-	0.0536	-	0.0528	0.4756	-	0.4877	-	
15	**Dew point**	℃									
16	**CONNECTIONS**										
17	**No. of nozzles**		1		1		1		1		
18	**Nozzle size**	mm NB	80 NB		80 NB		50 NB		50 NB		
19	**Flange class**		Cl 1500 RTJ		Cl 1500 RTJ		Cl 300 RF		Cl 300 RF		
20	**Max strainer aperture**	microns	320				320				
21	**MATERIALS**										
22	**Nozzle material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
23	**Flange material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
24	**Header material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
25	**Header belt or comp pad material**		-		-		-		-		
26	**Core material**		SS 316L								
27	**THERMAL DESIGN**										
28	**Design heat load**	kW	1184		**LMTD**			℃	22.8		
29	**Corrected TD**	℃	21.7		**Fouling allowance**			%	10 [4]		
30	**Overall htc, clean**	W/m²K	2961		**Oversizing**			%	10 [3]		
31	**Area provided**	m²	22		**Area required, clean**			m²	18		
32	**MASS & SIZE**										
33	**Mass: dry/operating/test**	kg	607 / 631 / 647 [2]								
34	**Core dimensions**	mm	196 x 596 x 597 [2]								
35											
36	**Design Code**		ASME BPV Code Section VIII Division 1								
37	**Notes**										

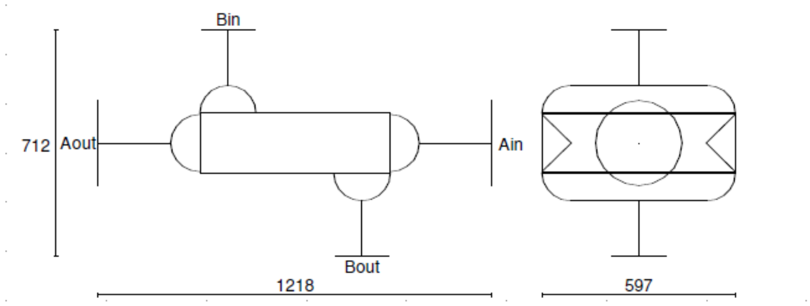


1. Pressure drops exclude strainer.
2. Weights and dimensions are approximate. Do not use for construction. Core length excludes support brackets.
3. 10% additional oversizing included, please confirm if required
4. 10% fouling allowance for dry gas as per statoil frame agreement.
5. Duty and fluid properties are generated using HYSYS based on the gas composition provided
6. TEG 30% properties are generated by Heatric. Flowrate is based on heat balance.
7. Straight line heat release assumed

DS-E7946--	PCHE DATA SHEET	Sheet 2 of 2

Operator	Statoil	**Project**	Nat gas coolers - Comp systems
Contractor	BHGE Thermodyn	**Project No**	-
Enquiry/Order No	-	**Item No(s)**	-
Equipment	Gas cooler HEIDRUN	**No. of items required**	1
Case	Mini (Rated)	**Parallel sections per item**	N/A

	SERVICE PER ITEM		SIDE A				SIDE B				Rev
1	**FLUID CONDITIONS**		In		Out		In		Out		
2	**Fluid**		Hydrocarbon Gas				Cooling Medium 30% TEG				
3	**Flow rate, total**	kg/hr	9000				8490				
4	**Flow rate, gas/vapour**	kg/hr	9000		9000		0		0		
5	**Flow rate, liquid**	kg/hr	0		0		8490		8490		
6	**Temperature**	°C	65.0		25.0		14.0		49.0		
7	**Design temp: max/min**	°C	170 / -28				170 / -28				
8	**Pressure: inlet/design**	barg	137.0 / 200.0 FV				6.6 / 15.7 FV				
9	**Pressure drop: calc/allwd**	bar	0.23 / 1.00				0.15 / 1.00				
10	**FLUID PROPERTIES**		Liq	Vap	Liq	Vap	Liq	Vap	Liq	Vap	
11	**Density**	kg/m³	-	109.7	-	140.3	1053	-	1033	-	
12	**Specific heat**	J/kg K	-	2957	-	3345	3711	-	3790	-	
13	**Viscosity**	cP	-	0.0171	-	0.0176	3.669	-	1.362	-	
14	**Thermal conductivity**	W/mK	-	0.0518	-	0.0521	0.4756	-	0.4877	-	
15	**Dew point**	°C									
16	**CONNECTIONS**										
17	**No. of nozzles**		1		1		1		1		
18	**Nozzle size**	mm NB	80 NB		80 NB		50 NB		50 NB		
19	**Flange class**		Cl 1500 RTJ		Cl 1500 RTJ		Cl 300 RF		Cl 300 RF		
20	**Max strainer aperture**	microns	320				320				
21	**MATERIALS**										
22	**Nozzle material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
23	**Flange material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
24	**Header material**		UNS S31803		UNS S31803		UNS S31803		UNS S31803		
25	**Header belt or comp pad material**		-		-		-		-		
26	**Core material**		SS 316L								
27	**THERMAL DESIGN**										
28	**Design heat load**	kW	310		**LMTD**			°C	13.3		
29	**Corrected TD**	°C	12.7		**Fouling allowance**			%	10 [4]		
30	**Overall htc, clean**	W/m²K	1500		**Oversizing**			%	24 [3]		
31	**Area provided**	m²	22		**Area required, clean**			m²	16		
32	**MASS & SIZE**										
33	**Mass: dry/operating/test**	kg	607 / 631 / 647 [2]								
34	**Core dimensions**	mm	196 x 596 x 597 [2]								
35											



36	**Design Code**	ASME BPV Code Section VIII Division 1	
37	**Notes**		

1. Pressure drops exclude strainer.
2. Weights and dimensions are approximate. Do not use for construction. Core length excludes support brackets.
3. 10% additional oversizing included, please confirm if required
4. 10% fouling allowance for dry gas as per statoil frame agreement.
5. Duty and fluid properties are generated using HYSYS based on the gas composition provided
6. TEG 30% properties are generated by Heatric. Flowrate is based on heat balance.
7. Straight line heat release assumed

Appendix J. Plates Heat Exchangers Datasheet

Type	T2	M3	TL3	T5	M6	TL6	TS6
Max. Flow rate kg/s/GPM	2/30	4/60	5/80	14/220	16/250	20/300	20/300
Max. Temperature C° (PED) /F° (ASME)	180/-	180/300	180/350	180/350	180/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	16/-	16/150	16/150	16/150	25/300	25/300	25/300

Type	T8	M10	TL10	M15	TL15	TS20	T20
Max. Flow rate kg/s/GPM	30/475	50/800	50/800	80/1300	120/1900	190/3040	225/3600
Max. Temperature C° (PED) /F° (ASME)	180/350	180/350	180/350	180/350	180/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	16/150	25/300	25/400	30/300	30/400	30/400	30/400

Type	MX25	TS35	T35	TL35	T45	TS50	T50
Max. Flow rate kg/s/GPM	350/5600	550/8700	550/8700	650/10400	1000/16000	1300/20800	1300/20800
Max. Temperature C° (PED) /F° (ASME)	180/350	180/350	180/350	180/350	250/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	30/400	25/400	25/400	30/400	16/250	25/300	25/300

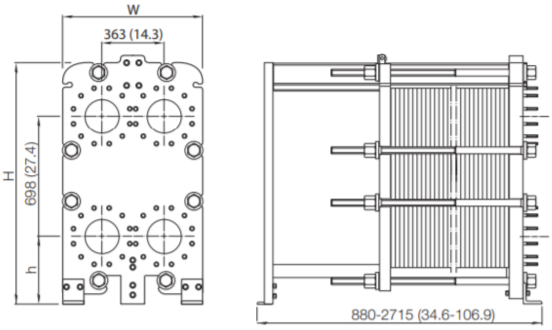
Type	AQ1A	AQ1	AQ1L	AQ2A	AQ2	AQ2L	AQ2S
Max. Flow rate kg/s/GPM	2/30	4/60	5/80	14/220	16/250	20/300	20/300
Max. Temperature C° (PED) /F° (ASME)	180/-	180/300	180/350	180/350	180/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	16/-	16/150	16/150	16/150	25/300	25/300	25/300

Type	AQ3	AQ4	AQ4L	AQ6	AQ6L	AQ8S	AQ8
Max. Flow rate kg/s/GPM	30/475	50/800	50/800	80/1300	120/1900	190/3040	225/3600
Max. Temperature C° (PED) /F° (ASME)	180/350	180/350	180/350	180/350	180/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	16/150	25/300	25/400	30/300	30/400	30/400	30/400

Type	AQ10	AQ14S	AQ14	AQ14L	AQ18	AQ20S	AQ20
Max. Flow rate kg/s/GPM	350/5600	550/8700	550/8700	650/10400	1000/16000	1300/20800	1300/20800
Max. Temperature C° (PED) /F° (ASME)	180/350	180/350	180/350	180/350	250/350	180/350	180/350
Max. design pressure bar (PED)/psi (ASME)	30/400	25/400	25/400	30/400	16/250	25/300	25/300

Dimensional drawing

Measurements mm (inches)



Type	H	W	h
TS20-FM	1405 (55.3")	740 (29.1")	360 (14.2")
TS20-FG	1405 (55.3")	800 (31.5")	360 (14.2")
TS20-FS	1435 (56.5")	800 (31.5")	390 (15.4")

The number of tightening bolts may vary depending on pressure rating.

Technical data

Plates

Name	Type	Free channel, mm (inches)
TS20-M	Single plate	4.0 (0.16)

Materials

Heat transfer plates	316/316L, 254 C-276, C-2000 Ni, Ti, TiPd
Field gaskets	NBR, EPDM, FKM, FEPM
Flange connections	Carbon steel Metal lined: stainless steel, Alloy C-276, titanium Rubber lined: NBR, EPDM
Frame and pressure plate	Carbon steel, epoxy painted

Other materials may be available on request.

All option combinations may not be configurable.

Operational data

Frame, PV-code	Max. design pressure (barg/psig)	Max. design temperature (°C/°F)
FM, pvcALS	10.0/145	180/356
FM, PED	10.0/145	210/410
FG, pvcALS	16.0/232	180/356
FG, ASME	10.3/150	177/350
FG, PED	16.0/232	180/356
FS, ASME	31.7/460	177/350
FS, PED	30.0/435	160/320

Extended pressure and temperature rating may be available on request.

Flange connections

FM, pvcALS	EN 1092-1 DN200 PN10 ASME B16.5 Class 150 NPS 8 JIS B2220 10K 200A
FM, PED	EN 1092-1 DN200 PN10 ASME B16.5 Class 150 NPS 8
FG, pvcALS	EN 1092-1 DN200 PN10 ASME B16.5 Class 150 NPS 8 JIS B2220 10K 200A
FG, ASME	ASME B16.5 Class150 NPS 8
FG, PED	EN 1092-1 DN200 PN16 ASME B16.5 Class 150 NPS 8
FS, ASME	ASME B16.5 Class 150 NPS 8 ASME B16.5 Class 300 NPS 8
FS, PED	EN 1092-1 DN200 PN25 EN 1092-1 DN200 PN40 ASME B16.5 Class 300 NPS 8

Standard EN1092-1 corresponds to GOST 12815-80 and GB/T 9115.

STANDARD MATERIALS

Frame plate
Mild steel, Epoxy painted

Nozzles
Carbon steel
Metal lined: Stainless steel, Titanium, Alloy C-276
Rubber lined: Nitrile, EPDM

Plates
Stainless steel Alloy 316 (Alloy 254, Alloy C-276 or Titanium
Other grades and material available on request.

Gaskets
Nitrile, EPDM, Viton or HeatSealF™
Other grades and material available on request.

TECHNICAL DATA

Pressure vessel codes, PED, ASME, pvcALS™
Mechanical design pressure (g) / temperature

FM	PED	10 MPa / 210°C
FM	pvcALS™	1.0 MPa / 180°C
FG	PED	1.6 MPa / 180°C *)
FG	ASME	150 psig / 350°F
FG	pvcALS™	1.6 MPa / 180°C
FS	PED	3.0 MPa / 160°C
FS	ASME	460 psig / 350°F

*) Frame FG also approved for 1.2 MPa / 200ºC to allow use in steam systems without safety valves.

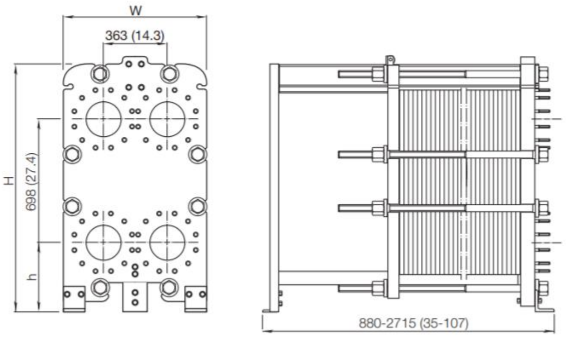
Connections

Size: DN200 / NPS 8 / 200A

FM	PED	EN 1092-1 PN10, ASME B16.5 Class 150
FM	pvcALS™	EN 1092-1 PN10, ASME B16.5 Class 150, JIS B2220 10K
FG	PED	EN 1092-1 PN16, ASME B16.5 Class 150
FG	ASME	ASME B16.5 Class 150
FG	pvcALS™	EN 1092-1 PN10, ASME B16.5 Class 150, JIS B2220 10K, JIS B2220 16K
FS	PED	EN 1092-1 PN25, EN 1092-1 PN40, ASME Cl. 300
FS	ASME	ASME B16.5 Class 150, ASME B16.5 Class 300

Standard EN 1092-1 corresponds to GOST 12815-80 and GB/T 9115.

Dimensions



Measurements mm (inch)

Type	H	W	h
AQ8S-FM	1405 (55 5/16)	740 (29⅛)	360 (14⅛)
AQ8S-FG	1405 (55 5/16)	800 (31½)	360 (14⅛)
AQ8S-FS	1435 (56½)	800 (31½)	390 (14⅛)

The number of tightening bolts may vary depending on pressure rating.

Maximum heat transfer surface
85 m² (910 sq. ft)

Particulars required for quotation
- Flow rates or heat load
- Temperature program
- Physical properties of liquids in question (if not water)
- Desired working pressure
- Maximum permitted pressure drop
- Available steam pressure

The thermal performance is third party certified through the AHRI Liquid to Liquid Heat Exchangers certification program

AHRI CERTIFIED™
www.ahridirectory.org
Liquid to Liquid Heat Exchangers
AHRI Standard 400

Appendix K. Chiller Datasheet

Model	Chiller				Motor		Evaporator			Condenser			Footprint			Weight		
	Cooling Capacity		Input Power	Full load COP	RLA	LRYA	Flow Rate	Pressure Drop	Water Connection	Flow Rate	Pressure Drop	Water Connection	Length	Width	Height	Operating	Rigging (w/o Refrigerant)	Refrigerant
	kW	Tons	kW	ikW/ kW	A	A	L/S	kPa	mm	L/S	kPa	mm	mm	mm	mm	kg	kg	kg
19XR3031327CLS52	1055	300	210	0.199	369	896	50.4	86.4		60.8	66.9		4172	1707	2073	6555	5725	371
19XR3131336CMS52	1231	350	240	0.195	410	782	58.8	84.2		70.6	87.8		4172	1707	2073	6677	5791	396
19XR3132347CNS52	1407	400	278	0.198	481	916	67.2	107.1	DN200	80.8	86.2	DN200	4172	1707	2073	6805	5884	396
19XR4040356CPS52	1583	450	306	0.193	534	1119	75.6	77.9		90.7	79.1		4365	1908	2153	7970	6678	483
19XR4141386CQS52	1759	500	335	0.190	580	1122	84	78.1		100.5	78.5		4365	1908	2153	8212	6828	508
19XR5051385KGH52	1934	550	346	0.179	604	1146	92.4	71.3		109.6	51.7		4460	2054	2137	9433	7730	609
19XR5P51436DES52	2110	600	381	0.181	667	1357	100.8	68.8		119.8	60.7		4460	2054	2207	9719	8110	493
19XR5P504QEDDS52	2110	600	380	0.180	664	1357	100.8	68.8		119.7	70.4		4460	2054	2207	9967	8393	493
19XR5Q5144FLEH52	2286	650	427	0.187	748	1521	109.2	73.2	DN200	130.5	71	DN250	4460	2054	2207	10096	8449	510
19XR5R514QELEH52	2286	650	407	0.178	715	1521	109.2	66.8		129.7	70.2		4460	2054	2207	10549	8864	524
19XR5Q5245FLFH52	2462	700	469	0.190	808	1637	117.6	83.9		140.9	72		4460	2054	2207	10239	8558	510
19XR5Q524R5LFH52	2462	700	442	0.180	765	1637	117.6	83.9		139.9	71.1		4460	2054	2207	10614	8932	510
19XR6X65467LGH52	2638	750	487	0.185	851	1794	126	77.2		150.3	80.2		5000	2124	2261	11797	9735	619
19XR6R614T5LGH52	2638	750	460	0.174	807	1794	126	58.4	DN250	148.9	64	DN250	4480	2124	2261	11570	9589	579
19XR6Z6747FLGH52	2814	800	508	0.181	886	1794	134.4	72.8		159.8	73.1		5000	2124	2261	12259	10029	657
19XR6Z664U5LGH52	2814	800	484	0.172	847	1794	134.4	72.8		158.5	79.3		5000	2124	2261	12497	10305	657
19XR7P704V5LGH52	3164	900	554	0.175	961	1794	151.2	74		179.2	80		5169	2426	2750	15575	12787	836
19XR70704W6LHH52	3517	1000	621	0.177	1055	1837	168.1	108.5		199.3	97.2		5169	2426	2750	16354	13381	1020
19XR7P71E53MDB52	3869	1100	682	0.176	1149	2362	184.9	106.8	DN300	218.5	97.8	DN300	5169	2426	2902	17497	14499	966
19XR7Q72E53MDB52	3869	1100	673	0.174	1133	2362	184.9	89.5		218.2	85.1		5169	2426	2902	17976	14802	1005
19XR7Q72E53MEB52	4220	1200	739	0.175	1255	2729	201.7	105		238	99.9		5169	2426	2902	18010	14836	1005
19XR8P81E51MEB52	4220	1200	700	0.166	1192	2729	201.7	72.6		236.4	76.5		5205	2711	2950	20486	16619	1115
19XR8P80E63MFB52	4572	1300	803	0.176	1365	3276	218.5	84		257.9	102.2		5205	2711	2950	20286	16495	1115
19XR8Q81E61MFB52	4572	1300	769	0.168	1310	3276	218.5	72.6	DN350	256.5	88.9	DN350	5205	2711	2950	20793	16806	1158
19XR8P81E63MFB52	4924	1400	867	0.176	1469	3276	235.3	96.2		279	103.7		5205	2711	2950	20550	16684	1115
19XR8R84E63MFB52	5276	1500	913	0.173	1543	3276	252.1	83.4		297.3	84.9		5205	2711	2950	21776	17435	1206

Appendix L. Fan coils Datasheet

HVAC & Refrigeration Engineering

HZ18 FAN COIL UNIT RANGE DATASHEET

HAZCOOL®

FAN COIL UNIT RANGE GENERAL DATA				
No.	Description	Data		
1	Model	HZ18-015G11	HZ18-020G11	HZ18-025G11
2	Suitable Environment	Zone 1 and Zone 2	Zone 1 and Zone 2	Zone 1 and Zone 2
3	Unit Classification	II 2G IIB T3	II 2G IIB T3	II 2G IIB T3
4	Operating Limits	0 to +40°C	0 to +40°C	0 to +40°C
5	PED Category	SEP	SEP	SEP
6	Operating Modes	Cooling Only	Cooling Only	Cooling Only
7	Nominal Cooling Duty	15 (kW)	20 (kW)	25 (kW)
8	Sensible Cooling Duty	7.5 (kW)	10 (kW)	12.5 (kW)
9	Designed Amnbient Temperature / Humidity	+32 / 70 (°C / %RH)	+32 / 70 (°C / %RH)	+32 / 70 (°C / %RH)
10	Designed Room Temperature / Humidity	+24 / 92 (°C / %RH)	+24 / 92 (°C / %RH)	+24 / 92 (°C / %RH)
11	Refrigerant	Chiller Water	Chiller Water	Chiller Water
12	Fluid Inlet Temperature	+6 (°C)	+6 (°C)	+6 (°C)
13	Fluid Outlet Temperature	+12 (°C)	+12 (°C)	+12 (°C)
14	Maximum Allowable Pressure	11.5 / 166.8 (barg / psig)	11.5 / 166.8 (barg / psig)	11.5 / 166.8 (barg / psig)
15	Unit Dry Weight	140 (kg)	142 (kg)	158 (kg)
16	Overall Dimensions (*l* x *w* x *h*)	1336 x 525 x 780 (mm)	1340 x 525 x 780 (mm)	1536 x 525 x 780 (mm)
17	Service Space/ Airflow Clearance	500 (mm)	500 (mm)	500 (mm)
18	Evaporator Unit Airflow	0.80 (m^3/s)	0.67 (m^3/s)	0.67 (m^3/s)
19	Fluid Flow Rate	0.60 (l/s)	0.99 (l/s)	0.99 (l/s)
20	Fan Coil Connection Type / Size	PN16 Flange / 1 (inch)	PN16 Flange / 1 1/4 (inch)	PN16 Flange / 1 (inch)
21	Coil Tube / Fin Material	Copper / Copper	Copper / Copper	Copper / Copper
22	Electrical Power Supply	380-420 / 3 / 50 and 420-480 / 3 / 60 (V/Ph/Hz)	380-420 / 3 / 50 and 420-480 / 3 / 60 (V/Ph/Hz)	380-420 / 3 / 50 and 420-480 / 3 / 60 (V/Ph/Hz)
23	Total Power Consumption	1.1 (kW)	1.1 (kW)	1.1 (kW)
24	Running Current	5 (A)	5 (A)	5 (A)
25	Protection Circuit Breaker	6 (A)	6 (A)	6 (A)

Notes:
1. Details given are for guidance only.
2. Exact equipment supplied may vary according to geographical location.
3. Bespoke systems available, please contact us for a quote.

Appendix M. Compressors Datasheets

APPLICABLE TO:	● PROPOSAL ○ PURCHASE ○ AS BUILT		
FOR	CNG Navalprogetti	UNIT	
SITE	Ipotesi B	SERIAL NO.	
SERVICE	CNG Compressor	NO. REQUIRED	1
MANUFACTURER	MAN Diesel & Turbo	DRIVER TYPE (1-3.1.1)	EM (VFD)
MODEL	RB 28-7 + RB 28-7	DRIVER ITEM NO.	

INFORMATION TO BE COMPLETED: ○ BY PURCHASER □ BY MANUFACTURER △ MUTUAL AGREEMENT (PRIOR TO PURCHASE)

OPERATING CONDITIONS

(ALL DATA ON PER UNIT BASIS)	Car 100-1		Car 100-2		Car 100-3	
	Section 1	Section 2	Section 1	Section 2	Section 1	Section 2
○ GAS HANDLED (ALSO SEE PAGE 2)	CnHm	CnHm	CnHm	CnHm	CnHm	CnHm
△ GAS PROPERTIES (1-2.1.1.4)						
○ Nm3/h (1.013 barA, 0°C) WET	49'999	49'999	49'999	49'999	49'999	49'999
○ WEIGHT FLOW (kg/h) WET	37'581	37'581	37'581	37'581	37'581	37'581
INLET CONDITIONS						
○ PRESSURE (barA)	75.0	115.2	95.0	158.6	100.0	188.3
○ TEMPERATURE (°C)	10.2	30.0	18.2	30.0	20.0	30.0
○ RELATIVE HUMIDITY %						
○ MOLECULAR WEIGHT (kg/kmol)	16.85	16.85	16.85	16.85	16.85	16.85
□ Cp/Cv ~~(K_1) OR (K_{AVG})~~	1.658	1.730	1.736	1.869	1.728	1.932
□ COMPRESSIBILITY (Z_1) ~~OR (Z_{AVG})~~	0.846	0.841	0.830	0.822	0.832	0.823
□ INLET VOLUME (m3/h) WET	593	411	472	291	452	246
DISCHARGE CONDITIONS						
○ PRESSURE (barA)	117.0	150.0	161.0	250.0	191.2	330.0
□ TEMPERATURE (°C)	58.8	71.7	73.5	83.5	90.2	98.7
□ Cp/Cv ~~(K_2) OR (K_{AVG})~~ (NOTE 1)	1.572	1.589	1.602	1.662	1.579	1.631
□ COMPRESSIBILITY (Z_2) ~~OR (Z_{AVG})~~ (NOTE 1)	0.898	0.908	0.910	0.954	0.936	1.029
□ Gas kW REQUIRED						
□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING)	1'080	1'090	1'220	1'345	1'580	1'830
□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING) TOTAL	2'170		2'565		3'410	
□ SPEED (RPM)	9'202		9'202		10'119	
□ TURNDOWN (%)						
□ POLYTROPIC HEAD (Nm/kg)	58'637	36'487	72'664	66'522	93'590	88'365
□ POLYTROPIC EFFICIENCY (%)	63.0	39.5	70.4	61.5	70.3	61.8
○ CERTIFIED POINT						
○ EXPECTED OPERATION AT EACH CONDITION (%)						
□ PERFORMANCE CURVE NUMBER						

PROCESS CONTROL (1-3.4.2.1)

METHOD ● SUCTION THROTTLING FROM ____ (BAR)~~(kPa abs)~~ TO ____ (BAR)~~(kPa abs)~~ ○ VARIABLE INLET GUIDE VANES (2-3.4.2.2) ● SPEED VARIATION FROM 65 % TO 1) 105 % ○ DISCHARGE BLOWOFF TO ____ ○ COOLED BYPASS FROM ____ TO ____

SIGNAL ● SOURCE (1-3.4.2.1) ____

TYPE ● ELECTRONIC ○ PNEUMATIC ○ OTHER ____

RANGE ____ mA ____ (BAR)~~(kPa abs)~~ ____

○ ANTI-SURGE SYSTEM (1-3.4.2.2)

REMARKS: 1) 100% Speed is 14157rpm

NOTE 1: IF GAS ANALYSIS IS GIVEN, MANUFACTURER SHALL SUPPLY DATA, OTHERWISE DATA SHALL BE SUPPLIED BY USER.

2ZTHERM160621_CNG_Navalprogetti_Ipotesi_B_RB_28-7_+_RB_28-7_API_DS_Rev0.xlsx

SI UNITS

APPLICABLE TO: ● PROPOSAL ○ PURCHASE ○ AS BUILT

FOR: CNG Navalprogetti — UNIT:

SITE: Ipotesi B — SERIAL NO.:

SERVICE: CNG Compressor — NO. REQUIRED: 1

MANUFACTURER: MAN Diesel & Turbo — DRIVER TYPE (1-3.1.1): EM (VFD)

MODEL: RB 28-7 + RB 28-7 — DRIVER ITEM NO.:

INFORMATION TO BE COMPLETED: ○ BY PURCHASER □ BY MANUFACTURER △ MUTUAL AGREEMENT (PRIOR TO PURCHASE)

OPERATING CONDITIONS

(ALL DATA ON PER UNIT BASIS)	Car 50-1		Car 50-3		Car 50-3	
	Section 1	Section 2	Section 1	Section 2	Section 1	Section 2
○ GAS HANDLED (ALSO SEE PAGE 2)	CnHm	CnHm	CnHm	CnHm	CnHm	CnHm
△ GAS PROPERTIES (1-2.1.1.4)						
○ Nm3/h (1.013 barA, 0°C) WET	49'999	49'999	49'999	49'999	49'999	49'999
○ WEIGHT FLOW (kg/h) WET	37'581	37'581	37'581	37'581	37'581	37'581
INLET CONDITIONS						
○ PRESSURE (barA)	50.0	84.6	50.0	106.1	50.0	126.2
○ TEMPERATURE (°C)	20.0	30.0	20.0	30.0	20.0	30.0
○ RELATIVE HUMIDITY %						
○ MOLECULAR WEIGHT (kg/kmol)	16.85	16.85	16.85	16.85	16.85	16.85
□ Cp/Cv ~~(K_1) OR (K_{AVG})~~	1.471	1.601	1.471	1.677	1.471	1.769
□ COMPRESSIBILITY (Z_1) ~~OR (Z_{AVG})~~	0.910	0.872	0.910	0.847	0.910	0.830
□ INLET VOLUME (m3/h) WET	990	580	990	449	990	370
DISCHARGE CONDITIONS						
○ PRESSURE (barA)	85.8	150.0	107.7	250.0	128.1	330.0
□ TEMPERATURE (°C)	99.0	117.5	115.5	145.9	132.5	166.5
□ Cp/Cv ~~(K_2) OR (K_{AVG})~~ (NOTE 1)	1.397	1.449	1.395	1.466	1.394	1.455
□ COMPRESSIBILITY (Z_2) ~~OR (Z_{AVG})~~ (NOTE 1)	0.956	0.963	0.959	1.017	0.973	1.077
□ Gas kW REQUIRED						
□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING)	1'890	2'170	2'230	2'880	2'620	3'570
□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING) TOTAL	4'060		5'110		6'190	
□ SPEED (RPM)	12'833		13'449		14'157	
□ TURNDOWN (%)						
□ POLYTROPIC HEAD (Nm/kg)	81'670	90'544	120'915	145'726	153'450	174'166
□ POLYTROPIC EFFICIENCY (%)	48.3	48.5	61.2	61.8	66.6	61.6
○ CERTIFIED POINT						
○ EXPECTED OPERATION AT EACH CONDITION (%)						
□ PERFORMANCE CURVE NUMBER						

PROCESS CONTROL (1-3.4.2.1)

METHOD: ● SUCTION THROTTLING FROM ____ (BAR)~~(kPa abs)~~ TO ____ (BAR)~~(kPa abs)~~ — ○ VARIABLE INLET GUIDE VANES (2-3.4.2.2) — ● SPEED VARIATION FROM 65 % TO 1) 105 % — ○ DISCHARGE BLOWOFF TO ____ — ○ COOLED BYPASS FROM ____ TO ____

SIGNAL: ● SOURCE (1-3.4.2.1)

TYPE: ● ELECTRONIC ○ PNEUMATIC ○ OTHER

RANGE ____ mA ____ (BAR)~~(kPa abs)~~

○ ANTI-SURGE SYSTEM (1-3.4.2.2)

REMARKS: 1) 100% Speed is 14157rpm

NOTE 1: IF GAS ANALYSIS IS GIVEN, MANUFACTURER SHALL SUPPLY DATA, OTHERWISE DATA SHALL BE SUPPLIED BY USER.

SI UNITS

1	APPLICABLE TO: ● PROPOSAL ○ PURCHASE ○ AS BUILT		
2	FOR: CNG Navalprogetti	UNIT	
3	SITE: Ipotesi B	SERIAL NO.	
4	SERVICE: CNG Compressor	NO. REQUIRED	1
5	MANUFACTURER: MAN Diesel & Turbo	DRIVER TYPE (1-3.1.1)	EM (VFD)
6	MODEL: RB 28-7 + RB 28-7	DRIVER ITEM NO.	
7			
8	INFORMATION TO BE COMPLETED: ○ BY PURCHASER □ BY MANUFACTURER △ MUTUAL AGREEMENT (PRIOR TO PURCHASE)		
9	OPERATING CONDITIONS		

No.		Bypass Flare HP					
10							
11	(ALL DATA ON PER UNIT BASIS)	Section 1	Section 2				
12	○ GAS HANDLED (ALSO SEE PAGE 2)	CnHm	CnHm				
13	△ GAS PROPERTIES (1-2.1.1.4)						
14	○ Nm3/h (1.013 barA, 0°C) WET	49'999	49'999				
15	○ WEIGHT FLOW (kg/h) WET	37'581	37'581				
16	INLET CONDITIONS						
17	○ PRESSURE (barA)	69.5	151.9				
18	○ TEMPERATURE (°C)	30.0	30.0				
19	○ RELATIVE HUMIDITY %						
20	○ MOLECULAR WEIGHT (kg/kmol)	16.85	16.85				
21	□ Cp/Cv ~~(K_1) OR (K_{AVG})~~	1.526	1.831				
22	□ COMPRESSIBILITY (Z_1) ~~OR (Z_{AVG})~~	0.891	0.820				
23	□ INLET VOLUME (m3/h) WET	721	303				
24	DISCHARGE CONDITIONS						
25	○ PRESSURE (barA)	154.3	330.2				
26	□ TEMPERATURE (°C)	121.7	133.7				
27	□ Cp/Cv ~~(K_2) OR (K_{AVG})~~ (NOTE 1)	1.443	1.505				
28	□ COMPRESSIBILITY (Z_2) ~~OR (Z_{AVG})~~ (NOTE 1)	0.966	1.055				
29	□ Gas kW REQUIRED						
30	□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING)	2'110	2'715				
31	□ TRAIN kW REQUIRED (AT COMPRESSOR COUPLING) TOTAL	4'825					
32	□ SPEED (RPM)	12'291					
33	□ TURNDOWN (%)						
34	□ POLYTROPIC HEAD (Nm/kg)	128'162	131'490				
35	□ POLYTROPIC EFFICIENCY (%)	70.2	61.6				
36	○ CERTIFIED POINT						
37	○ EXPECTED OPERATION AT EACH CONDITION (%)						
38	□ PERFORMANCE CURVE NUMBER						

39 PROCESS CONTROL (1-3.4.2.1)

40 METHOD ● SUCTION THROTTLING ○ VARIABLE INLET ● SPEED VARIATION ○ DISCHARGE ○ COOLED BYPASS

41 FROM ____ (BAR)~~(kPa abs)~~ GUIDE VANES FROM 65 % BLOWOFF FROM ____

42 TO ____ (BAR)~~(kPa abs)~~ (2-3.4.2.2) TO 1) 105 % TO ____ TO ____

43 SIGNAL ● SOURCE (1-3.4.2.1) ____

44 TYPE ● ELECTRONIC ○ PNEUMATIC ○ OTHER ____

45 RANGE ____ mA ____ (BAR)~~(kPa abs)~~ ____

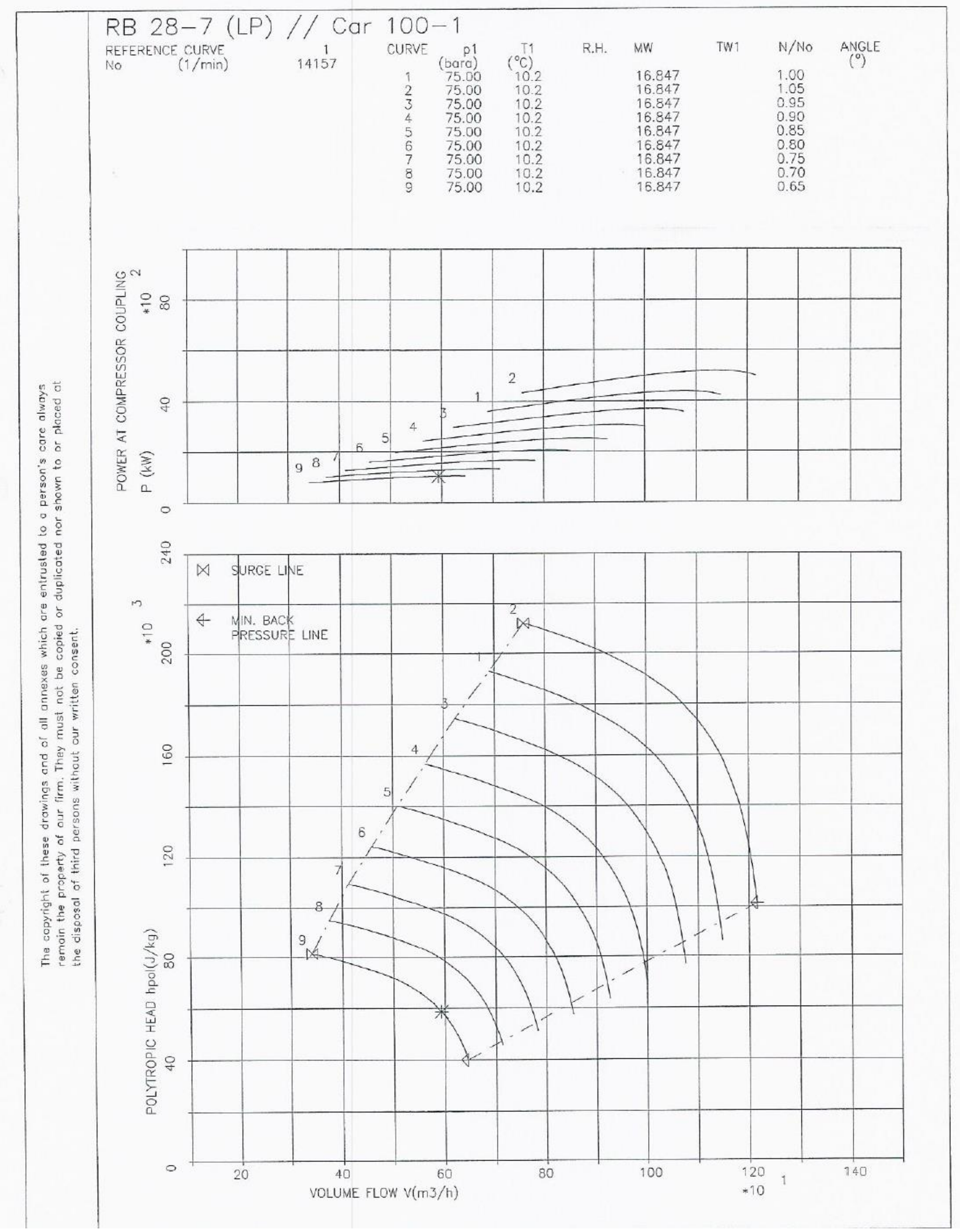
46

47 ○ ANTI-SURGE SYSTEM (1-3.4.2.2)

48 **REMARKS:** 1) 100% Speed is 14157rpm

49

50 NOTE 1: IF GAS ANALYSIS IS GIVEN, MANUFACTURER SHALL SUPPLY DATA, OTHERWISE DATA SHALL BE SUPPLIED BY USER.


RB 28–7 (LP) // Car 100–1
REFERENCE CURVE No 1
(1/min) 14157
CURVE | p1 (bara) | T1 (°C) | R.H. | MW | TW1 | N/No | ANGLE (°)
1 75.00 10.2 16.847 1.00
2 75.00 10.2 16.847 1.05
3 75.00 10.2 16.847 0.95
4 75.00 10.2 16.847 0.90
5 75.00 10.2 16.847 0.85
6 75.00 10.2 16.847 0.80
7 75.00 10.2 16.847 0.75
8 75.00 10.2 16.847 0.70
9 75.00 10.2 16.847 0.65
POWER AT COMPRESSOR COUPLING P (kW) *10 2
SURGE LINE
MIN. BACK PRESSURE LINE
POLYTROPIC HEAD hpol(J/kg) *10 3
VOLUME FLOW V(m3/h) *10 1
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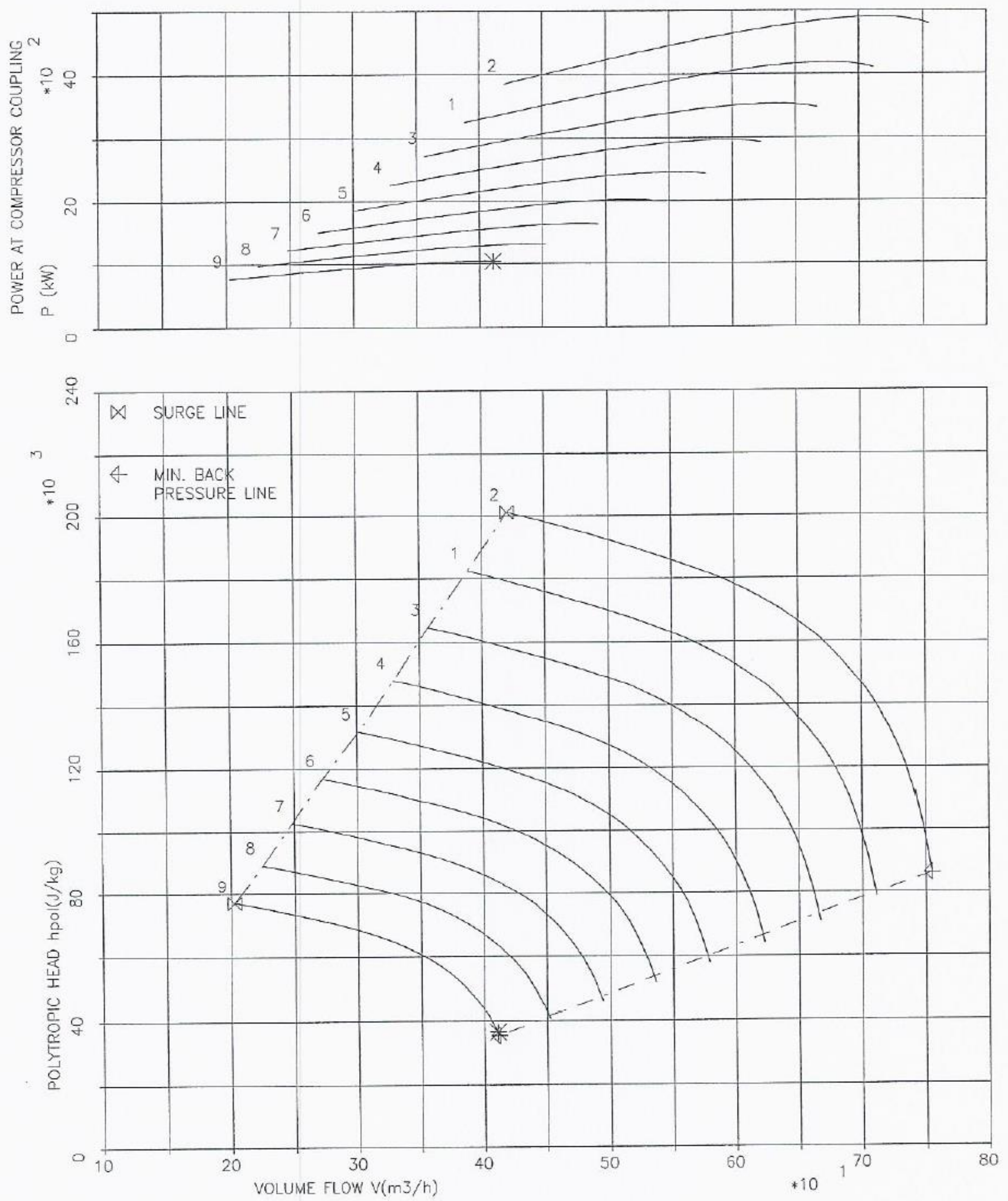
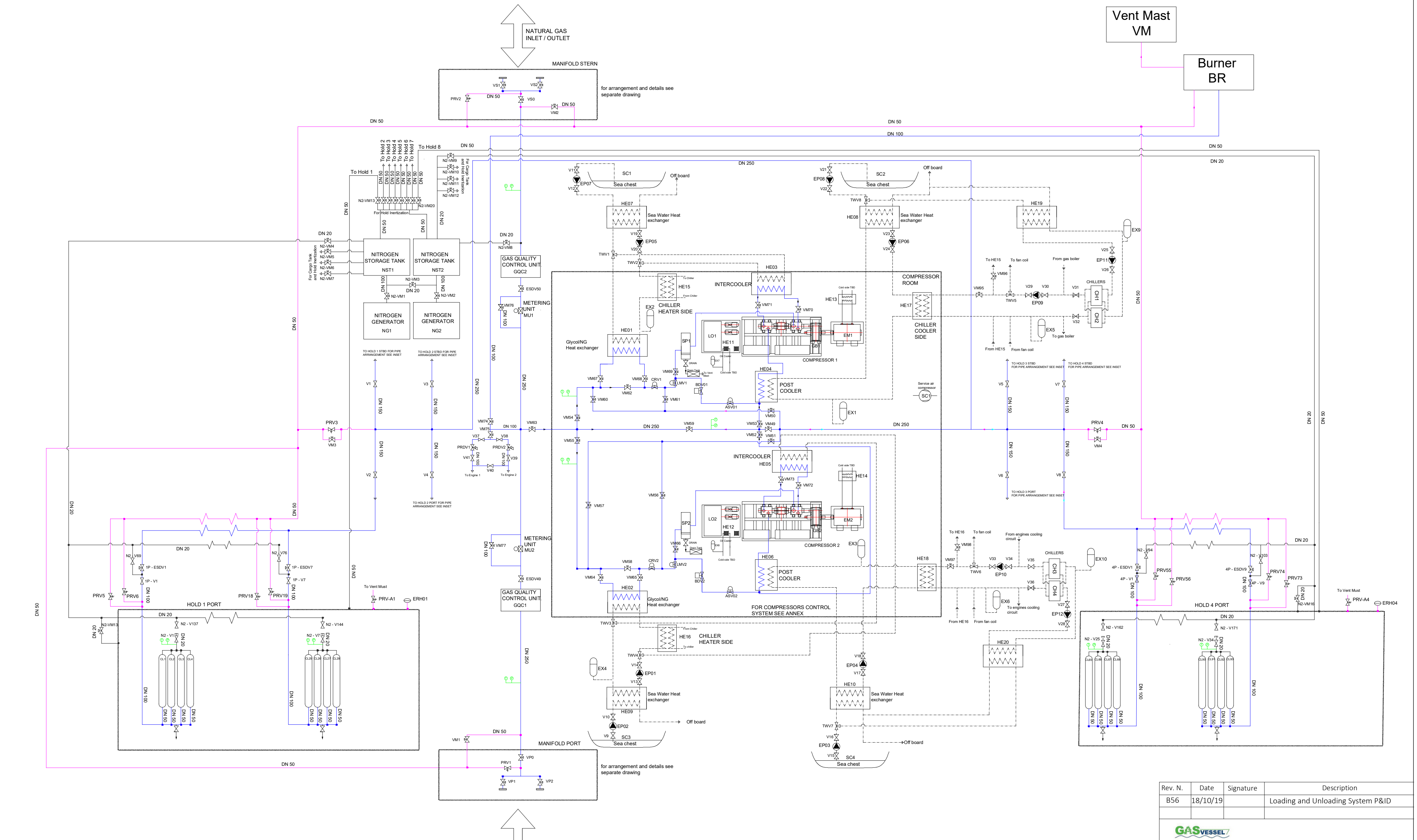
RB 28–7 (HP) // Car 100–1

REFERENCE CURVE No	(1/min)
1	14157

CURVE	p1 (bara)	T1 (°C)	R.H.	MW	TW1	N/No	ANGLE (°)
1	115.23	30.0		16.847		1.00	
2	115.23	30.0		16.847		1.05	
3	115.23	30.0		16.847		0.95	
4	115.23	30.0		16.847		0.90	
5	115.23	30.0		16.847		0.85	
6	115.23	30.0		16.847		0.80	
7	115.23	30.0		16.847		0.75	
8	115.23	30.0		16.847		0.70	
9	115.23	30.0		16.847		0.65	





Rev. N.	Date	Signature	Description
B56	18/10/19		Loading and Unloading System P&ID

GASVESSEL

CNG LOADING & UNLOADING SYSTEM

DRAWN: TC	SCALE:	DRAWING N. 180GASV-DRW-050-T02A01 Loading and Unloading System P&Id
CHECKED: RT	—	
SIGNATURE:		DATE: 18/10/2019

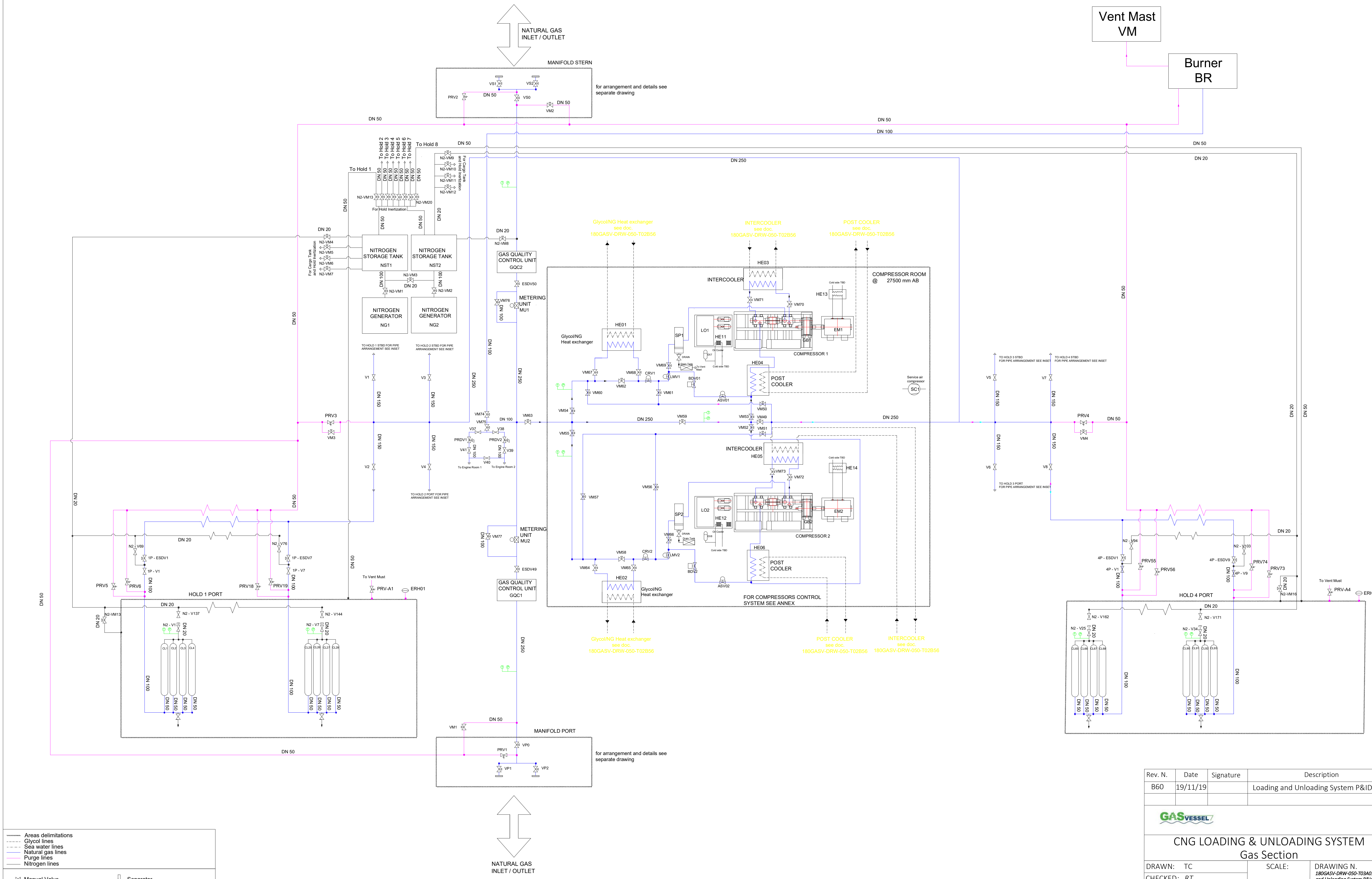
cEnergy CENERGY S.r.l.
C/O AREA SCIENCE PARK-BASOVIZZA
Strada statale 14, KM 163,5-BLD. Q1
34149 TRIESTE (TS) Italy

Areas delimitations
Glycol lines
Sea water lines
Natural gas lines
Purge lines
Nitrogen lines

Manual Valve
Actuted Valve
Pressure Regualting Valve
Drain Valve
Relief Valve
Control Valve
Blowdown Valve
Emergency Relief Hatch
Three ways valve

Separator
Pump
Heat Exchanger
Sea Chest
Service Compressor Air
Pressure Cylinder
Metering Unit
Expansion Vessel

NOTES:
All pipes are isolated and traced.
All pipes outside of the dangerous area are double pipes.



Areas delimitations
Glycol lines
Sea water lines
Natural gas lines
Purge lines
Nitrogen lines

Manual Valve	Separator
Actuted Valve	Pump
Pressure Regualting Valve	Heat Exchanger
Drain Valve	Sea Chest
Relief Valve	Service Compressor Air
Control Valve	Pressure Cylinder
Blowdown Valve	Metering Unit
Emergency Relief Hatch	Expansion Vessel
Three ways valve	

NOTES:
All pipes are isolated and traced.
All pipes outside of the dangerous area are double pipes.

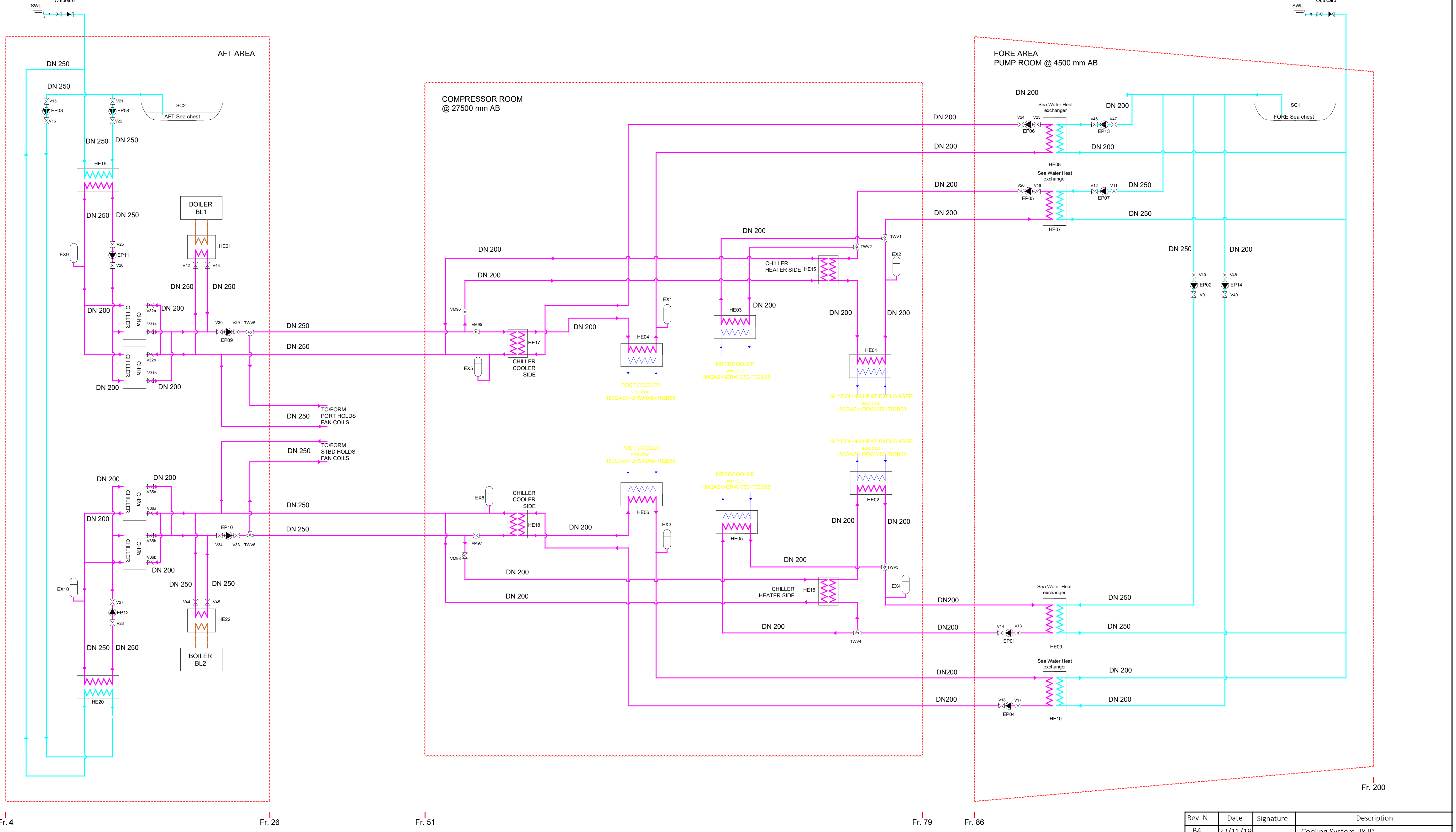
Rev. N.	Date	Signature	Description
B60	19/11/19		Loading and Unloading System P&ID

GASVESSEL

CNG LOADING & UNLOADING SYSTEM
Gas Section

DRAWN: TC
CHECKED: RT
SIGNATURE:
SCALE: —
DRAWING N. 180GASV-DRW-050-T03A01 Loading and Unloading System P&Id
DATE: 19/11/2019

cEnergy CENERGY S.r.l.
C/O AREA SCIENCE PARK-BASOVIZZA Strada statale 14, KM 163,5-BLD. Q1 34149 TRIESTE (TS) Italy



...s delimitations
...ol lines
... water lines
...ting thermal oil lines
...ral gas lines

...ual Valve
...ted Valve
...-Return Valve
...e ways valve

Pump
Heat Exchanger
Sea Chest
Expansion Vessel

NOTES:
All glycol and thermal oil pipes are insulated.

REFERENCE DOCS:
180GASV-DRW-050-T02B58 Loading and Unloading System P&Id

Rev. N.	Date	Signature	Description
B4	22/11/19		Cooling System P&ID

GASVESSEL

Cooling System

DRAWN: TC	SCALE:	DRAWING N. 180GASV-DRW-050-T02A01 Cooling System P&Id
CHECKED: RT	–	
SIGNATURE:		DATE: 22/11/2019

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C/O AREA SCIENCE PARK-BASOVIZZA
Strada statale 14, KM 163,5-BLD. Q1
34149 TRIESTE (TS) Italy